

**DESIGN, DEVELOPMENT AND PERFORMANCE
EVALUATION OF BENCH GRAFTING TOOL**

THESIS

**Submitted in partial fulfilment of the requirements
for the Degree of**

MASTER OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

(FARM MACHINERY AND POWER ENGINEERING)

By

**Mr. Biradar Shridhar Somling
(ENDPM/2020/181)**

**DEPARTMENT OF FARM MACHINERY AND POWER ENGINEERING,
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY,
DAPOLI**



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JUNE, 2023

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Under the Guidance of
Dr. K. G. Dhande
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JUNE, 2023

DECLARATION OF STUDENT

I hereby declare that the experimental work and its interpretation of the Thesis entitled **“DESIGN, DEVELOPMENT AND PERFORMANCE EVALUATION OF BENCH GRAFTING TOOL”** or part thereof has neither been submitted for any other degree or diploma of any University, nor the data have been derived from any thesis/publication of any University or scientific organization. The source of materials used and all assistance received during the course of investigation have been duly acknowledged and that no part of the thesis has been submitted for any other degree or diploma.

Place: Dapoli

Date: 01 / 06 /2023



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(Biradar Shridhar Somling)

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LIST OF ABBREVIATIONS

Abbreviations	Meanings
A	Ampere
ASAE	American Society of Agricultural Engineers
ASTM	American Society for Testing and Materials
Avg.	Average
CAET	College of Agricultural Engineering and Technology
CAGR	Compound annual growth rate
COA	College of Agriculture
DBSKKV	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth
DC	Direct current
Dept.	Department
Engg.	Engineering
<i>et al.</i>	and others
etc.	et cetera
EW	Equivalent weight
Fig.	Figure
FMPE	Farm Machinery and Power Engineering
ISO	International Organization for Standardization
FYM	Farm yard manure
GDP	Gross domestic product
ha	hectare
hp	Horse Power
i.e.	that is
IASRI	Indian Agricultural Statistics Research Institute
kg/cm ²	Kg per square centimeter
kWh	Kilowatt-hour
m	meter
M.S.	Mild Steel
Mha	Million hectares
mm	millimeter
MPa	Mega Pascal
MT	Mega tonne
N	Newton
no./h	Number per hour
rpm	revolutions per minute
SWG	Standard Wire Gauge
V	Voltage

GLOSSARY

Cutting Strength : Cutting strength is the maximum Cutting force which a material is capable of sustaining.

Hardness : Hardness is the ability of material to resist localised plastic deformation.

Grafting : Grafting is the science and technique of two living parts from different plants together in such a manner that they will unite and continue to grow as one plant.

Softwood Grafting : Softwood portion of the rootstock is utilized for making cleft and the scion is mended into wedge shape, this method is known as softwood grafting technique.

Scion cutting success rate : Scion cutting success rate is the ratio of number of successful scion cutting with smooth surface without burr to the total number of sticks cut.

Rootstock cutting success rate : Stock cutting success rate is the ratio of number of successful stock cutting with smooth surface without burr to the total number of sticks.

Scion cutting capacity : Scion cutting capacity is the number of scion cut in wedge shape at bottom end by cutting mechanism per unit time.

Rootstock cutting capacity : Rootstock cutting capacity is the number of scion cut in wedge shape by cutting mechanism per unit time.

Graft union wrapping success rate : Graft union wrapping success rate is the ratio of number of successful wrapping (Binding) of graft union to the total number of wrapping of grafts.

Graft union wrapping capacity : Graft union wrapping capacity is the number of graft union wrapped by wrapping mechanism per unit time.

Success of Grafting : Success of grafting is the ratio of number of Successful grafts or grafts sprouted and alive after 15 days of grafting to the total number of grafts produced.

Grafting Capacity, per hour : Grafting capacity is the number of grafts produced after cutting scion-rootstock and wrapping graft union per unit hour.

CHAPTER I

INTRODUCTION

Indian horticulture sector contributes about 33 % to the agriculture Gross Value Added (GVA) in agricultural GDP with 18 % area making very significant contribution to the Indian economy. India is currently producing about 331 Mt of horticulture produce during 2020-21 which has surpassed the food grain production (Anonymous, 2022). India is the second largest producer of horticultural crops. India has maintained its dominance in the production of spices, coconut, ranks second in cashew nut and third in citrus. Increase in demand for horticultural produce due to greater health awareness, rising income, export demands and increasing population poses the challenge for further increasing the production and productivity of horticultural crops. It is strongly believed that the consistent and rapid increase in production and availability of horticultural crops shall over period of time translate into bridging the gap between the nutritional security of the country in relation to global average (Singh *et al.*, 2022). In Maharashtra average share of horticulture in Gross State Value Added (GSVA) of crop sector is 28.4 per cent. Horticulture area increased from 1.9 Mha in 2019-20 to 2.11 Mha in 2020-21, showing an increase of 11.4 %. Maharashtra is also leading producer of grapes, mango, Sapota, pomegranate, onion and cashew nut (Anonymous, 2022).

Cashew (*Anacardium occidentale L.*) is a tree native of Eastern Brazil, which was introduced to India by the Portuguese in the 16th Century. At global scenario, though India occupied second largest area under cashew cultivation (18.76 %), but contributes only 16.33 % in production. Seedling progenies of non-descript origin is one of the prime factors for low productivity in cashew because of their high degree of heterozygosity. Hence, vegetative propagation is considered as suitable method to develop uniform and healthy cashew plantation. Different methods of vegetative propagation namely layering, grafting and budding are followed. The Directorate of Cashew Research and various cashew research stations in country studies indicated the superiority of softwood grafting over other vegetative propagation methods and has been recommended for commercial multiplication of quality planting material in cashew (Anonymous, 2019). To enhance the quality and increase the production of horticultural produce there should be a relentless supply of good quality plants. The grafting technique is extensively used to produce high quality, superior varieties and high yielding grafted plants for plantation of horticulture crops. The grafting in India is done manually which has certain limitations and has much drudgery involved in it.

Grafting is the science and technique of two living parts from different plants together in such a manner that they will unite and continue to grow as one plant. One of the two plants serve as the bottom part which contact with soil and is called rootstock or stock and other as the top part or scion. In this plant union, only scion is allowed to grow as new shoot of the plant parts in a graft.

Importance of Grafting:

1. Change or improve variety: Newer varieties may offer improved insect or disease resistance, better flavour, or higher yields.
2. Reproduce vegetative : Numerous plants will not reproduce true from seeds or uneconomical. These needs to be reproduce vegetatively.
3. Change root system: Certain Plants with a weeping growth habit are often grafted onto rootstocks have superior growth habits, disease and insect resistance, and better anchorage.
4. Grafts are true to type in nature but seed propagated plants are highly heterozygous in nature. Grafts are precocious and early bearing over seedlings, use of grafted plants helps to develop uniform shape and size to plantations, helps to induce dwarfness, helps to establish uniform orchards and responds well for package of practices.

Existing Grafting technique:

Spliced approach grafting, whip or tongue grafting, Side grafting, Cleft or wedge grafting, Veneer grafting, softwood grafting, Epicotyl Grafting or stone grafting and Inarching are most commonly used asexual method of propagation in horticultural crops. Cleft or wedge grafting is useful for grafting older plants with thick stem having equal and/or greater diameter than the scion. This method is commonly employed in rejuvenating the old orchard by top working. Grape, walnut, hazelnut, etc. are propagated by this method. A graft may be made to join a scion and rootstock of nearly equal size or large scion and small size rootstock.

Softwood Grafting:

Softwood portion of the rootstock is utilized for making cleft and the scion is mended into wedge shape, this method is known as softwood grafting technique. In this method, grafting is done with mature, procured scion (defoliated 7 to 10 days prior to grafting) on the emerging soft shoot of rootstock which is about 3 to 8 months old. The grafts are secured firmly using 1.5 cm wide, 200 gauge polythene strip or grafting tape. It is being used successful in propagating the mango, cashew, sapota, avocado, tamarind, etc. The Bench grafting is insertion of scion stick onto a rootstock to grow a new tree. It works best when the stock and scion are of similar diameter,

preferably between 6 mm and 12.7 mm. The best time for grafting should be selected which is different for each crop. The two slanting cuts are made at the bottom of the scion stick forms wedge shape. Make vertical cut along longitude of rootstock or two slanting cut making slit of 'V' shape with length same as scion cutting length is done. After the cuts are made, scions must be inserted immediately, or cuts should be kept moist until used. Insert the prepared scion stick into the split of rootstock enough tight that the cut surface of scion and rootstock matches as closely as possible. The stock and scion must have cambial contact for union and growth to take place. The lower tip of the scion should not hang over the stock. Wrap the graft with a rubber budding strip, grafting tape or a plastic tape tightly to prevent drying (Singh *et al.*, 2022). Softwood grafts can be prepared almost throughout the year with a mean graft success of 65 - 70 per cent saleable grafts. However, the best season for grafting would be June to November under Konkan weather conditions. The cost of production is comparatively cheaper and field establishment of softwood grafts is very high (Nayak, 2015).

Grafting is usually done manually (hand) using grafting knife and grafting tape in konkan region and some part of Maharashtra. Currently, the nurserymen in konkan region produce nearly 50,000 – 1,00,000 cashew nut grafts annually valued Rs. 40 – 80 lakh in every nursery. The Nursery, Dr. BSKKV, Dapoli every year supplies 5,00,000 quality grafts of high yielding cashew varieties (Gajbhiye *et al.*, 2018). Produce quality grafts with high capacity of graft production within time limit of grafting period (grafting season) is one of major problem. Only highly skilled and well experienced person is able to carry out successful grafting operation using hand grafting method. During grafting period, the skilled persons are easily not available in peak of season. The current shortage of farm labour, unavailability of skilled grafter during grafting season and the scarcity of skilled grafters and budder's make more apparent, the need of a machine for bench grafting. There are numerous grafting tools, machine and robotic system available worldwide in developed countries. Prototype of an automatic machine for the herbaceous grafting of tomatoes (Belforte *et al.*, 2018), Hand-manual grafting units for grapevine propagation in Itali (Celik and Boz, 2001), prototype of tobacco and other seedling grafting robot in Japan (Kurata, 1994), automatic sapling branch grafting robot for vegetable grafting in China (Sun *et al.*, 2014) and other tools, machines and robots were developed. There are several research reported in mechanizing and automating the grafting process for numerous plant like tomato, vine, watermelon, cucumber, apple, walnut etc. These tools and machines were developed for specific vegetable or for limited fruit plants and considering large capacity nurseries. These machines are prototypes and have certain limitations, tools with very low capacity and low machine life. Numerous tools and limited machines for softwood grafting are available in India. The hand grafting tools for grapevine grafting are commercially available in India but these are with low capacity, drudgerous in

handling, only cutting of scion and rootstock was done and there is no provision for wrapping the joint. Robotics control system or grafting robots, machines and tools have high initial cost i.e. the initial cost of robotics control system machines are around Rs. 2 - 3 lakhs which is highly expensive, not affordable by farmers and small scale nurseries producing 1000 – 2000 grafts per day. The numerous farmers and small scale backyard nursery growers in Konkan region faces many grafting and mechanization problems. There is necessity for mechanization of cashew grafting operation which operates automatically and also requires less initial cost. The mechanization of grafting will eliminate the need of grafting skill that directly affects the success of grafting, minimize drudgery, improve the efficacy, efficiency and economics of operation.

To solve this problem, the research work titled “Design, Development and Performance Evaluation of Bench Grafting tool” has been taken under study with the following objectives:

1. To study grafting techniques and engineering properties related to scion and stock cutting.
2. To design and develop bench grafting tool.
3. To evaluate performance of bench grafting tool.

CHAPTER II

REVIEW OF LITERATURE

The work carried out by different researchers earlier was reviewed for getting through the study of design of bench grafting tool. The problems encountered, suggestion by them, and methodologies used were reviewed. The review made for grafting process and technique, Engineering properties related to scion and rootstock cutting, mechanization of grafting process, performance evaluation of grafting tool and machines is presented as below:

2.1 Grafting Process and Technique

Uradya, (1976) studied on veneer grafting in mango at Horticulture Nursery, KKV, Dapoli. Effect of skill of grafter on success in veneer grafting was experimented as one of important factor. The percentage of sprouting and survival ranging from 86 to 100 % and 73.33 to 93.33 % respectively was obtained. The lowest survival rate was 73 % for unskilled labour and maximum survival of 100 % of grafts for skilled labour.

Haldankar, (1985) studied on standardization of soft wood grafting in Kokum. A series of trials on vegetative propagation of Kokum were adopted in the konkan region. Studied effect of season on sprouting and survival, effect of provision of shade on sprouting, survival and growth, effect of prior defoliation of scion shoots on number of days required for grafting, sprouting on survival and growth of softwood grafting, effect of length of scion stick, effect of age of scion stick, effect of in situ grafting on sprouting, success and growth, adaptability of softwood grafting in kokam by grafters. Grafting in October showed maximum sprouting percentage (93 %) and Survival (86 %). Grafts in glass house showed 88.8 % success rate. Graft with no defoliation shown 84 % Survival rate. Scion length of 75 mm - 125 mm used for Grafting shown maximum survival obtained. Maximum survival was found in graft with 5-month-old scion.

Panicker, (1986) studied on softwood grafting in Mango at Department of Horticulture, COA, Dapoli. Scion of 3-4 months ago with dark green color having a thickness 5 mm from 15 year old Alphonso mango trees was used. A longitudinal cut ('V' shape) of about 30 mm in length was done and 80 mm long stem retained on the stock plant. The percentage of survival of grafting in May (72 %) and September (66 %), October (82 %), November (70 %) to December (68 %) respectively. Scion of age 4 months showed 82.5 % of survival. 5 days prior defoliation and no defoliation showed same result as 78 % of survival. Scion length of 100 - 125 mm (75 %) survival obtained suitable with high survival percentage.

Lantos, (1990) tested Walnut varieties for successful propagation by winter bench grafting and followed by forcing. The seedlings of cv. *Kopcos* gave the best results 80 %. *Juglans regia* seedlings usually gave better results than *J. Nigra*. Heeling occurred earlier at post grafting time, but the buds of the scion started to grow during the forcing. Both one and two year old seedling can be used if there size was suitable. Trees in nursery required two years to reach standard size.

Waghmare, (1990) studied standardization of softwood grafting in Sapota (var. Kalipatti) at Konkan Krishi Vidyapeeth, Dapoli. Rootstock was split vertically into cleft from the top to length 4 cm and scion shoot prepared like a wedge (4 cm slanting cut from both sides of lower end). Then on insertion scion into prepared cleft the union was tied tightly with polythene sheet of 250 gauge and 1.5 cm width. The grafting was done on 7th and 21st date of each month throughout the year. This experimentation showed that grafting done in August has maximum success percentage. Five months old scion used for grafting gives highest Success percentage (43 %) after 90 days. The scion with length of 10-12.5 cm had highest Success percentage (72-77 %) after 90 days. These results standardize the process of softwood grafting in sapota.

Kadam, (1992) studied in situ softwood grafting in Cashew nut carried out at the COA, Dapoli. The in-situ softwood grafting was performed with scion budsticks prepared like wedge by giving about 50-70 mm slanting cut into cleft of rootstock. The union was tied tightly with polythene strip of 250 gauge thickness. The new shoots (sprout) arising on rootstock below graft joint were removed. Effect of season on success of in situ softwood grafting studied. The plants grafted on 15th of every month (July, 1990 to July, 1991). Percentage success of sprouting (up to 3 months after grafting) and Percentage survival of grafts (alive grafts counted up to 3 months) was found maximum in July (73.33 %, 71.66 %), August (73.33 %, 70 %) and September (83.33 %, 81.66 %), respectively. Percentage of graft survival was found maximum in graft with 120-150 days old scion. The result shown that graft survival percentage of graft prepared with 100-125 mm long scion was highest (65 – 70 %).

Kaur and Malhi, (2006) studied effect of age of rootstock and growing medium on the success of epicotyl grafting in Mango. Grafting was carried out with seven growth media and 5, 7, 9, 11, 13 and 15 day old rootstocks. The highest sprouting of graft scion was recorded in soil + FYM + sand followed by soil + leaf mold. Sprouting was significantly higher with the use of 7-day old rootstock for Grafting followed by 9 and 5-day-old rootstock. The highest survival was observed with 7-day-old stock, the survival rate decreased when the age of the stock increased to 15 days. The graft survival was better in soil + FYM + sand followed by soil + FYM after 4 months of Grafting. The survival percentage was higher in transplanted grafts than those grafted in-situ in

polybags. Vegetative growth viz. sprout diameter were the highest in plants grafted on 7-day-old rootstock followed by 9 and 11-day-old rootstocks.

Kumar *et al.*, (2006) studied growth of Dashehari Mango after grafting on different height of seedling rootstock. This experiment was carried out from July 1997 to February 1999 at Horticulture Research Centre, Patharchatta. They have reported that success after three months of grafting (Veneer and Cleft grafting) was always more than 80 % at higher grafting height of 750 – 1000 mm on the seedling rootstock than those grafted at 250 – 500 mm height of rootstock. The Growth of Dashehari mango scion was sigmoid for 4 months (15 August – 15 November) after grafting.

Kumar and Shukla, (2008) studied bench grafting in Custard apple as influenced by scion thickness and time of grafting. Cleft grafting technique was conducted at Indian Grassland and Fodder Research Institute, Jhansi. Bare rooted stocks of Custard apple with 6 mm diameter grafted with dormant scion of cv. Balanagar. Scion of thickness 6 mm had shown highest graft success (96.4 %) and minimum when 8 mm thick scion used for grafting. They concluded those days taken to sprouting, length of sprout, collar diameter, number of secondary branches and number of secondary roots per plant were significantly influenced by scion thickness and time of grafting.

Gandev, (2009) studied and compared different methods of Walnut propagation, in which the grafting success was not depend on the external climatic conditions. The investigation was carried out with variety 'Izvor 10' grafted on common walnut rootstock (*Juglans regia* L.). The tested grafted plants were placed under controlled temperature of 27 °C for callus formation. Four weeks after grafting the plants were transferred to a room temperature of 15-18 °C for twenty days, after which the percentage of graft take was recorded. The lowest percentage of successfully grafted plants was reported for the classical Omega bench grafting method (control) 40.8 %. For the new propagation techniques, close percentages of successfully grafted plants was obtained 74.2 % in average for the method of hot callus and 77.5 % for the method of Epicotyl grafting.

Dehgan *et al.*, (2010) found out the most suitable procedure for Walnut grafting in season, different bench grafting methods (side stub, omega and whip tongue). The effect of forcing pre-treatment on grafting components (placing of grafting components in a forcing room at a temperature of 26-28 °C and relative humidity of 80-90 % for two weeks (rootstocks) or 3 days (scions) before grafting) was assessed using the side stub grafting method in two varieties. The omega grafting method had the highest average callus score (2.61 out of 4), number of callused grafts (82.22 %), graft take (71.11 %) and graft survival (81.03 %). In the second experiment, the effect of stocks and scions pre-treatment (forcing) were significant on the callus rate, graft take

and graft survival characters. In this experiment, grafted plants treated with the forcing pre-treatments showed the highest callused grafts (82.7 %), graft take (73.8 %) and grafting survival (71.9 %). Treated grafting components with forcing pre-treatments under controlled conditions increase grafting success considerably.

Korkutal *et al.*, (2011) determined the different effects of scion types on bench grafting. Scion performed burst cutting-burst scion, burst cutting-swollen scion, and burst cutting-unburst scion. They measured and recorded grafting cuttings after 21 days of grafting. The results concluded that discarded grafted-cuttings ratio was 3 %. Swollen and unburst scions were in same statistical group (53.72 and 52.92 %). Best results of shoot length ratio from burst scion in group 0-50 mm were (38.62 %) and group 50-100 mm was (40.0 %). Rooting ratio increased with development of bud, 1.42, 3.44 and 4.67 %, respectively for unburst, swollen and burst scions.

Chipojola *et al.*, (2013) carried out a micro level study on effect of tree age, scion source and grafting period on the grafting success of Cashew nut. An assessment of grafting success of cashew nut was conducted in nursery where graft-take was compared for scions obtained from different populations of different ages and then grafted from the month of August to October 2008. Mature and immature scions were collected from forty cashew accessions of age 12 and 20 years. Results showed that scion source and tree age had no effect on grafting success. However, there were significant differences ($p \leq 0.05$) for scion type. Immature scions showed better results in August while mature scions shown well in October. The differences are attributed to differences in temperature in the two months that further affect rate of healing of graft unions. There were significant differences ($p \leq 0.05$) for graft take of mature scions as compared to immature scions with 57.5 % and 72.5 % in August and October respectively. There were no correlations between cashew tree age and scion type on the grafting success, concluded that the cashew scions could be collected from trees of different ages to be used for grafting.

Kumar *et al.*, (2015) studied the effect of propagation techniques on survivality in Mango. They evaluated the survival percentage and time consumed to propagate mango plants under different techniques of vegetative, an experiment was conducted at Horticultural Research Center of Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut (U.P.). The results obtained from the experiment indicate that the Maximum survival percentage 82 % was recorded in veneer grafting performed in July. Epicotyl grafting was found to be most time saving technique for vegetative propagation as it took minimum time to propagate mango plants.

Ullah *et al.*, (2017) studied effect of time and technique for quality production of nursery plants of Dashehari Mango. Field experiment was carried to find the response of Dashehari mango

and techniques of Grafting (Veneer, Softwood and epicotyl). The epicotyl grafting performed in August recorded minimum time (13.46 days) for bud sprouting, whereas veneer Grafting performed in August was found to be the best technique in terms of sprouting percentage after one (89.62 %) and six (82.30 %) months of Grafting. The study suggests that veneer grafting should be preferred over softwood and epicotyl grafting in order to get better survival and overall sprout growth for commercial propagation of quality plants.

Chatse *et al.*, (2019) standardized the season of softwood grafting on survival and growth in Hibiscus under Konkan conditions of Maharashtra. Propagation of Hibiscus through softwood grafting, the grafts were tied in different season January to December and the experiment was conducted in randomized block design with twelve treatments and three replications. The maximum survival (96.67 %) and sprouting percentage (100.00 %), number of leaves (12.20) and sprouts (3.93) was observed in the treatments February. They concluded that propagation through softwood grafting in April month had proved to be the best month for propagation under konkon conditions of Maharashtra.

Thapa *et al.*, (2021) studied effect of grafting methods and dates on the graft take rate of Persian Walnut in open field condition. They carried out a field- based experiment in Rukam (East), Nepal. Two factors were studied includes the grafting dates (13th, 19th and 26th of Feb and 4th and 11th of March) and grafting methods including outdoor grafting and bench grafting. The findings revealed that bench grafting resulted in significantly better outputs than outdoor method for length of scion (at 30 and 60 days after grafting) and graft take rates. Bench grafting showed 44 % graft take followed by outdoor grafting (38 % graft take). Plants grafted on 13th and 19th of February showed statistically better result for growth performance over the other dates. Plants grafted on 19th of February showed 67 % graft take with 53 % saleable plants, but statistically similar to the plants grafted on 13th and 26th of February. Bench grafting on 19th February showed significantly higher length of scion (164 mm) at 60 days after grafting. Non-significant results were seen for other parameters due to the interaction. Therefore, bench grafting on 13th, 19th and 26th of February led to the best graft take in Persian walnut.

The above review gives the details about the grafting process and technique of different horticultural crops such as Mango, Cashew Nut, Kokam, Walnut, Sapota and Custard apple. The effect of age of rootstock and growing medium on the success of grafting, media used in seedling preparation were experimented and concluded. The softwood grafting of Cashew Nut, Mango and other orchard crops in Konkan region gives high success rate. In standardized Cashew Nut grafting slanting cut of 50 mm – 70 mm in scion and length of 100 – 125 mm gave best results.

2.2 Engineering Properties Related to Scion and Rootstock Cutting

Blahovec, (1988) studied mechanical properties of some plant materials. He concluded that the tensile strength of these plant material was controlled by a relatively close exponential regression relation $\sigma_m = 0.2E^{0.75}$, where E is the Young's modulus. Significant deviation showed with buckling strength in the deformation by compression of the materials. Demonstrated the dependence of Young's modulus and strength of plant tissues on the crude content.

Pezzi *et al.*, (2009) evaluated the cutting force of Vine branches in winter pruning. Samples of branches were collected during three different periods, three vine varieties; three classes of diameter (3 - 5, 5 - 7 and 7 - 9 mm) were used. The cutting force of the branches were evaluated in term of penetration force of a triangular-section blade, 3 mm thick, moved down with a constant speed of 0.1 mm/s. ASAE standard (ASAE, 1989) for determining mechanical attributes of food texture, resistance to mechanical injury, and force-deformation behaviour of convex shaped food materials. The experiment was conducted using a Texture Analyzer TA-HDi (Stable Micro System UK). The curves started with a fast increase of the cutting force, which reached the maximum at the rupture point; the following peaks were due to the uncut fibres dragging. The comparison between the three classes of diameter showed, in all cases, significant differences the cutting force increased with the increase of diameter and the increment ranged from 56 % to 86 %.

Sessiz *et al.*, (2013) determined the cutting properties of five different varieties of the table olive, namely Halhali, Gullaki, Mavis, Belloti and Zoncuk respectively. Olive suckers and branches cutting behaviour optimize the design of cutting elements in pruning machines. The cutting properties were measured at three moisture content levels (17.05, 34.44, and 39.47 %) and four cross-sectional areas (12.56, 28.27, 50.26 and 78.54 mm²). The cutting force and cutting energy requirement of olive suckers decreased with increasing moisture content in all of the olive varieties. These properties increased with increasing cross-sectional area. The maximum cutting force, cutting strength, cutting energy requirement and specific cutting energy of olive sucker were obtained for the Halhali variety as 869.15 N, 18.66 MPa, 4.29 J and 0.0875 Jmm⁻², respectively, while the minimum cutting values were obtained for the Zoncuk variety as 619.19 N, 14.75 MPa, 2.44 J and 0.0531 Jmm⁻², respectively.

Leroux, (2014) evaluated the standard hardness of biological tissue using nano-indentation. The Nanovea Mechanical Tester, in Nano-indentation mode, was used to study the hardness and elastic modulus of 3 separate areas of prosciutto (fat, light meat and dark meat). Nano-indentation was based on the standards for instrumented indentation, ASTM E2546 and ISO 14577. The results present the measured values of Hardness and Young's modulus as the penetration depth with their

averages and standard deviations. The fat area was about half the hardness of the meat areas. Provided the precise measurement of mechanical properties on extremely hard materials the same system can also be used for soft biological tissue with low kPa hardness value.

Sessiz *et al.*, (2015) determined the cutting properties such as cutting force, cutting strength, cutting energy of different wine grape branch (cutting) as function of moisture content, diameter and variety. The cutting properties were measured at three moisture content levels (35.2, 42.4, and 46 %), four cross-section area (12.56, 28.27, 50.26 and 78.54 mm²) and eight wine grapes varieties (Tannat, Merlot, Cot, Chardonnay, Viognier, Cabernet Sauvignon, Shiraz, Cabernet Franc). The Lloyd LRX plus materials testing machine was used to measure the cutting force and cutting energy. The cutting speed of the machine, 100 mm/min, was used for all tests. The results indicated that cutting force, cutting strength and cutting energy requirement varied from variety to variety. The maximum cutting force, cutting strength and cutting energy were obtained at Cabernet Franc grape variety as 1397.60 N, 21.68 MPa and 3.68 J, respectively. The minimum cutting force, cutting strength and cutting energy were obtained at Tannat grape variety as 981.65 N, 13.94 MPa, and 2.39 J, respectively. This effect could be related to higher stem wall thickness and cross-sectional area of Cabernet Franc compared to the other examined varieties.

Sessiz *et al.*, (2017) studied some physical, mechanical and ripening properties of variety Boğazkere Grape and their relationships were determined depend on three different phenological stages and five cane internode (IN) diameters. Cutting properties and energy values were measured by the Lloyd LRX plus materials testing machine. Determined the cutting properties of cane, grape berries length, width, thickness, geometric mean diameter, sphericity, surface area, berry detachment force (BDF), berry weight (W), berry detachment force/weight (BDF/W). The mean length, width and thickness value of berries was found 16.64 mm, 15.49 mm, and 15.42 mm, respectively. The ratio of BDF/W decreased with phenological stages. The BDF was decreased from 2.60 N to 2.13 N, the grape berries skin firmness decreased from 1.60 N to 0.93 N, while berries weight increased from 2.48 g to 2.76 g at harvesting stages. Total soluble solids content and pH values increased with phenological stages. Whereas the total acids were slight changed and reduced from 0.413 to 0.323 % with ripening stages. The phenological stages has not significant effect on the cutting properties of cane ($P > 0.05$). However, cutting force were found highly correlated with the cane diameter, the significant differences were found among internodes diameter of grape canes at a 5 % probability level. While the maximum cutting force and energy were obtained at IN5 diameter as 600.92 N and 5.05 J, the minimum cutting force and energy were obtained at IN1 diameter as 289 N and 1.52 J, respectively.

Shah *et al.*, (2017) standardized the theory and experimental methods to measure the mechanical properties of stems. Evaluated various methods to test structural properties of stem, included flexural-bending and axial loading (tensile, compressive and buckling) test. Recommended best practices for determining the stem strength. Explored plant biomechanics, mechanical phenotyping of plants and determined the mechanical properties of plants.

Aydin and Arslan, (2018) determined some physical and mechanical properties of cotton (*Gossypium hirsutum* L.) shoots. The samples were obtained from two different plant segments; i.e. 0–15 cm (Segment A) and 16–30 cm (Segment B) from the top of cotton plants and were subjected to shearing test using a universal test machine in the laboratory. In Segment A, average shoot diameter, shearing force, water content, maximum shearing stress, and specific shearing energy were determined as 4.35 mm, 73 N, 72 %, 4.94 MPa, and 0.069 J/mm², respectively. In Segment B the same parameters were 5.79 mm, 121 N, 64.8 %, 4.65 MPa, and 0.078 J/mm², respectively. Although displacement at the bio yield point was similar in both sampling locations, the maximum shearing force requirement was more (121 N) in Segment B compared with Segment A (73 N), suggesting that topping should be done as high as possible from the ground to complete the topping process with low energy consumption. They concluded that, for less cutting energy requirement the topping should be done as early as possible from 100 to 120 days from the planting.

The physical and engineering properties of plant material such as diameter, moisture content, cutting force, cutting energy and hardness of stem or stick of plant and seedlings were reported for plant material. Also information of standard process of properties measurement and methods used for different plant material were reviewed. The information of various instruments used for properties measurement and experimentation methodology were noted.

2.3 Mechanization of Grafting Process:

Alley, (1957) developed portable machine for grapes bench or field grafting. the grafting operation was mechanized in grapes which saves time and eliminates the need for skilled labour. Grafting has been done by hand but the current shortage of farm labour and the scarcity of skilled grafters and budders make more apparent the need of a machine for bench grafting rootings or cuttings. Grafting machine comprised of one half horsepower, 110 V electric motor with 5.1/4 inches pulley, V belt and 3500 rpm. Water sprayed on the saw blades through the top of the saw blades. The machine makes cut on scion in V shape by centering the groove. The entire saw unit was covered with a sheet metal guard, except the cutting guide opening for the insertion of the

scion and stocks. For field use, two saw disc were placed together with the two pairs of saw. The process of cut making in scion and rootstock and joining of cuttings was experimented for grapes.

Onoda *et al.*, (1992) studied the grating robot with the object of mechanical grafting of cucurbitaceous vegetables. Robots were developed further to make its performance stable and practical depending on feeding wheels, gripping hands, conveying wheels, cutters, fixing clipper, discharge hand, programmable controller and power supply. One cycle time from feeding nursery plants to releasing a grafted nursery plant required about 3 seconds. A cutting speed of 2.5 m/s and a cutting blade of 30° for both stock and scion were found favourable. The results of cucumber grafting test shown successful grafting rate of 98 % and after acclimation successful rate was 95 %. The ratio of successful fixing of stocks and scions (mechanical success) was between 95-100 %, 98 % on average. 97 % of the mechanically successful grafted nursery plants agglutinated, which proved the relative positioning of the cut sections.

Kurata, (1994) studied cultivation of grafted vegetable and development of grafting robot in Japan. The grafting robot uses a special tube to join the rootstock and scion and secure them together. The tubes were made of plastic and shrink when heated. The rotary cutting disc cut the stem of rootstock and scion seedlings at an angle to the axis and joined. Tube was heated by hot air at 150 °C to 250 °C for several seconds and then cooled. They studied different prototypes of grafting robot developed by different institutes and companies. The Institutions, researchers and companies were still attempting to develop the feasible grafting robot.

Nishiura *et al.*, (1995) developed an automatic production system for grafted seedlings on the basis of Plug-in Method. A stem shaped up as a form of plug like a pencil-tip in case of scion and for stock stem will be drilled to make a conical hole. The grafting robot system fabricated to perform Plug-in Method on the basis of characteristics of seedlings for processing as the botanical physiology, the structure and physical properties inside the stem of material. Vegetative materials had been cut using an ultra-sonic level vibrating blade technique that reduced the damage to the vegetative tissue for cutting. The characteristics of material to be cut were one of important elements for designing or fabricating cutting device. It was necessary to measure and investigate parameters and properties as the size range, contour of materials, the structure within a stem at cutting position, and the dynamic properties for cutting at cutting position. The results shown difference in conical shape, surface smoothness, strain due to twist, square of non-peeled epidermis, center matching of cutting process, broken degree at the tip of stem which occurred at various speeds set of feeding a material to the cutting device. Developed high frequency cutting device had performed the acceptable work at any combination of the rotational speed and vertical speed within the range.

Celik, (2000) studied the effects of different grafting methods applied by manual grafting units on grafting success in Grapevines. In this study, Amasya Beyazi and Alphonse Lavallee grape varieties were grafted on 5 BB (*V. berlandieri* x *V. riparia*) rootstock by chip-budding, cleft and omega cut manual grafting units under nursery condition. Grafts was done on the 15th of May with one-year-old rooted rootstocks were used in the experiment. The highest graft take was observed in chip budding, 87.00 % for Amasya Beyaz, and 82.50 % for Alphonse Lavallee. The graft takes of cleft and omega cut grafts were 81.00 % and 74.25 % for Amasya Beyazı, and 79.75 % and 74.50 % for Alphonse Lavallee, respectively. The highest rate of grafted grapevines was also obtained from chip-budding, 54.19 % and 61.50 % for Amasya Beyazı and Alphonse Lavallee, respectively.

Celik and Boz, (2001) studied on grafted Grapevine propagated by bench grafting, field or nursery budding, different grafting method and using hand manual grafting units. They found that budding of rootstocks in an open ground nursery was a widely used method of producing grafted vines. Also it was easier and cheaper than classical methods. Furthermore the classical methods have expensive investments, extensive care and labour during callusing period. Hand manual grafting units under nursery conditions must become widespread to increase the grafted grapevine production and decrease the inputs. The seven different hand manual grafting tools of company were undertaken for study. These involve Chip-budding grafting unit, Omega grafting unit, Cleft grafting unit, topgrafter and chipbudder. Chip-budding made by hand manual grafting unit has two incisions made on rootstock like those done for bottom of the classic chip-budding made by hand. A dormant bud inserted into the rootstock trunk such as both angles above and below the bud will fit better than the classic one. These type of chip budding do not need wrapping when mounding.

Sumrah *et al.*, (2002) studied apple propagation using mechanically and manually prepared stock for bench grafting in four phases i.e., mechanically made stock and manually prepared scion, second phase was vice versa while in third stage both stock and scion were prepared scion and stock. In fourth operation all the grafting process was performed by manually. Maximum sprouting and success percentage found in mechanically prepared scion and stock. Results proved that this operation was also the efficient which took 95.4 minutes to graft 100 plants. The results concluded that mechanical technique of grafting is the best and efficient method.

Legare, (2007) studied about grafting machines and their use, number of cuttings/hour/person, budding/hour/person, and grafts/hour/person done in the nurseries. Difficulty to find good workers to do grafting, growing grafted plants or growing plants on their own roots, short and long-term incompatibility problems with grafts, loss of knowledge due to retired workers, new developments about grafting in nurseries had been surveyed. Conclusion was

grafting will be used to propagate plants as long as there will be no other existing method to root plant easily.

Chen *et al.*, (2010) developed an automatic tubing-grafting robotic system using soft rubber tubes as the grafting material that is suitable for the rootstock and scion of fruit-bearing vegetables having similar stem diameter, such as tomato, bitter melon and sweet pepper. The soft rubber tube approach is low-cost and minimizes water loss from the grafting wounds compared with grafting using grafting clips. As the grafted seedlings grow, the soft rubber tubes automatically peeled off from seedlings due to embrittlement and this saves recycling. The tubing-grafting robotic system comprises of six major units, namely the rootstock gripping, the rootstock cutting, the scion gripping, the scion cutting, the tube supplying, and the guiding units. A logically controlled and programmable pneumatic mechanism was used to process the sequential events needed. The scion and rootstock cutting unit cut off the lower part of the scion or upper part of the rootstock, and generate a slanting grafting surface. The rootstock cutting unit and scion cutting unit were similar but the difference was that the blade for cutting the scion is mounted with their edge slanted downward. The scion is pulled upward to cut its lower parts and removed, leaves a grafting surface slanted from left to right. The removed lower part and the medium falls into the collection bucket. The rootstock and scion were inserted into the rubber tube, a pair of guiding sleeves in the guiding unit to ensure the smoothly insertion either the rootstock or scion were defective. The results shown that the average grafting success rate was over 93.8 % and the system had a working capability of 327 seedlings per hour; the overall adhesion rate for the grafted seedlings kept in an acclimatization chamber was over 84.4 %.

Chiu *et al.*, (2010) developed a top plug-in grafting robotic system for grafting a scion into a mature rootstock before the scion's cotyledons spread. The required scion would be very delicate and greatly different from the rootstock in terms of seedling age. The grafting robotic system for watermelon seedlings comprised of a rootstock processing unit and a scion processing unit, with dimensions of 120 cm × 105 cm × 130 cm. The rootstock and scion processing unit both had a rotating disc, with the disc of the rootstock processing unit being lower than that of the scion processing unit. The two discs rotate in opposite direction; a Geneva Wheel intermittent motion mechanism was adopted to drive the discs so that simultaneous and opposite movement was possible. The rootstock processing unit remove the leaf bud from the rootstock seedling and drill a hole for the scion. The scion processing unit cut the scion seedling to make a sharp angle and finishes the grafting operation by inserting the scion into the hole in the rootstock. The developed grafting robotic system has absence of grafting clips. The research involves mechanical grafting experiments of bottle gourd “Chiang-Li #1” as the rootstock and watermelon “Fu-Bao #2” as the scion. The experimental results showed that the grafting robotic system was able to accurately

finish all grafting procedures and operations, with an average success rate of 95 % and a working capability of 480 seedlings per hour.

Lee *et al.*, (2010) reviewed vegetable grafting, diffusion, grafting techniques and automation. Different hand grafting methods such as Hole insertion grafting, Tongue approach grafting, Splice grafting, Tube grafting, One cotyledon splice grafting, Cleft grafting and Pin grafting was explained. Also studied the grafting machines and robots developed in chronological order and acclimatization. Use of grafted plants increases the income by high yield and off season growing, lower input of fertilizers and irrigation water. Wide root systems of the rootstocks, saving in agrochemicals due to high resistance of rootstocks, extension of harvest period, efficient maintenance of popular varieties against diseases and other physical disorders were also helpful to growers. Suggested that growers can purchase grafted seedlings of any specific combination from commercial plug seedling growers rather than doing the tedious grafting.

Zhang *et al.*, (2011) evaluated the graft robot (named ZSTU-GR01) an automatic machine for grafting fruits and vegetables with parallel insert method. Tested the performance of ZSTU-GR01 automatic graft robot and determined the most suitable parameters for grafting. They developed the PLC program and grafting experiment for graft robot. The results shown that the total grafting speed was 514 seedlings per hour, total success rate was 84 %. Eight independent comparison experiments that shown the most suitable seedling parameters for grafting. These were rootstock diameter 3.5 - 4.5 mm, scion diameter 2 - 3 mm, rootstock stem and scion stem straight, angle of rootstock cotyledons close to 180°. Graft robot can adjust grafting speed from 5 to 9 seconds per seedling by modifying the program's parameter.

Pekkeriet and Henten (2011) studied the current developments of high-tech robotic and mechatronic systems in horticulture and future perspectives. Driving forces for mechanization was identified. Dutch greenhouse crop production was used as an example. In greenhouse horticulture the production steps and control that needs to be done in the growing area of high value crops and flowers were often done manually. Growers are investing a lot of labour in processes like crop sensing, crop maintenance and harvesting the products. To do this, a lot of human intelligence is required, such as precise, effective and efficient eye-hand coordination.

Subo and Donglei, (2011) concluded that vegetable grafting is one of the most effective means to resist soil-borne diseases and to improve yield. Manual grafting has the problems of low production and poor grafting quality, so grafting robot is significant for the development of vegetable grafting production. The development and current status of domestic and foreign automatic grafting machine was analysed based on the grafting principles. Found out some problems restricting the advancement of grafting machine.

Chang *et al.*, (2012) studied the growth and union acclimation process of sweet pepper grafted by tubing-grafting robotic system. Sweet pepper 'Andalus' (*Capsicum annuum* L. 'Andalus') was grafted on chili pepper 'P' (*Capsicum chinense* 'P') by hand and by using a tubing-grafting robotic system. The survival ratio was recorded every two days from the 1st day after grafting (DAG) to the 13th DAG. Recorded plant growth and also changes in the height and diameter of both stock and scion. In one group, 128 plants grafted manually and in other group, 128 plants grafted mechanically. They found that growth and condition of the seedlings grafted by machine were similar to that of the seedlings grafted by the traditional hand method. Seedlings acclimation process was similar to grafted seedlings which had been grafted by hand, but the cut interfaces on the mechanically was more irregular. The recovery process of the machine-grafted seedlings was slower than that of the hand-grafted one, by the seven days after grafting. All of the machine-grafted seedlings showed visible vigour. They concluded that the tubing-grafting robotic system can be applied generally to grafting operations, thus allowing improvements in production efficiency.

Sun *et al.*, (2016) developed a grafting robot based on cleft grafting method to improve efficiency of grafting solanaceae vegetables. The robot comprises of four parts includes a clamping manipulator and carrying, cutting, feeding mechanisms. These enabled the robot to conveniently perform clamping, carrying, positioning, cutting, joining, and binding rootstock and scion, and also improved the grafting efficiency. The cutting blade can perform forward and backward cutting movements led by a dual acting double rod linear cylinder of the rootstock cutting mechanism. According to the rootstock manipulator cylinder was chosen a TPMTN16×50 and provide 100 mm displacements in two directions. Liner cylinder and pneumatic claw used together to remove the remaining seedlings. The average success rates for cutting rootstock, cutting scion and conjugation are 98.7 %, 99.0 % and 59.6 % respectively. The developed robot was able to perform steady operations, suggesting potential value for practical applications.

Chiu *et al.*, (2016) developed the grafting robots and an acclimatization chamber for watermelon and tomato seedlings. They had developed top plug-in robotic grafting system for watermelon seedlings which was applicable for grafting a scion into a mature rootstock before the scions cotyledons spread. Results shown that the grafting robotic system accurately finished all grafting procedures and operations with an average success rate of 95 %, and working capability of 480 seedlings per hour. The experimental results indicated that the average grafting success rate was 95.5 % with working capability of 327 seedlings per hour. An acclimatization chamber with dimension of 5400×2650×2100 mm was developed curing environment for seedlings after grafted. Results indicate that survival rate of grafted seedlings kept in the chamber is more than 96 %.

Seedlings which were acclimatized in the chamber after grafting shown a higher survival rate than those acclimatized under protected cover in the open field.

Yu *et al.*, (2017) designed the automatic grafting device for grafting machine based on vision driven. A vision based automatic upper and lower seedling device of grafting machine to solve the problem of plant grafting and manual grafting degree of mechanization and low operation efficiency and to provide technical support for further design of automatic grafting machine. The device mainly comprised of the manipulator and control system, the end clip mechanism, the visual drive device. The end device adopts the electromagnet stroke 5 mm, the electromagnet carries on 20 times electricity test, obtains the clamp maximum opening width. Experiments were conducted with plug seedlings as grafting objects, the maximum opening of the device was 4.805 mm, fully meeting the stock average width of 2.36 mm and scion width of 2.02 mm requirements. After 50 groups of seedlings test, the success rate of the device reached more than 97 %.

Belforte *et al.*, (2018), presented a prototype of an automatic machine for the herbaceous grafting of Tomatoes. To reduce the use of pesticides, grafting is important as it gives superior plant and eco sustainable. The developed machine comprises of electro-pneumatically controlled and innovative robotic system. The purpose of this device was to instrument a fully automatic machine proficient of picking, choosing, cutting and joining the two plants to accomplish the complete grafting process. They conclude that fingers gripper geometry was innovative and works without damaging the crop, the solution adopted for the junction station configuration was easy, safe and functional, the whole machine was convenient and the low cost construction of the system.

Pardo-Alonso *et al.*, (2019) studied combined influence of cutting angle and diameter differences between seedlings on the grafting success of tomato using the splicing technique. The experiment attempts presented the combined influence of cutting angle and different random diameters on grafting success with the objective of detecting an optimum working range that will be applicable to automated and robotic grafting systems. An increase in the grafting angle was associated with a higher survival of grafted plants despite variations in diameter. Moreover, a threshold cutting angle has been observed from which the success rate no longer increases but decreases drastically. Therefore, for a given working range with a significant cutting angle, whether the seedlings of origin were similar in diameter was not important, and this factor had more influential outside the optimal cutting angle range.

Cho *et al.*, (2020) evaluated hand-grafting and commercially available grafting tools for efficiency and successful graft union. The standards provided for selection of scion and rootstock, pregrafting preparation and justification. Rootstock planted in February, grafted in starting of July

and result were taken after July, 2019. The details of commercially available tools which undertaken for study and material used was given. Hand grafting tools, Bud grating tool and V grafting tool were compared for costing and performance. V graft tool was cheap tool and shown maximum result.

Xie *et al.*, (2020) developed a high- productivity grafting robot for solanaceae. To improve grafting productivity, plug trays was used to feed crown-removed rootstocks automatically and carried out multi-plant simultaneous grafting to improve grafting productivity and extensibility. Manipulators were employed to take out rootstocks, increase the distance between them, and transfer them to transfer cups for the simultaneous multi-plant grafting. Negative pressure mechanisms were designed for speeding up the auxiliary feeding of root-removed scions. The HPR was designed in a two-operator mode, one-operator mode can also be implemented by adjusting the control program. Varying the artificial feeding speed tests was conducted to analyze the performance of the grafting robot. The results shown that the productivity of the robot in the two-operator mode 2250 plants/h and 1542 plants/h in one-operator mode. Comparing the artificial feeding productivity with auto grafting productivity, they found that the capacity of the grafting robot was higher than the feeding speed of the one-operator mode but lower than that of the two-operator mode. General and unskilful operators achieved a 100 % success rate with a productivity of 1542 plants/h. Improving the productivity of the grafting robot were limited by the extreme speed of artificial feeding of scions. Capacity of skillful operators was about 258 plants higher when compared to the capacity of operators of other skill levels.

Benos *et al.*, (2020) studied the most common risks that operation of agricultural machineries causes like Musculoskeletal disorders (MSDs). They observed that these have long been undermining the ability to labour and quality of life. They investigated to thoroughly review the recent scholarly literature on ergonomics in agricultural mechanized operations. Performed an assessment of the methodological quality and strength of evidence of potential risk factors causing MSDs. Concluded that handheld machines causes disorders of the upper extremities and lower back pain. The main roots of these disorders were the whole-body vibration (WBV) and hand-arm transmitted vibration (HATV). The personal characteristics, awkward postures, mechanical shocks and seat discomfort were also recognized which cause MSDs.

Pardo-Alonso *et al.*, (2020) standardized the use of plastic or silicone grafting clips, equipped with manipulating wings and a frontal opening, to ensure proper bonding and allow for wound healing. It has been shown that 20 % more recorded successes if one first joins the graft seedlings and then places the grafting clip. In addition, they studied the different orientation alternatives for the cutting line and the seedling union with respect to the clip opening there were

approximately 10 % more successes obtained in grafts where the splice-union cutting line between the two plants faced the clip opening.

Chen *et al.*, (2020) designed and experimented on scion cutting mechanism of grafting robot for cucurbit. Based on the analysis of the geometric parameters and mechanical characteristics of scion seedlings, a scion cutting mechanism with holding seedling applied to cucumber seedlings and watermelon was designed and developed. The main structure and operating parameters of V-shaped holding seedling block and cutting unit were determined, and holding seedling and cutting performance tests were carried out. The test results showed that compared with the common arc clamp, the V-shaped holding seedling block had a better guiding and centering effect on the scion seedling.

Vairagi *et al.*, (2021) has done development based on the automating the process of grafting. In order to solve the problems of manual grafting and increase the degree of mechanization and low operation efficiency of developed machine design a vision based automatic upper and lower seeding device of grafting machine. Device was mainly composed of the manipulator and control system, the end clip mechanism. They worked on the design of Geneva mechanism, gripper mechanism, punch mechanism and clipping mechanism.

The large amount of information about grafting mechanization, automation and methodology was reviewed for design and development of bench grafting tool. Portable machine for grapes grafting, robotics for vegetable grafting and automation in grafting of other plants, were noted. Mechanism used in mechanical grafting of vegetables, characteristics of material to be cut, various cutting method such as ultra-sonic level vibrating blade method, important elements for designing or fabricating of cutting device or other components of machine will help to develop the mechanical grafting system.

2.4 Performance evaluation of Grafting tool and machines:

Suzuki *et al.*, (1998) evaluated the materials and machines for vegetable seedling production like grafting systems. The grafted nursery plants of fruits and vegetables for cultivation require precise techniques and careful management, grafting had so far been performed manually. However, the development of grafting systems enabled to perform this work mechanically. They classified representative grafting systems of YANMAR, ISEKI and MITSUBISHI companies for their general configuration, object crop, seedling feeding method, grafting method and materials, and release of grafted nursery plants, and analysed the functions of each system. Described the work performance of each grafting system and emphasized the importance of raising scions and stocks for mechanical grafting. Indicated that the development of new technologies like

automation of accessory operations, preparation of manuals for raising seedlings, seedling storage technology, and cultivation technology, were important for the development of grafting systems. A wide range of uses for other crops required because the production of grafted nursery plants for fruits and vegetables is seasonal and consequently the operation rate of the system decreases. The mechanical grafting success rate of any type of system was 95 % or more. An agglutination rate of 90 % or more obtained under specified acclimation conditions.

Zenginbal *et al.*, (2006) studied the effect of tying and wrapping materials and their colour on budding success in kiwifruit. The work was done in the open field. Three-year-old, gallon container grown Hayward seedlings were chip-budded with Hayward chip-bud sticks in the first quarter of May. Raffia (black), cannabis fiber, leathery polyethylene band (white), soft rubbery polyethylene tape (white), paper tape, cotton yarn and plastic string (white) were used as tying and wrapping material in the first experiment. Green, red, black and white raffia was used as wrapping material in the second experiment. In the first trial, the soft rubbery plastic tape gave the highest graft-take (100 %), sprouting rate (96.67 % and 100 %, respectively), graft shoot diameter (7.58 mm and 7.62 mm, respectively) and length (70.43 cm and 78.01 cm, respectively). Paper tape gave the lowest results. In the second trial, the white raffia gave the best results on graft success (96.67 % and 93.33 %, respectively) and graft shoot length and diameter. Concluded that the soft rubbery plastic tape could be effectively used for tying the kiwifruit bud-grafts and white wrapping material increased the bud success. The conventional wraps like cannabis fiber, plastic string, cotton yarn or paper tape are not suitable for kiwifruit budding.

Goldschmidt, (2014) reviewed new mechanism and evolutionary implications in plant grafting. Fruit trees have been propagated by grafting technique since long time and in recent years same practiced in vegetable also. The mechanism underlying interspecific graft in compatibility was yet understood insufficiently. Incomplete and convoluted vascular connections impede the vital upward and downward plant transfer routes. Grafting onto resistant rootstocks serves as a principal tool in the management of fruit tree and vegetable soil borne diseases. Concluded that the technology of grafting has advanced tremendously, the long term survival of grafted, composite plants is still unpredictable.

Sun *et al.*, (2014) developed a sapling grafting robot to implement automatic grafting for saplings. The developed grafting robot includes clipping mechanism, moving mechanism, cutting mechanism, binding mechanism, and Arduino MCU based control system, which was capable of clipping, moving, positioning, cutting, grafting, and binding saplings. Experiment results showed that the stock cutting efficiency is 98.4 %, the scion cutting efficiency is 98.9 %, the grafting efficiency is 87.3 %, and the binding efficiency is 68.9 %.

Pisciotta *et al.*, (2017) evaluated graft success of Grapevine after incubation room by means of thermographic, electrical and mechanical techniques. The trial was carried out at Vivai Mannone. Experimental results showed that they were able to distinguish the successful grafting only with the thermographic test. The technique was the only non-destructive test from which it was possible to derive quantitative parameters, useful to provide successful nursery forecast. Engraftment results detected at the nursery showed a 15 % error in forecast based on the proposed thermal image method, which is a satisfactory value for a feasibility study.

Wu *et al.*, (2021) experimentally evaluated rootstock clamping device for inclined inserted grafting of melons. The study proposed an effective, flexible clamping device for grafting. The suction hole diameter (HD), the negative pressure (NP), and the surface inclination angle (IA) of the clamping device were studied via a single factor experiment to obtain optimal parameter ranges. Optimal HD, NP, and IA were 2–3 mm, 4–8 kPa, and 10–20°, respectively. Maximum holding success rate was HD, 2.5 mm; NP, 6 kPa; and IA, 10°. The experimental verification was carried out using the optimal parameter combination, with a holding success rate of 98.3 % and no damage. The study provided a reference for the optimal design of an inclined inserted grafting machine.

In above section of literature, the performance evaluation of grafting machines or systems developed and commercial grafting robot were reviewed. Standard evaluation method and process for plant materials and grafting machines used by researchers along with the parameters for evaluation such as moisture content of plant material, plant growth indices, scion cutting rate, rootstock cutting rate, cutting capacity, grafting capacity and graft take success rate were used. The information available will be helpful for evaluation of performance of machine.

A large amount of information about grafting method, process, raising of seedlings, media for raising, season of grafting, preparation of seedling or rootstock material and scion material, age of rootstock and scion, pregraft treatments, postgraft acclimatization standardization were reviewed. In cashew nut grafting softwood grafting method is suitable in konkan region of Maharashtra. In this grafting, rootstock of age 3 – 8 months with diameter of 4 - 6 mm and scion of 4 – 12 mm diameter with length 7 – 13 cm were recommended and joined after slanting cut 4 – 7 cm long as per standardization. The diameter of scion and rootstock, moisture content, cutting force, hardness and age of rootstock are important engineering properties required for design of bench grafting tool. These properties measurement helps in design of machine, force calculation and selection of material of construction. The cutting mechanism, type of cutting, type of blades, ‘V’ shape cutting, design of blade for clean surface cut, binding techniques and wrapping mechanism required for design and fabrication of bench grafting tool. The grafting machine should

make clean surface cut without burr, cut made must be in wedge like shape and cut must be aligned with centerline. Also the machine should wrap the graft union tightly by grafting tape with leaving no gap space. After reviewing the above literature not any single machine available for grafting of Cashew Nut and other suitable orchard crop which involve cutting of scion and rootstock and wrapping graft union. Therefore it is necessary to work on the design and development of bench grafting tool.

CHAPTER III

MATERIAL AND METHODS

This chapter elaborate the methodology and procedures followed to achieve the following objectives.

- i. To determine engineering properties related to scion and rootstock cutting.
- ii. To design and develop bench grafting tool.
- iii. To evaluate performance of bench grafting tool.

It also covers detailed procedure of design, development and performance of newly developed bench grafting tool. The procedures and methods are illustrated with figures and photographs where felt necessary. Due acknowledgment is also given to the literature source and investigations in this manuscript.

The chapter is presented in the following sub-headings.

- 3.1 Study of existing grafting technique
- 3.2 Engineering properties of scion and rootstock
- 3.3 Design considerations of bench grafting tool
- 3.4 Design and development of bench grafting tool
- 3.5 Study of parameters in laboratory condition
- 3.6 Field performance evaluation of developed bench grafting tool

3.1 Study of Existing Grafting Technique

Tropical fruit crops were generally propagated by grafting i.e. graft scion onto a rootstock to grow as new tree. In present study softwood grafting method was used for bench grafting of cashew. The rootstocks were grown at Central Workshop and Nursery, Dr. BSKKV, Dapoli. The scions were collected from the mother plant nursery, Dr. BSKKV, Dapoli.

In konkan region, the grafting of cashew is done using the softwood grafting method. The grafting works best, when the stock and scion are of similar diameter, preferably between 6 mm and 12 mm. The stock should be smooth and straight-grained. Graft near a point where side twigs or branches have developed. The scion used by grafter is 1-year-old softwood, preferably the same

size as the stock. The both stock and scion cuts made with matching surfaces. On both parts, smooth sloping cut of about 40 mm to 63 mm long depending on the thickness of the material. A single smooth cut with no waves or whittling was made as first cut with grafting knife and second cut on opposite face. A good-quality, sharp knife was used for grafting. The stock was a stem and root system of a young plant. A slanting cut of about 60 mm from the decapitated point of the young plant. Although grafts were made with a simple union of two slanting cuts, the strongest graft results from wedge insertion in notch. The cuts were made at the bottom of the scion piece to form the tongue, scion was hold and the one-sided, slanting cut facing to operator and supported it with operator finger was made. The scion and rootstock were hold together by plastic film of 63.5 micron thickness tightly and airtight seal around the area was provided. The scion and rootstock cutting time, wrapping time during grafting of cashew for 10 skilled grafters in nursery were measured. The average cutting length of scion and rootstock by different grafters was measured using vernier calliper. The total time required for grafting one seedling by grafter was also noted. The grafts grafted by skilled grafter were prepared for evaluating success rate of manual method at nursery. The grafted seedlings were kept in polyshed for 15 days and success rate of graft was determined.

3.2 Engineering Properties of Scion and Rootstock Stick

It was observed from review literature on physical properties of various fruit crop sticks like length, width and engineering properties regarding cutting were available. Information about engineering properties of Cashew scion stick and rootstock such as size, moisture content, hardness and cutting strength are not available. Mechanization of operation and characterization of any process require engineering properties to be determined. In this study, engineering properties regarding the cutting of scion and rootstock were measured and studied. The standard method and detailed procedure is adopted. Also details of the instruments or equipments used for measurement are given.

3.2.1 Preparation of rootstock sample

The healthy seedlings with brownish coloured softwood were chosen to determine the engineering properties. Cashew seedlings of Vengurla 1 variety were selected for testing. The sticks with length 100 mm of approximately 3 months and 8 months old each were collected. Also the samples of three different approximate diameter for both age and for replications (Plate 3.1). Collected samples were stored in individual moisture proof zip lock polythene bags in refrigerator at temperature 4-5 °C (Sessiz *et al.*, 2013) to avoid moisture exploitation. Each polythene bag with samples of various diameter and age group were tagged as shown in Plate 3.2. The tests were conducted as early as possible after collecting sample from nurseries to get accurate readings.

3.2.2 Preparation of scion sample

Cashew trees of 12 years old of Vengurla 4 variety were selected as scion mother trees from the progeny bud wood orchard maintained at the Nursery, CoH, Dr.BSKKV, Dapoli. Unsprouted terminal, mature and healthy softwood scion budsticks were selected. The scion sticks of approximately 6 mm, 8 mm and 10 mm size with length of 100 -120 mm length were collected. Samples for different diameter and classified in three different moisture groups were collected. Collected samples were stored in moisture proof zip lock polythene bags with tags for identification in refrigerator at temperature 4-5 °C (Sessiz *et al.*, 2013).

3.2.3 Size

Size of scion and rootstock was characterized in terms of diameter of stick, which was measured using vernier caliper. The diameter of stick was measured at the cutting side, where the V shape cut has been taken. The measurement of diameter of sticks was taken same as measurement of properties of plant material by Mohsenin, 2019. The length of selected scion stick was kept 100 mm -120 mm, which showed maximum success (Kadam, 1992). For characterization of size, different samples of scion and rootstock each were randomly selected and divided into three diameter classes (Sessiz *et al.*, 2013). The results of the measurement are reported in Appendix A.

3.2.4 Moisture Content

The scion and rootstock samples for moisture content determination from sample kept in moisture proof zip lock polythene bag and coded were taken as immediately as possible after completion of other measurement. The samples for moisture determination were taken from sticks used for cutting strength and hardness determination with different diameter classes and age of stick. The moisture content of scion and rootstock were calculated by using standard test procedure for direct moisture content (ASTM D4442-16, 2016). The stick sample was cut in 10 - 30 mm length pieces and filled in aluminium sample boxes (plate 3.4). The sample boxes with stick pieces were weighed with the digital precision balance, numbered and kept in hot air oven at 103 °C for 24 hours to remove moisture. After 24 hours, sample boxes were taken out and kept in desiccator and closed with lids for cooling to room temperature without moisture absorption. Sample boxes were weighed after cooling with the digital precision balance. The moisture content of stick was calculated as follows:

$$\text{Moisture Content, \%} = \frac{(W_1 - W_2)}{W_1} \times 100 \quad \dots \text{on wet basis} \quad \dots (3.1)$$

Where, W_1 – Initial weight of stick sample, g

W_2 – Final weight of oven dried stick sample, g

Moisture content of selected scion and rootstock sticks were calculated and presented in Appendix B. Above method was used to determine moisture content of sticks before which they were tested for engineering properties.



Plate 3.1 Scion diameter measurement



Plate 3.2 Samples prepared for property determination



Plate 3.3 Cutting force determination using Texture Analyser

Plate 3.4 Samples prepared for moisture content determination

3.2.5 Hardness

Hardness (N/mm^2) is the ability of material to resist localised plastic deformation, which was determined by a standard test, where the surface resistance to indentation is measured. A hardness test is typically performed by pressing a specifically dimensioned and loaded object (indenter) into the surface of the material. Indentation was based on standard instrumented indentation (ASTM E2546-15, 2015). Indenter tip with a known geometry was driven into material, by increasing normal load (Leroux, 2014).

The Perten Instruments, TEXVOL TVT – 300 XP Texture Analyser (Plate 3.3) was used to determine the hardness of scion and rootstock sticks. Cylinder probe of 2 mm diameter and material of stainless steel with Perten Instruments Texture Analyser inserting in Insert with hole 10 mm was used as attachment. Prior to test the stick samples were divided into three different diameter groups from 4 mm to 10 mm for scion and rootstock each. The test was conducted with test speed i.e. indenting speed of 1 mm/s. The stick samples were kept in horizontal position on Heavy Duty Stand insert and loading was applied in vertical direction. The indentation was up to the depth equal to diameter of sticks. The graph of force-displacement was drawn with the peak point as maximum indenting force. The readings were recorded in table using computer data acquisition system. Then the hardness was calculated by,

$$\text{Hardness, } H (\text{N/mm}^2) = P_{\max} / A_c \quad \dots(3.2)$$

Where, $P_{\max}$ = maximum load or maximum indenting force, N

$$A_c = \text{projected contact area, mm}^2$$

The observations are presented in Appendix C.

3.2.6 Cutting Strength

Cutting strength is the maximum Cutting force which a material is capable of sustaining. Prior to experiment, the scion and rootstock stick diameter was measured with the vernier calliper (Plate 3.1), and then both the stick samples were divided into three different diameter groups (6, 8, 10 mm) for scion and (4, 6 and 8 mm and 6, 8 and 10 mm) for rootstock, respectively. Then sticks were tested for cutting force and maximum cutting force was recorded. The Perten Instruments, Texture Analyser with Probe Holder Knife and Blade Set Insert was used for testing. The cutting knife was made up of steel, 1 mm thickness, 50 mm width. During the test, the stick samples were placed on the Blade Set Insert in horizontal position (Plate 3.3). Loading was applied

in vertical direction with test speed of 1 mm/s. Texture Analyser shows the graph of force-displacement from start of cutting to end of cutting with one peak point of maximum cutting force. The maximum cutting force readings for various experimental samples were obtained and recorded using computer data acquisition system in table and presented in Appendix D. The diameters (mm) of sticks were converted into cross section area in (mm²). Cutting strength was studied using direct cutting test method with constant cutting velocity. The maximum cutting strength was calculated by, (Mohsenin, 2019; Sessiz *et al.*, 2013).

$$\text{Maximum Cutting Strength, } \sigma_s = \frac{F_{max}}{A} \quad \dots(3.3)$$

where, σ_s = maximum cutting strength, N/mm² (MPa)

F_{max} = maximum cutting force, N

A = cross-sectional area of stick at the shear plane, mm²

Table 3.1 Operating setup of TexVol Texture Analyser set before testing

Sr. No.	Operating Setup Particular	Value
1.	Test type	Compression
2.	Test mode	Single cycle
3.	Force unit	Grams
4.	Sample height	85 mm
5.	Starting distance from sample	5.0 mm
6.	Compression	20 mm
7.	Initial speed	1 mm/s
8.	Test speed	1 mm/s
9.	Retract speed	10 mm/s
10.	Trigger force	5 g
11.	Data rate	200 pps
12.	Diameter	6, 8, 10 mm

3.2.7 Age of Rootstock

The hardness of stem stick or woodiness of rootstock increases with the increased in age of rootstock. The younger rootstock was easy to cut and older one gives more resistance to cutting. In Cashew grafting, rootstock of age 3 months (90 days) old to its age still showing softwood characteristics were used. Therefore, the two extreme different age old rootstock were tested, one 3 month old and other 8 months (240 days) old rootstocks. Above mentioned properties such as cutting strength, hardness and moisture content were measured for two different age rootstock. Study of the effect of age of rootstock on other properties or variation in measured properties due to variation in woodiness of stick was conducted.

3.3 Design Considerations of Bench Grafting Tool

Bench grafting tool to accurately cut the scion and rootstock in wedge shape ('V') and properly wrap the polythene on graft union joint was to be designed in this research work. The system's component designs were based on agronomic requirements, operational concepts, and comparisons to manual grafting by grafters. This component of the study includes information about mechanical design in order to provide the machine's design with the necessary functional stiffness.

3.3.1 Agronomic Requirement

For grafting operations, it is important to consider the agronomic requirements. The bench grafting tool was developed using the principal requirements of cutting scion and rootstock, graft union wrapping concepts. Based on suggestions and the findings, the agronomic needs of the bench grafting tool are as follows:

1. Success in grafting depends not only on a technically correct graft but in preparation of the scion and rootstock for grafting so, they should be prepared properly.
2. The optimum time for grafting, and proper aftercare should be taken.
3. The vascular cambium of the scion must be placed in direct contact with that of the rootstock.
4. Immediately after the grafting operation is completed, all cut surfaces must be protected from desiccation.
5. The graft union should be wrapped tightly such that air should not enter at grafted area that will cause drying of the graft union area.
6. The healthy emerging soft coppery red shoot which is about 3 to 12 months old rootstock should be preferred.
7. For most species, the wood should be 1 year old or less (current season's growth).

8. The best type of scion material is vigorous (but not overly succulent), well-matured, hardened shoots from the upper part of the tree, which have grown 600 mm to 900 mm the previous summer.
9. The mature, procured scion defoliated 7 to 10 days prior to grafting should be prepared.
10. A satisfactory size of scion 4 to 10 mm in diameter and length of 100 – 120 mm should be used.
11. The best scions are obtained from the center portion or from the basal two-thirds of the shoots. The terminal sections, which are likely to be too succulent, pithy, and low in stored carbohydrates, should be discarded.
12. Clear or coloured polyethylene or polyvinyl chloride (PVC) grafting strips, which are 5 to 13 mm wide and slightly elastic, allowing for a more secure wrap.

The recommended size of scion and rootstock for softwood grafting of various fruit crops as per various researchers (Haldankar, 1985; Kadam, 1992; Uradya, 1976; Waghmare, 1990) is given in Table 3.2.

Table 3.2 Recommended details of scion and rootstock for various fruit crops

Sr. No.	Fruit crop	Rootstock		Scion		Cutting length, mm
		Thickness, mm	Age, months	Thickness, mm	Length, mm	
1.	Cashew	4 - 8	3 - 8	4 - 12	70 - 130	40 – 70
2.	Mango	5	4 - 12	5 – 10	75 - 130	30 – 50
3.	Sapota	3 - 5	9 - 24	3 - 6	100 - 120	40
4.	Kokam	3	5 - 6	5 - 6	100 - 120	40
5.	Jackfruit	3 - 5	9 - 12	4 - 6	75 - 100	40 – 50

3.3.2 Machine Requirement

The machine was designed to mechanise the grafting process in nurseries. The following assumptions were made while designing bench grafting tool for Cashew grafting.

- a. Machine should capable of making ‘V’ cut in scion sticks and rootstock for different mechanical grafting characteristics of growing geometry parameters, cutting characteristics, cutting force characteristics, cutting surface physiology, and biochemistry characteristics available.
- b. The scion stick should cut into double wedge shaped incision.

- c. The cut made in scion stick or rootstock must be clear and smooth surface cut without any burr.
- d. The rootstock holding platform or tray besides cutting mechanism should be enough long to provide place for maximum height of rootstock.
- e. The sliding tray or platform besides the wrapping mechanism should slide enough long to provide proper sliding and slide length.
- f. The control lever and switch to operate the mechanism should in comfort reach of operator ergonomically and easy to operate.
- g. The graft union joining between rootstock and scion should be good, the central lines of both well aligned and good contact without deflections.
- h. Wrapping mechanism must tightly wrap the grafting tape on graft union, without obvious misplacement of joining cut surfaces of scion stick and rootstock.
- i. Wrapping mechanism should wrap various size graft union formed due to variation in diameters of scion stick and rootstock.
- j. The machine should have provision for changing operational speed of wrapping and operating air pressure of cutting.
- k. The operation cost of machine must be low.
- l. The machine should be portable to use conveniently in field conditions.
- m. The system or parts of machines should be easily assembled and dismantled for checking and repair.

3.4 Design and Development of Bench Grafting Tool

Based on agronomic requirement of grafting of fruit crop (Cashew) assumption made, the pneumatic powered scion stick and rootstock cutting system and graft union wrapping system was designed by designing the individual components.

The schematic view of bench grafting tool is as shown in Fig. 3.10. The design of systems is given below:

3.4.1 Design of Stick ‘V’ Shape Cutting Mechanism

The stick 'V' shape cutting mechanism is the pneumatic powered impact cutting by 'V' shape blade with sharpness at bottom side hold in blade holder and attached to pneumatic cylinder piston rod orienting downward. This mechanism was mounted on stand with base providing platform for cutting. The hard rubber flat is fitted at bottom to provide base for cutting. The compressed air is passed through the air filter regulator. Filtered air is provided to system through the polyurethane tube. Control lever is fitted before cylinder controls the downward and upward action in cutting stroke of scion and rootstock cutting system by changing the pressurised airflow through different ports. The stick is placed at base platform and then control lever is operated which was mounted near foot on main table frame for foot pedal control. The stick is cut with impact by 'V' shape blade; blade travels upward when foot pedal control is released. The air was released to atmosphere through button silencer. Provision of platform was made for placing the rootstock soil media bag horizontally. Developed pneumatic system view is as shown in Fig. 3.1. The designs of various components are described below:

3.4.1.1 Pneumatic System

a. Selection of pneumatic system

The pneumatic system is selected considering lower cost, flexibility and higher safety levels of system. The pneumatic system is selected instead of electric actuator because of lower initial cost and high speed of operation. Pneumatic system makes use of pressurized gas or air for mechanical motion based on the working principle of fluid dynamics and pressure. Pneumatic systems are commonly powered by compressed air or inert gases. Pneumatic systems are primarily used for shock absorption application because gas is compressible and allows the equipment to be less susceptible to shock damage. The pneumatic system consists of interconnected set of components including a gas compressor, air tanks, transition lines, hoses, standard cylinders and gas (atmosphere air). According to working force required the different sizes of pneumatic system or cylinder can be selected.

b. Design of pneumatic System

In the pneumatic system, selection of pneumatic cylinder size decides the force exerted by system at given air pressure. To get the desired force of cutting, the cylinder is designed with the maximum cutting force required to cut material in 'V' shape easily. The maximum cutting force required for cutting a Cashew scion stick and rootstock stick were determined using texture analyser and results are presented in Appendix E. The results indicated that, using 0.8 mm thick

blade, the required cutting force for Cashew sticks are less than 300 N as shown in Appendix F. Therefore, the size of cylinder is selected as follow:

As per ISO 19973-3 2015, pneumatic cylinder are standardized to give proper optimum force and considering the force to overcome internal friction from seals, bearings, guides, pressure losses due to leaks and other external forces. The Force exerted by pneumatic cylinder can be expressed as,

$$F = P \times (\pi/4) \times D^2 \quad \dots(3.4)$$

Where,

F = Force exerted by pneumatic cylinder, N

P = Pressure of compressed air, N/mm²

D = Bore diameter of cylinder, mm

Considering the safety factor 10 % and frictional loss of 5 %, the theoretical force required for cutting is given as,

$$F_{\max} = 300 + 15 \% (300 \text{ N}) \quad \dots(3.5)$$

$$F_{\max} = 300 + 45$$

$$F_{\max} = 345 \text{ N}$$

Therefore, the maximum cutting force required is 345 N at 0.5884 N/mm² (6 kg/cm²). The cylinder size is given as:

$$A = F_{\max} / P \quad \dots(3.6)$$

Where,

A = Area of bore cross section of cylinder, mm²

$$= (\pi/4) \times D^2 \quad \dots(3.7)$$

F_{max} = Maximum cutting force required, N

P = Pressure of compressed air, N/mm²

$$A = 345 / 0.5884$$

$$(\pi/4) \times D^2 = 586.336$$

$$D^2 = (4/ \pi) \times 586.336$$

$$D^2 = 746.925$$

$$D = 27.33 \text{ mm}$$

Pneumatic cylinders are available in bore diameter size of 16 mm, 25 mm, 32 mm, 40 mm, 50 mm and more, out of which 32 mm bore diameter is suitable. The pneumatic cylinder of standard bore diameter value 32 mm was selected considering nearby and larger size than calculated 27.33 mm size pneumatic cylinder. The other components accessories were selected as

per standard size compatible to cylinder selected. Compressed air inlet was connected to air filter regulator which filters the air and removes the moisture from compressed air. Air filter regulator is fixed on one of convenient bottom of main table frame and it has knob to regulate the pressure of compressed air. The outlet of air filter regulator is connected to foot pedal control lever. The control lever has two outlets to the cylinder and two outlets for removing air trapped in cylinder after every stroke through the button silencers. Button silencer reduces the noise of escaping of pressurized air to the atmosphere. Two outlets of control lever were connected to one of outward pushing port and other to inward pushing port. Foot pedal lever was fabricated by connecting the control lever with the extension spring at top and supporting mechanism for steady up-down motion of lever. A pedal made of 25 mm square pipe of galvanized iron (GI) material and length of 100 mm was joined to lever supporting mechanism foot pedal. The angle between horizontal line and base of foot was kept 30° according to ergonomic design of foot pedal. (Human Engineering in machine design, IASRI)

Table 3.3 Pneumatic cylinder selected for cutting mechanism

Sr. No.	Particular	Details
1	Company	Nu-Flow Automation (India) Pvt. Ltd.
2	Cylinder Series	NCS series
3	Type	Double acting single rod
4	Material	Pressure die cast Aluminium (body), SS 410 (Piston rod), Anodized Aluminium (Cylinder Tube)
5	Operating air pressure	1 -10 bar.
6	Operating Temperature	Up to 70 °C
7	Cylinder Size	Ø 32 mm / 50 mm Stroke

Table 3.4 Pneumatic system details required for cutting mechanism

Sr.No.	Components	Specifications	Quantity
1	Pneumatic Cylinder	NCS D-32/50 mm	1
2	Air Compressor	1 hp	1
3	5/2 Lever Valve	Port size : 1/4"	1

4	Polyurethane Tube	Size: 8 mm × 6 mm	1 bundle
5	Air Filter Regulator	Size: 1/4"	1
6	Straight Fitting	Size: 1/8" × 8 mm & 1/4" × 8 mm	8
7	Button Silencer	Size: 1/8"	2

3.4.1.2 Cutting Mechanism Mounting Stand with Platform

The cutting mechanism mounting stand has the base frame for mounting the pneumatic cylinder in downward direction, so that the piston rod side of cylinder should be at bottom as shown in Fig. 3.2. The bottom base frame prepared of joining 30 mm × 30 mm mild steel (MS) square pipe of length 260 mm. The metal plate was welded on the square frame of 260 mm × 260 mm. A vertical 30 mm × 30 mm MS pipe was welded to base frame and 30 mm square pipe which was also welded horizontally. The height of this pipe is 360 mm from base plate and at top MS flat 60 × 6 × 120 mm was fixed by nut bolts to attach the cylinder. Similar arrangement was also used for mounting bottom cylinder. The flats were drilled with four 6 mm holes for inserting 5 mm bolts of cylinder in both upper and bottom flats. One large central Ø 30 mm hole was made to fit cylinder top and bottom (Plate 3.5). The frame is mounted on main table frame by nut bolt. The wooden block base was fitted on bottom base frame on which the hard rubber sheet was fixed. Wooden block of height 80 mm from base and length 240 mm × 80 mm which provide sufficient space for stick handling during cutting of sticks. Hard rubber sheet with stick holder was fitted on wooden block; this will avoid wearing and blunting due to striking with any hard metal or other material used. Stick holder holds the sticks in horizontal position under the cutting blade, so that there is no need to hold the stick by hand during cutting stroke. The total height of cutting base is 95 mm to start cutting before cushioning effect of pneumatic cylinder. Hard rubber can also be replaced easily by removing screw head nut bolts. The platform of 22 SWG galvanised iron (GI) sheet size 500 mm × 120 mm was welded on main table frame which provide the base for keeping soil media bags of rootstock while cutting the rootstock under cutting mechanism.

3.4.1.3 Cutting Blade and Blade Holder

In manual hand grafting, the 60 mm long slant cut is made on both sides of scion stick to form a wedge shape ('V' cut). Rootstock is decapitated and 60 mm long vertical cut along length to cut the stick into two equal sections. The mechanization of grafting process involves making 'V' shape cut in scion in single stroke and clean surface cut in scion stick and in some growth

stage of rootstock. Considering the maximum 12 mm thickness stick, the depth of cut by blade was kept greater than thickness of stick i.e. 16 mm to give clean cut and to avoid crushing of stick. The blade was mounted in metal blade holder. The blade and blade holder were attached to piston rod of pneumatic cylinder with help of nut-bolt. A blade (22 mm width, 120 mm long and thickness of 0.8 mm) was used for making ‘V’ shape blade of material D2 steel. Straight blades of 120 mm length were bent at three different size and angle.

Table 3.5 Details of blades designed for cutting three different diameter classes of sticks.

Sr.No.	Particular	Total Length of Blade	Bending Angle	Gap Distance
1.	Blade - 1	120 mm	6 °	6 mm
2.	Blade - 2	120 mm	8 °	8 mm
3.	Blade - 3	120 mm	10 °	10 mm



Plate 3.5 Fabrication of cutting mechanism mounting stand



Plate 3.6 Groove making in blade holder

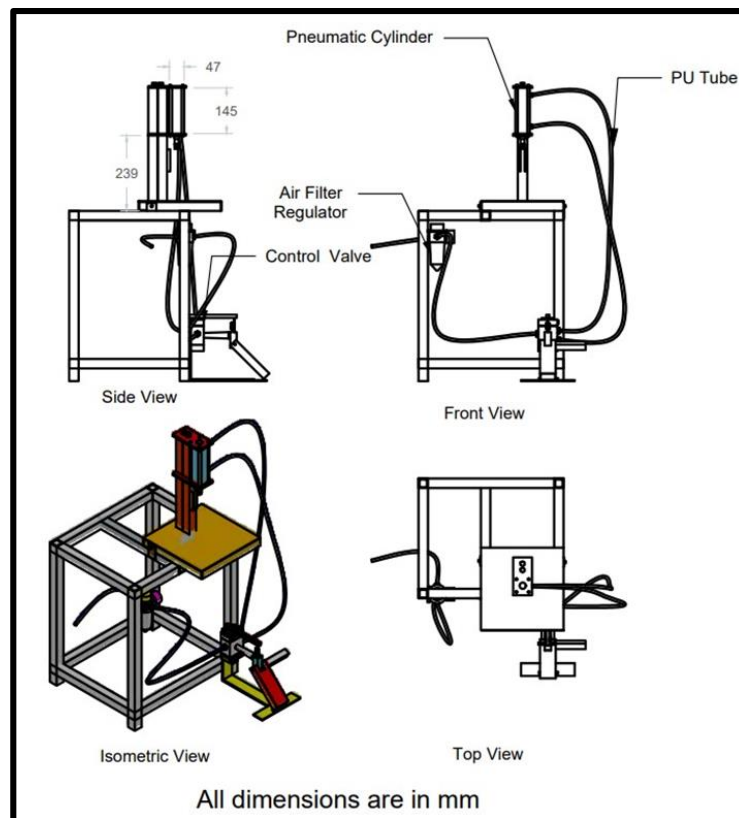


Fig. 3.1 Developed pneumatic system for cutting mechanism

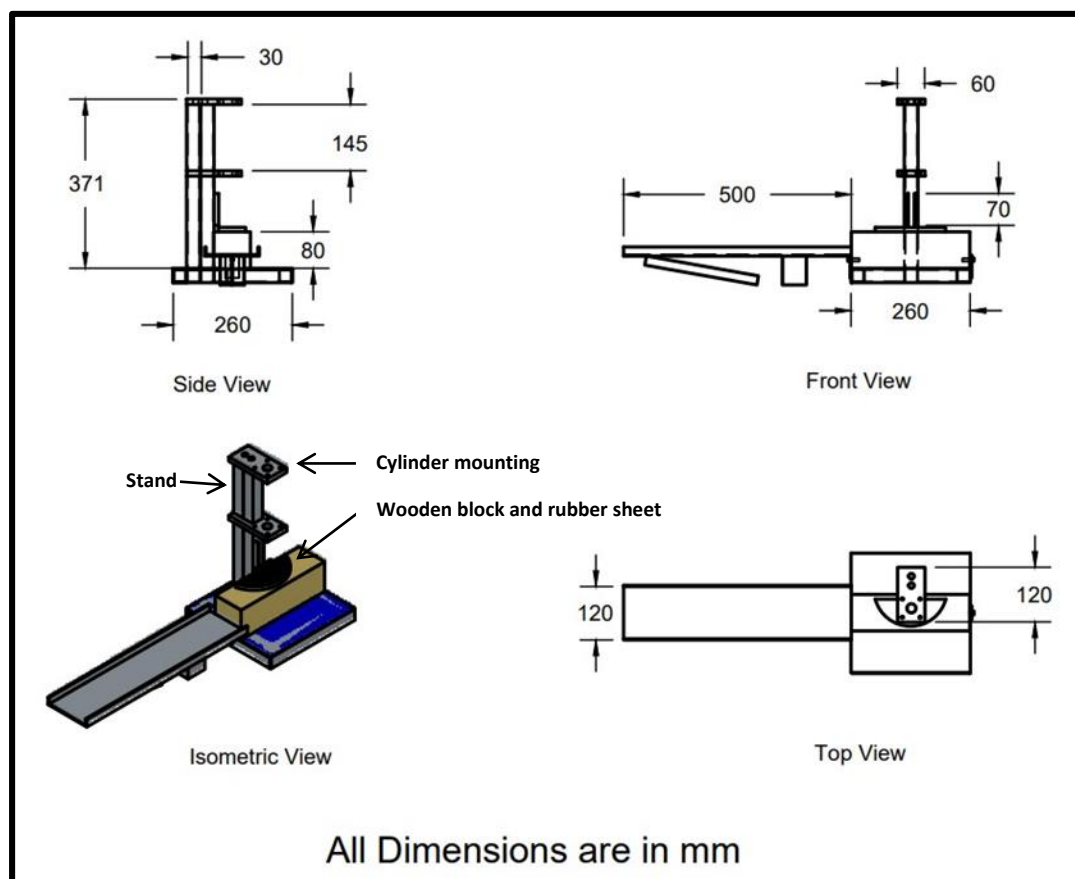


Fig. 3.2 Developed cutting mechanism mounting stand

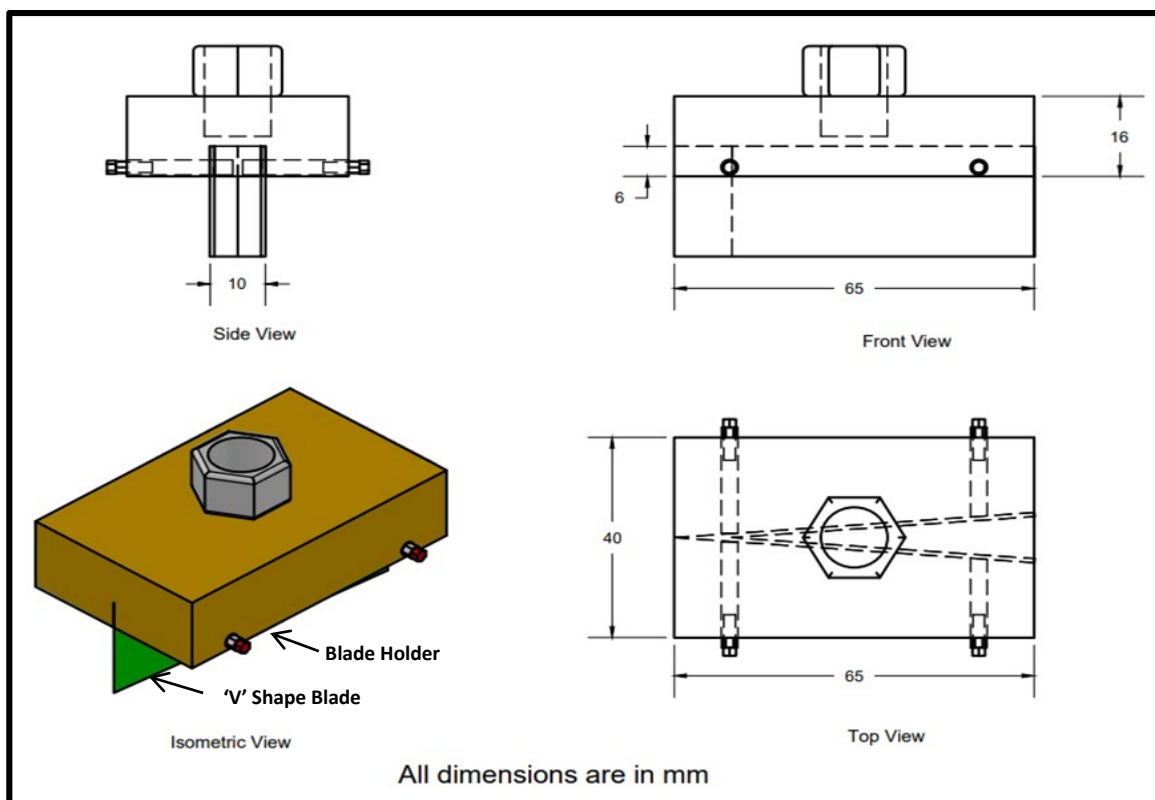


Fig. 3.3 Designed cutting blade and blade holder for cutting mechanism

The gap is the maximum distance between two wings of blade which is according to the diameter of sticks. According to dimensions of blade designed for three diameter class of sticks, the blade holders for each blade type were designed (Plate 3.6). For fabricating blade holder, the 'V' shaped groove of 6 mm was made in mild steel (MS) flat 40 mm × 16 mm × 65 mm length as shown in Fig. 3.3. For holding blades tightly in groove, the screw holding mechanism was provided, for easy replacement of blade whenever requires. The holes on each side perpendicular to groove were drilled in metal flat. The four nuts were welded on holes. At the top of blade holder, the hole is drilled and thread of size compatible to cylinder rod end thread was done. The extra check nut for proper fixing of blade holder to cylinder thread end was provided. As stroke length of cylinder is 50 mm, two guides of 70 mm length and 10 mm outward projections welded vertical stand of cutting mechanism. The guides help in fixing proper path of blade during cutting stroke.

3.4.2 Design of Graft union wrapping Mechanism

Grafting process involves the two steps: first cutting of scion stick and rootstock and second step wrapping of graft union joined. A wedge shaped ("V") scion is inserted into the rootstock as early as possible to avoid drying of cut section. The graft union is then wrapped with polythene strip or grafting tape. In manual hand grafting, polythene strip of width 15 mm is wrapped around graft union manually and at the end tied with same. The wrapping of graft union

with the grafting tape is drudgerous work and need to be mechanized. The design of wrapping mechanism component was done as given below:

3.4.2.1 Grafting Tape Holder

The grafting tape holding mechanism holds the grafting tape in position while turn around the centre of driven gear. This mechanism allows only limited turning of grafting tape on shaft, which unwrap the grafting tape slowly that induce the wrapping tightly on stick. There is no need for tying knot at the end of wrapping as grafting tape is self-adhesive. In wrapping process, the wrapping is started just before the graft union starts and continued to wrap one after one keeping some overlap of turns. The additional turns were wrapped beyond the end of graft union to secure air tightening and cut end self-stick to the inner turn.

The grafting tape wrapping mechanism consists of a shaft, plastic support block, tape bush and check nut. The steel bolt of size 8 mm and 100 mm length was fixed on driven gear wheel by nut fastening on both sides of driven gear wheel. The 80 mm free end bolt fixed on driven wheel to hold grafting tape. The two mild steel bush of diameter of 10 mm, length 15 mm and 14 mm head at other end was fabricated. These 10 mm end of bushes were inserted in hole of 10 mm provided in grafting tape at the centre as shown in Fig. 3.4. Washer was placed in bolt shaft. The grafting tape was inserted followed by another washer and check nuts were fastened. The check nuts fastening provide compatibility of various sizes (width) grafting tape fitting and also by adjusting check nuts, the variation in stretching of tape film or tightening of wrap. The nylon plastic block of size 50 mm × 15 mm × 10 mm was cut in half circle of radius 10 mm at one of end and other end is fixed to grafting tape holder. This nylon plastic block was provided to give support to stick in contradictory to pull by grafting tape wrapping and thus, avoid the breaking or damage of stick due to bending.

3.4.2.2 Sliding Platform

The sliding platform consists of two sliding channels (3 folds fully expandable), supporting wooden block, tray and supporting angle. A pair of telescopic sliding channel runner of material cold rolled steel (250 mm) with high density steel ball (Ø 6 mm) bearing slides of load capacity of 45 kg was used. The sliding pair was fixed on opposite vertical sides of wooden block of size 265 mm × 100 mm × 40 mm at 100 mm spacing. The block was then fixed on MS angle welded on base MS channel of wrapping mechanism frame. Tray platform of size 120 mm × 200 mm with 20 mm height wall on three sides was fitted on the sliding channel by nut bolt. The fabricated sliding platform slides up to the 500 mm axially to the wrapping mechanism as shown in Fig. 3.6.

3.4.2.3 Gear Mechanism

The gear mechanism functions as speed reduction and transmits motion to wrapping of grafting tape. The hollow hub gear of high density steel material driven by the drive gear mounted on gear motor shaft. Wrapping by grafting tape stretching on stick require high torque and lower speed. In manual hand grafting polythene strips, wrapping speed of 40 turns were wrapped around the stick per minute (40 rpm) by skilled grafter. The observations are given in Appendix E. The mechanism was designed to wrap the grafting tape equal to or greater speed than the manual method. A DC gear motor of 60 W was selected as power source for operation of wrapping mechanism. The gear mechanism and motor arrangements is as shown in fig. 3.5. The motor can operate on 12 – 24 V DC electric power supply. The different voltage input to the motor induces the change in speed of motor. The speed of motor was tested by varying the voltage using DC power supply unit and measurements are given in Appendix G. The speed of DC gear motor at shaft was found to be 152.3 rpm at 24 V and 1 A. The speed required for wrapping by hand was about 40 rpm, so the speed variation of around 40 to 60 rpm was used for experimentation. The speed reduction required to attain optimum speed is given as,

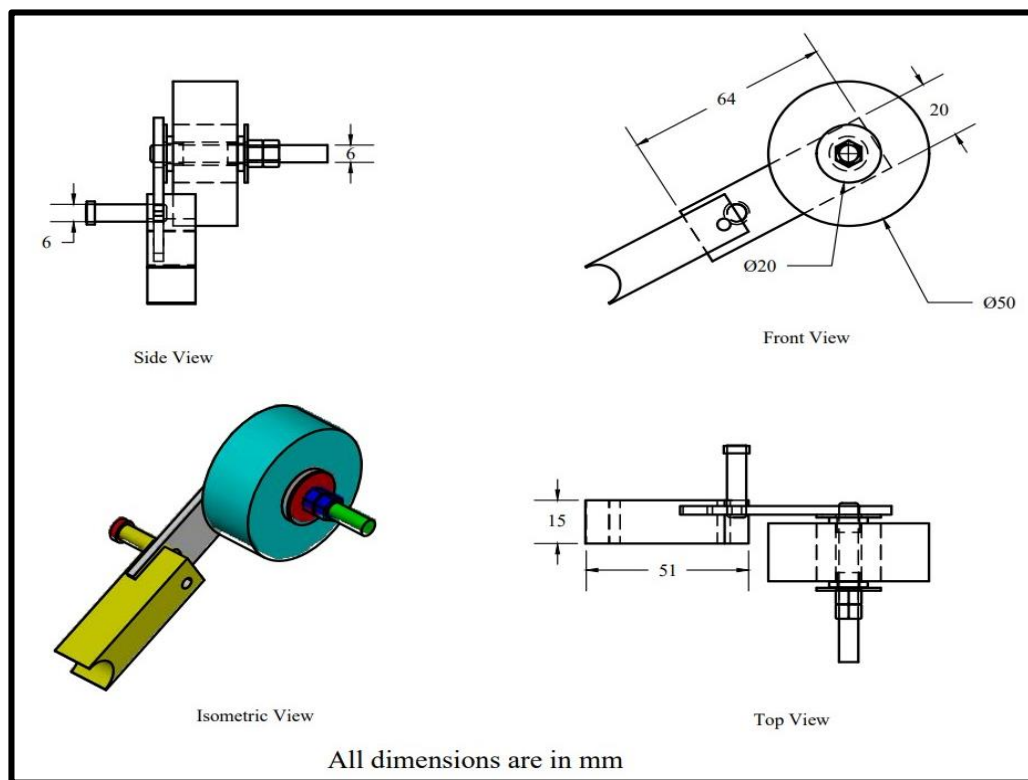


Fig. 3.4 Developed for grafting tape holder for wrapping mechanism

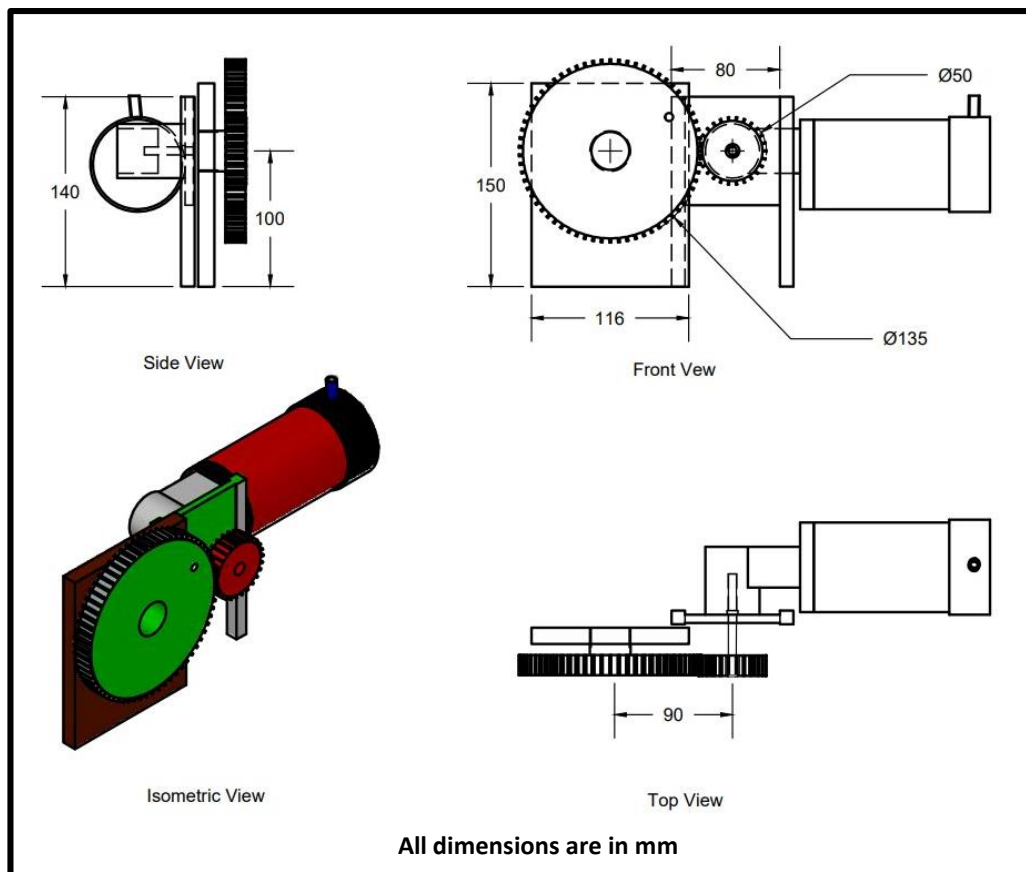


Fig. 3.5 Power transmission of wrapping mechanism

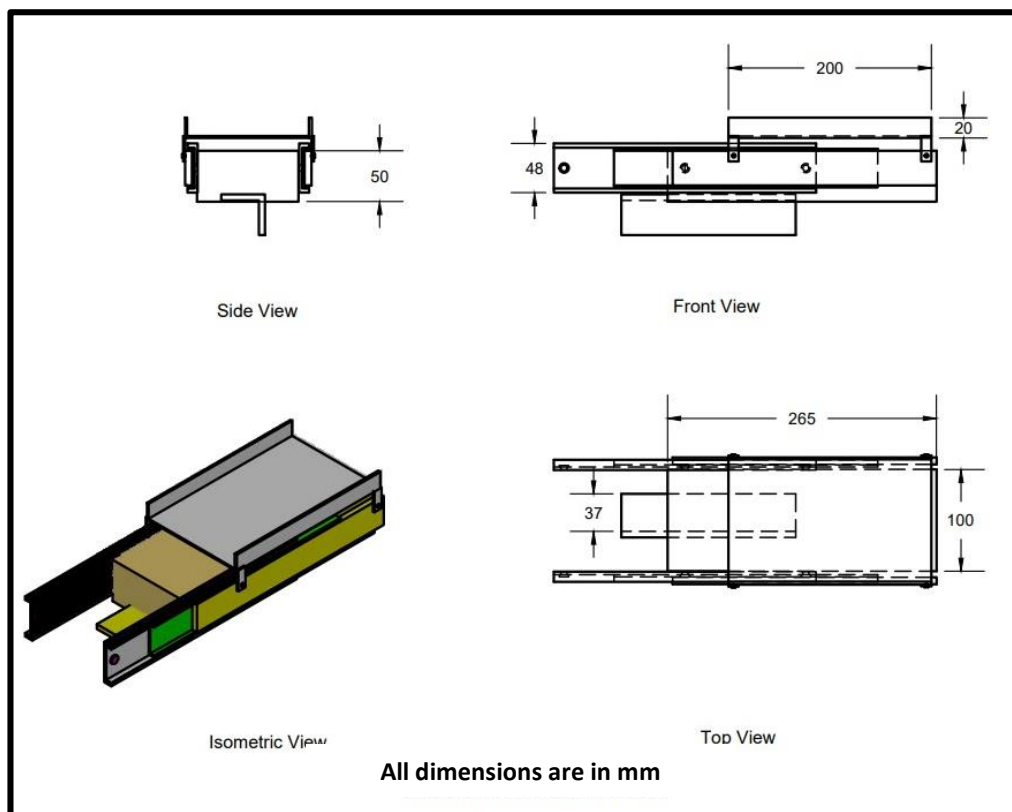


Fig. 3.6 Developed sliding platform for wrapping mechanism

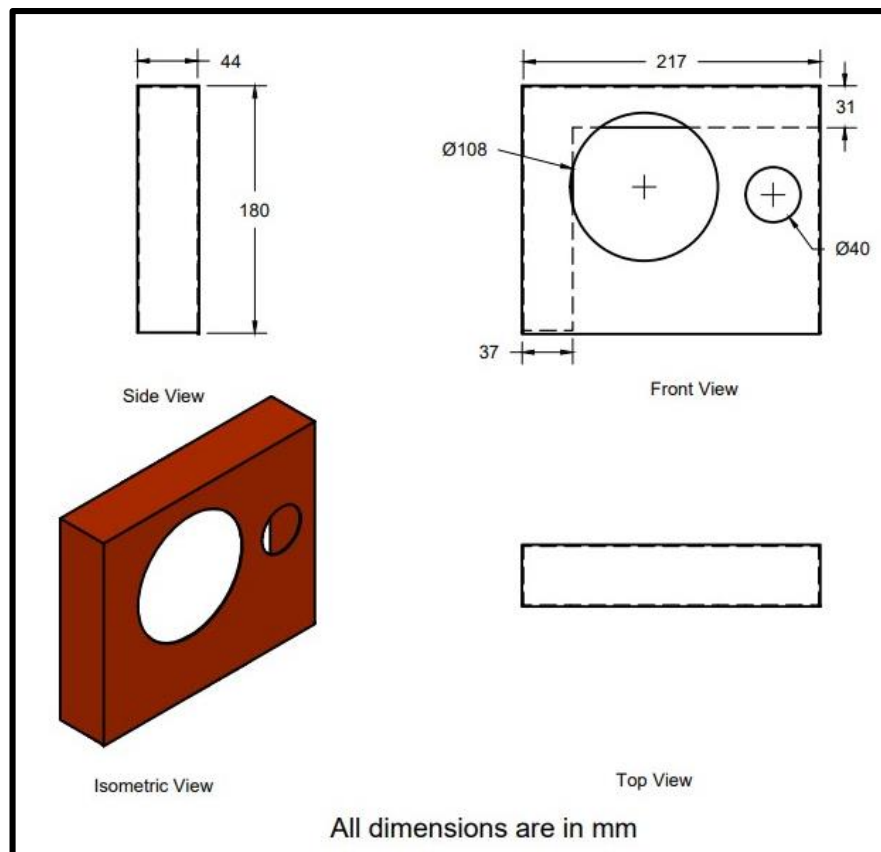


Fig. 3.7 Developed safety cover for protection of wrapping mechanism

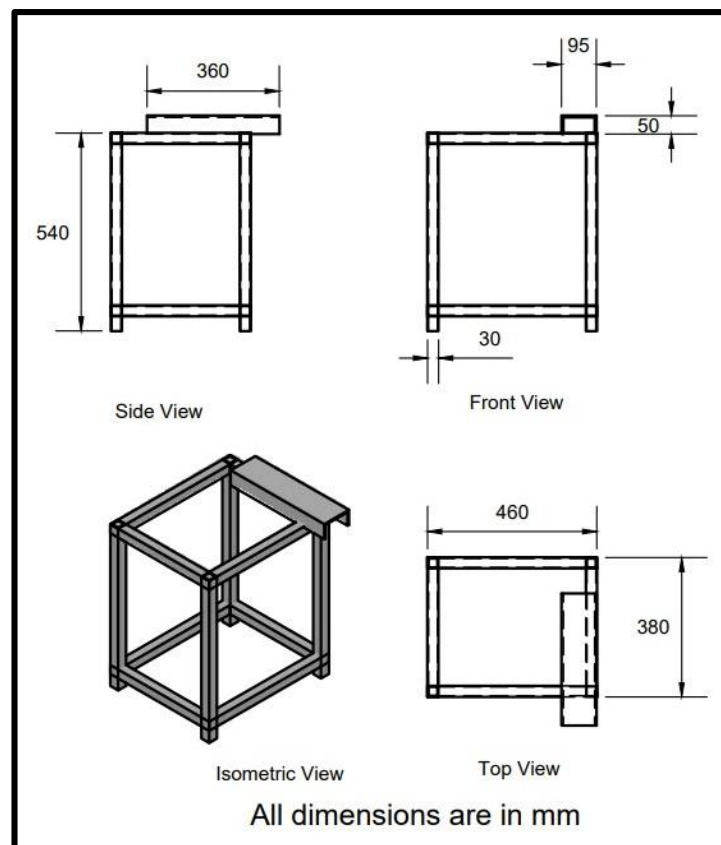


Fig. 3.8 The base frame of developed bench grafting tool

Speed reduction required (S_r) = n_2 / n_1

...(3.8)

Where,

n_2 = required speed of wrapping mechanism, rpm

n_1 = Speed of motor shaft, rpm

Speed reduction required (S_r) = 60/150

$$= 0.4$$

The reduction of the speed by 40 % was fulfilled by selecting optimum number of teeth on drive gear and driven gear. The gear drive with 26 numbers of teeth on drive gear and 66 numbers of teeth on driven gear were selected,

Speed reduction of gear drive (S_r) = T_1 / T_2 ... (3.9)

$$= 26 / 66$$

$$= 0.394$$

Table 3.6 Details of DC gear motor used for wrapping mechanism

Sr.No.	Particular	Specification
1	Model	24 V DC Reversible electric gear motor
2	Power	60 watts
3	Gear	Right angle worm gear
4	Mounting	M6 screw holes
5	Shaft	10 mm

Table 3.7 Power transmission of wrapping mechanism

Sr.No.	Particular	Specification	details
1.	Driven gear	Size	Ø 135 mm, width 20 mm
2.		Number of teeth	66
3.		Hollow shaft diameter	Ø 30 mm
4.		Material	S45C carbon steel
5.	Drive gear	Size	Ø 50mm
6.		Number of teeth	26
7.		Material	S45C carbon steel
8.	Speed reduction		0.394
9.	C to C, mm		90 mm

3.4.2.4 Base Frame

The base frame provide base and mounting surface for motor, gear drive and sliding mechanism. The MS Channel 230 mm × 93 mm × 5 mm was used as base of frame. The MS plate 16 × 150 × 120 mm was welded to base channel. Two MS square bar 10 mm of 130 mm height was welded to base channel at 80 mm pitch distance. The MS plate of 80 mm × 80 mm and 6 mm thickness was welded between two square bars and hole drilled for M6 bolt fitting for DC motor. The base frame was fixed on main frame with nut bolt as shown in Fig. 3.8.

3.4.2.5 Safety Cover

The safety cover protects the operator's hand or clothes from being stuck in gear drive and grafting tape holding mechanism. A safety cover of GI Sheet 22 SWG was used and covers the gear mechanism from all side as shown in Fig. 3.7. Safety cover also protects the gear drive from dust or other handling material by forming close case. The sheet was cut according to size of mechanism and bent to form the box that houses the drive mechanism. A case fabricated was welded to base support frame, driving gear bearing support frame and motor mounting support to form complete box cover around the mechanism. Provision for stick insertion during wrapping operation was made by proper cut in cover.

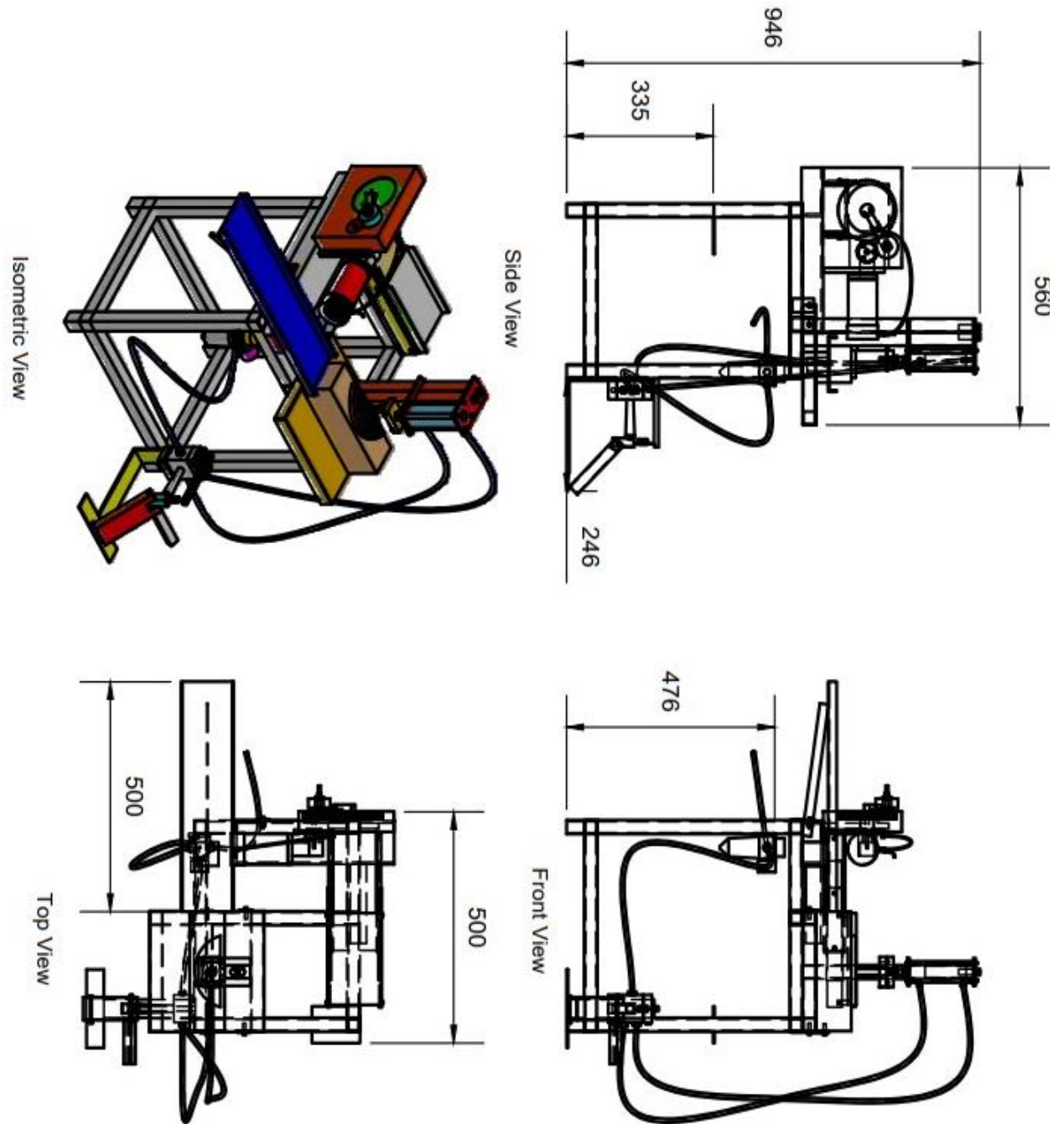


Fig. 3.9 Schematic of developed bench grafting tool

3.5 Study of Parameters in Laboratory

3.5.1 Engineering Properties Studies

To know the effect of moisture content, diameter of scion and age of rootstock on cutting strength and hardness was evaluated by finding out strength and hardness by texture analyser. The experiment was carried out as follows:

Table 3.8 Effect of parameters on engineering properties of scion stick

Sr.No.	Independent Parameter	Level	Range	Dependent Parameter
1.	Moisture content, %	5	62 - 72 %	i. Cutting Strength, N/mm ² ii. Hardness, N/mm ²
2.	Diameter of scion, mm	5	5 - 11 mm	

Table 3.9 Effect of parameters on engineering properties of rootstock

Sr.No.	Independent Parameter	Level	Range	Dependent Parameter
1.	Moisture content, %	3	70 – 90 %	i. Cutting Strength, N/mm ² ii. Hardness, N/mm ²
2.	Diameter of rootstock, mm	3	3 – 9 mm	
3.	Age of rootstock, days	2	90 and 240 days	

3.5.2 Machine Performance Evaluation

The developed bench grafting tool for Cashew grafting (Plate 3.7) was tested in the laboratory condition at Farm Machinery Workshop, College of Agricultural Engineering and Technology, Dr. BSKKV, Dapoli for its performance evaluation. The cutting mechanism was operated for cutting success rate test, cutting capacity and energy consumption in laboratory condition. The wrapping mechanism was operated for wrapping success rate, wrapping capacity and energy consumption in laboratory condition.

3.5.2.1 Stick Cutting Mechanism

The developed stick cutting system was tested for stick cutting success rate, cutting capacity and energy consumption in laboratory condition. To test the scion cutting success rate different operating air pressure settings were used to cut at different moisture content and stick of diameter with three different types of blade. The scions of different diameter were classified between 5 mm – 11 mm into three classes and used their median value. The diameter class and their representative mean diameter values were given in Appendix A. The scions were cut with ‘V’ shape blade using respective blade type for each diameter class. Scion success rate was calculated by taking ratio of number of successful scion cutting with smooth surface without burr to the total number of scion (Sun *et al.*, 2014). The rootstock cutting success rate for two different ages, stick of different moisture content and diameter using respective blade type and under different operating air pressure were evaluated. The stick cutting capacity of cutting mechanism was calculated as number of sticks cut per hour.

3.5.2.2 Procedure for Operation Cutting Mechanism

The developed stick 'V' shape cutting mechanism consist of pneumatic cylinder, air filter regulator, foot pedal control lever, cutting mechanism mounting stand, rootstock soil media bag placing platform and cutting blade and blade holder. The pneumatic cylinder was connected with the air compressor through the air filter regulator and foot pedal control lever with the polyurethane tube. The air compressor was switched ON to compress air in air tank and the valve of air compressor was turned ON after attaining required pressure. The operator seats on chair in front of cutting system for operation. The blade type according to class of scion thickness was fitted to cylinder rod. The scion sticks were kept on right side within reach of operator. The one scion stick at time was taken and placed in stick holder on base platform under the cutting unit. After placing stick operator hold stick in position by hand, the foot pedal control lever was operated with right foot and the cutting blade with cylinder rod moves downward and cut the scion. After blade reaching the base hard rubber sheet, the force from pedal was removed, causes immediate return of blade with cylinder rod. The wedge shaped scion was used for further process and 'V' notched part of scion stick was removed. After cutting, the scion was removed from base platform. Rootstock of same size was cut downward splitting stick into two halves manually or mature rootstock was cut by placing the rootstock bag on platform. The procedure for cutting of rootstock was same as scion stick. After cutting of rootstock, the 'V' notched bottom stem with bag was kept for further process and the wedge shaped shoot part was removed. The wedge shaped scion shoot was inserted in 'V' notched stem rootstock or vertically split rootstock manually.

3.5.2.3 Experimental Design and Statistical Analysis of Cutting Mechanism

Response surface methodology was used to analyse the effect of independent parameters on dependent parameters for scion and rootstock cutting. The mechanism was evaluated for scion and rootstock cutting separately. The evaluation of cutting mechanism for cutting scion using three independent parameters diameter of scion (mm), moisture content (%) and operating air pressure (kg/cm^2) with three levels Box-Behnken Design (BBD) on three dependent parameter, scion cutting success rate (%), scion cutting capacity (no./h) and energy consumption (kWh). The evaluation of cutting mechanism for rootstock cutting using three independent parameters diameter of rootstock (mm), moisture content (%) and operating air pressure (kg/cm^2), age of rootstock (days) as categoric factor with five level centre composite design (CCD) three levels Box-Behnken Design (BBD) on three independent parameters, rootstock cutting success rate (%), rootstock cutting capacity (no./h) and energy consumption (kWh). The dependent parameters are defined as given below.

The design setup of 29 experimental runs, including 5 center point runs as given in Table 3.11. The conditions were examined for process as independent variables include: A = Moisture content (%), B = diameter of stick (mm), C = Operating air pressure (kg/cm^2). The optimum

conditions of process variables were derived using desirability function. Design Expert Statistical Software package 11.0.0 trial version (Stat-Ease Inc., Minneapolis, MN, USA) was used for statistical analysis. To know the effect of five independent on two dependent parameters and interrelation to obtain optimized operating parameter for operation.

Table 3.10 Statistical experiment design for evaluation of developed cutting mechanism (scion cutting)

Sr.No.	Factor	Level 1	Level 2	Level 3
1.	Moisture content, %	62	67	72
2.	Diameter of scion, mm	5	8	11
3.	Operating air pressure, kg/cm ²	5	6	7

Table 3.11 Experimental design for evaluation of developed cutting mechanism

Run	A: Moisture Content	B: Diameter of scion	C: Operating air pressure
1	67	11	7
2	67	5	5
3	67	5	7
4	62	5	6
5	72	5	6
6	72	8	5
7	62	8	5
8	67	11	5
9	72	11	6
10	62	11	6
11	72	8	7
12	62	8	7
13	67	8	6
14	67	8	6
15	67	8	6
16	67	8	6
17	67	8	6

The design setup of 29 experimental runs, including 5 centre point runs as given in Table 3.13. The conditions were examined for process as independent variables include: A = Moisture content (%), B = diameter of stick (mm), C = Operating air pressure (kg/cm²), D = Age of rootstock (days). The optimum conditions of process variables were derived using desirability function.

Design Expert Statistical Software package 13.0.0 trial version (Stat-Ease Inc., Minneapolis, MN, USA) was used for statistical analysis. To know the effect of five independent on two dependent parameters and interrelation to obtain optimized operating parameter for operation.

Table 3.12 Statistical experiment design for evaluation of developed cutting mechanism (rootstock cutting)

Sr.No.	Factor	Level 1	Level 2	Level 3
1.	Moisture content, %	62	67	72
2.	Diameter of rootstock, mm	3	6	9
3.	Operating air pressure, kg/cm ²	5	6	7
4.	Age of rootstock, days	1	2	3

Table 3.13 Experimental design for evaluation of developed cutting mechanism

Run	A:Moisture Content, %	B:Diameter of Rootstock, mm	C: Age of Rootstock, days	D: Operating air pressure, kg/cm ²
1	75	9	3	6
2	85	9	2	6
3	85	6	1	6
4	75	3	2	5
5	65	6	1	6
6	85	6	3	6
7	65	3	2	6
8	65	6	2	5
9	75	6	1	5
10	85	3	2	6
11	85	6	2	5
12	75	6	2	6
13	65	9	2	6
14	75	6	3	5
15	75	6	2	6
16	75	6	2	6
17	75	3	3	6
18	75	6	2	6
19	75	9	1	6
20	75	6	2	6
21	75	3	1	6
22	65	6	2	7

Run	A:Moisture Content, %	B:Diameter of Rootstock, mm	C: Age of Rootstock, days	D: Operating air pressure, kg/cm ²
23	75	9	2	5
24	75	6	3	7
25	75	3	2	7
26	75	6	1	7
27	65	6	3	6
28	85	6	2	7
29	75	9	2	7

1. Scion cutting success rate, (%)

Scion cutting success rate is the ratio of number of successful scion cutting with smooth surface without burr to the total number of scion cut (Sun *et al.*,2014). The scion cutting success rate is given as,

$$\text{Scion cutting success rate, } S_{cr} (\%) = (N_{ss} / N_{ts}) \times 100 \quad \dots(3.10)$$

Where,

S_{cr} = Scion cutting success rate, %

N_{ss} = Number of successful scion cut without burr and smooth surface cut.

N_{ts} = Total number of scion cut.

2. Rootstock cutting success rate, (%)

Stock cutting success rate is the ratio of number of successful stock cutting with smooth surface without burr to the total number of rootstock (Sun *et al.*,2014). The rootstock cutting success rate is given as,

$$\text{Rootstock cutting success rate, } S_{cr} (\%) = (N_{sr} / N_{tr}) \times 100 \quad \dots(3.11)$$

Where,

R_{cr} = Rootstock cutting success rate, %

N_{sr} = Number of successful Rootstock cut without burr and smooth surface cut.

N_{tr} = Total number of rootstock cut.

3. Scion cutting capacity, no. per hour

Scion cutting capacity is the number of scion cut in wedge shape (“V”) at bottom end by cutting mechanism per unit time (no./h). The scion cutting capacity of cutting mechanism is given as,

$$\text{Scion cutting capacity, } S_{cc} = N_s / T_s \quad \dots(3.12)$$

Where,

S_{cc} = Scion cutting capacity, no./h

N_s = Total number of scion cut.

T_s = total time required for scion cutting, h

4. Rootstock cutting capacity, no. per hour

Rootstock cutting capacity is the number of scion cut in wedge shape (“V”) by cutting mechanism per unit time (/h). The rootstock cutting capacity of cutting mechanism is given as,

$$\text{Rootstock cutting capacity, } R_{cc} = N_r / T_r \quad \dots(3.13)$$

Where,

R_{cc} = Scion cutting capacity, no./h

N_r = Total number of rootstock cut.

T_r = Total time required for rootstock cutting, h

5. Energy consumption of cutting mechanism (kWh)

The energy required to operate cutting mechanism for grafting by developed machine is measured by Energy meter. The number of units (kWh) consumed by developed cutting mechanism in unit hour was measured with energymeter.

3.5.2.4 Graft Union Wrapping Mechanism

The developed graft union wrapping mechanism was tested for graft union wrapping success rate, graft union success rate and energy consumption. The sticks of different moisture content classes of scion and different diameter class 5 – 11 mm, three different ages of rootstock and operational rotational speed were used. The wedge cut scion and split or ‘V’ notch rootstock joined after placing in slider channel. The wrapping was done air tightly after insertion and removed by sliding back. Graft union wrapping success rate was calculated by taking ratio of number of successful wrapping to the total number of tightly bound wrapped grafts union. Graft

union wrapping capacity of wrapping system was measured as number graft union wrapped per hour (Sun *et al.* 2014).

3.5.2.5 Procedure for Operating Graft Union Wrapping

The developed graft union wrapping system consist of Grafting tape holding mechanism, gear drive with energy source, slider platform and safety cover. The operator operate the mechanism by seating in front of mechanism. Cut made rootstock with bag was placed in slider platform such that the upper stem facing towards the wrapping mechanism and the slider platform was pushed to pass the upper end of rootstock inside, the hollow shaft driven gear wheel from the left side of the operator. The wedge shape cut scion stick was inserted in rootstock split from right side of operator and the graft union was hold with the free end of grafting tape. The DC gear motor was started by pressing the switch near the left side of wrapping mechanism and wrapping mechanism wraps the grafting tape by turning around stick. Simultaneously operator guides the graft union towards the left side and after wrapping was completed the tape was stretched to break or cut by blade. Slider mechanism provided smooth and easy moving of grafted plant. The graft plants after wrapping removed and were kept for postgraft care in acclimatization chamber.

3.5.2.6 Experimental Design and Statistical Analysis of Wrapping Mechanism

Response surface methodology was used to evaluate performance of developed graft union wrapping mechanism using four independent parameters moisture content (%), diameter of stick (mm), operating rotational speed (rpm) and age of rootstock (days) with three levels for Box-Behnken Design (BBD) on three dependent parameters, graft union wrapping success rate (%), graft union wrapping capacity (no./h) and energy consumption (kWh).

The design setup of 29 experimental runs, including 5 centre point runs as given in Table 3.15. The conditions were examined for process as independent variables include: A = Moisture content (%), B = diameter of stick (mm), C = Operating rotational speed (rpm) and D = Age of rootstock (days). The optimum conditions of process variables were derived using desirability function. Design Expert Statistical Software package 11.0.0 trial version (Stat-Ease Inc., Minneapolis, MN, USA) was used for statistical analysis. To know the effect of five independent on two dependent parameters and interrelation to obtain optimized operating parameter for operation.

Table 3.14 Statistical experiment design for evaluation of developed wrapping mechanism

Sr.No.	Factor	Level 1	Level 2	Level 3
--------	--------	---------	---------	---------

1.	Moisture content, %	65	75	85
2.	Diameter of stick, mm	3	6.5	10
3.	Operating rotational speed, rpm	40	50	60
4.	Age of rootstock, days (Categoric Factor)	A1	A2	-

Table 3.15 Experimental design for evaluation of developed wrapping mechanism

Run	A: Moisture Content, %	B: Diameter of stick, mm	D: Age of Rootstock, days	C: Operating Rotational Speed, rpm
1	75	6.5	3	40
2	75	10	2	60
3	75	6.5	3	60
4	75	3	2	60
5	65	6.5	2	60
6	75	3	3	50
7	75	3	2	40
8	75	3	1	50
9	75	10	2	40
10	85	6.5	2	60
11	75	6.5	2	50
12	75	6.5	1	60
13	75	10	1	50
14	85	6.5	2	40
15	85	10	2	50
16	65	10	2	50
17	75	6.5	2	50
18	65	3	2	50
19	85	6.5	1	50
20	75	6.5	2	50
21	75	6.5	2	50
22	75	6.5	2	50
23	65	6.5	2	40
24	65	6.5	3	50
25	85	6.5	3	50
26	85	3	2	50

27	75	10	3	50
28	65	6.5	1	50
29	75	6.5	1	40

1. Graft union wrapping success rate, %

Graft union wrapping success rate is the ratio of number of successful wrapping (Binding) of graft union to the total number of wrapping of grafts (Sun *et al.*, 2014). Graft union success rate is given as,

$$\text{Graft union wrapping success rate, } W_{sr} (\%) = (N_{ws} / N_{wt}) \times 100 \quad \dots(3.14)$$

Where,

W_{sr} = Graft union wrapping success rate, %

N_{ws} = Number of successful wrapping of graft union.

N_{wt} = Total number of wrapping of graft union.

2. Graft union wrapping capacity, no. per hour

Graft union wrapping capacity is the number of graft union wrapped by wrapping mechanism per unit time. The graft union wrapping capacity is given as,

$$\text{Graft union wrapping capacity, } W_c = (N_{wc} / T_w) \quad \dots(3.15)$$

Where,

W_c = Graft union wrapping capacity, no./h

N_{wc} = Total number of graft union wrapped.

T_w = Total time required for wrapping, h

3. Energy consumption of cutting mechanism

The energy required to operate wrapping mechanism for grafting is measured by Energy meter. The number of units (kWh) consumed by developed wrapping mechanism in unit hour was measured with energymeter.

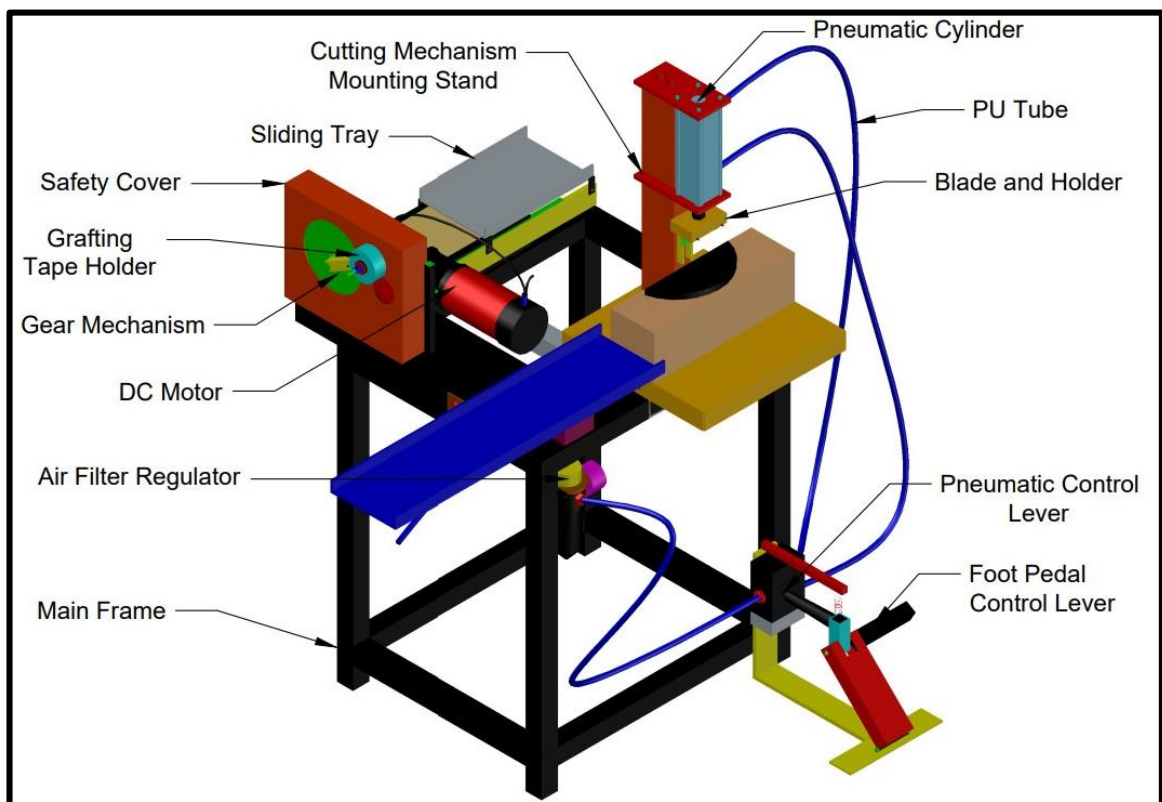


Fig. 3.10 Design of bench grafting tool and its components



Plate 3.7 Developed bench grafting tool

3.6 Field Performance Evaluation of Developed Bench Grafting Tool

The developed bench grafting tool for Cashew grafting was tested in the field as per the standard procedure. The machine was tested in the Farm Machinery Workshop, College of Agricultural Engineering and Technology, Dr. BSKKV, Dapoli for its performance evaluation. Developed machine was tested in field condition for success of grafting and grafting capacity in Cashew using Vengurla – 1 rootstock and Vengurla – 4 scion stick.

3.6.1 Preparation for Test

The following points considered during preparation for the test:

1. The machine is in good operating conditions.
2. The nuts and bolts of different parts tightened properly.
3. All working parts subjected to friction lubricated properly.
4. The blade holder attached to cylinder properly.
5. All components of pneumatic system connected tightly without any leak.

6. Pressure of pneumatic system kept optimum.

3.6.2 Material Preparation for Performance Evaluation of Machine

The conditions of scion sticks, rootstock, height of decapitation, scion length, season of grafting and preparation of graft union affects the performance of machine. Therefore the testing material prepared was as per standardized method of rootstock and scion. Standard defoliation of scion on parent tree was done 10 days before the grafting date and collected on the grafting date. Rootstocks of two different ages were grown in nursery as per standards and classified according to diameter class. Scion was classified into three diameter class and kept in group.

3.6.3 Field Performance Evaluation

The developed bench grafting tool was tested in field condition by completing whole grafting process continuously. Machine was operated by two operators simultaneously, one operator for stick 'V' shape cutting mechanism and one for graft union wrapping mechanism. Three different blade types used for different diameter class, two ages of rootstock, moisture content classes of scion stick was cut under different operating air pressure. The cut scion inserted into split or 'V' notched rootstock and was placed for wrapping. Three different operating air pressures of 5 kg/cm², 6 kg/cm² and 7 kg/cm² were set by adjusting knob of air filter regulator for laboratory and field performance. The three different operating rotational speeds of 40 rpm, 50 rpm and 60 rpm were tested using DC power supply unit. The effect of different operational rotational speed, different operating air pressure, blade type, two age rootstock, diameter of scion and moisture content on success of grafting and grafting capacity was observed. Success of grafting was measured as the number of successful grafts sprouted and alive after 15 days of grafting. Grafting capacity was measured as number of grafts produced per unit hour. The power requirement for cutting and wrapping mechanism was measured. The parameters evaluated in field condition are given as:

3.6.4 Experimental Design and Statistical Analysis

Performance evaluation of developed bench grafting tool was done using the response surface methodology with five independent parameters moisture content (%), diameter of sticks (mm) and using respective type of blade, Age of stick (days) as categoric factor, operating air pressure (kg/cm²) and operating rotational speed (rpm). The age of stick taken as character parameter for two level, other parameters with three levels for Box – Behnken design (BBD) for two dependent parameters, success of grafting (%) and grafting capacity (no./h)..

The design setup of 58 experimental runs, including 5 center point runs as given in Table 3.17. The conditions were examined for process as independent variables include: A = Moisture content (%), B = diameter of stick (mm), C = Operating air pressure (kg/cm²), D = Operating rotational speed (rpm) and E = Age of rootstock (days). The optimum conditions of process variables were derived using desirability function. Design Expert Statistical Software package 11.0.0 trial version (Stat-Ease Inc., Minneapolis, MN, USA) was used for statistical analysis. To know the effect of five independent on two dependent parameters and interrelation to obtain optimized operating parameter.

Table 3.16 Statistical experiment design for evaluation of developed bench grafting tool

Sr.No.	Factor	Level 1	Level 2	Level 3
1.	Moisture content, %	65	75	85
2.	Diameter of stick, mm	3	6.5	10
3.	Operating air pressure, kg/cm ²	5	6	7
4.	Operating rotational speed, rpm	40	50	60
5.	Age of rootstock, days	1	2	3

1) Success of Grafting, (%)

Success of grafting is the ratio of number of Successful grafts or grafts sprouted and alive after 15 days of grafting to the total number of grafts produced (Kadam, 1992). The success of grafting is given as,

$$\text{Success of grafting, } S_g (\%) = (N_{gs} / N_{gt}) \times 100 \quad \dots(3.16)$$

Where,

S_g = Success of grafting, %

N_{gs} = Number of successful grafts or grafts sprouted and alive after 15 days.

N_{gt} = total number of grafts produced.

Table 3.17 Experimental design for evaluation of developed bench grafting tool

Ru n	A: Moisture Content, %	B:Diameter of stick, mm	E:Age of Rootstock, days	C:Operating air pressure, kg/cm ²	D:Operating Rotational Speed, rpm
1	85	6.5	2	6	60
2	75	6.5	3	6	40
3	75	3	2	5	50
4	75	6.5	2	7	40
5	85	10	2	6	50

Ru n	A: Moisture Content, %	B:Diameter of stick, mm	E:Age of Rootstock, days	C:Operating air pressure, kg/cm²	D:Operating Rotational Speed, rpm
6	75	6.5	2	6	50
7	85	6.5	2	5	50
8	75	3	2	7	50
9	65	10	2	6	50
10	75	10	2	5	50
11	75	6.5	2	7	60
12	75	6.5	1	6	60
13	75	10	1	6	50
14	85	6.5	1	6	50
15	75	10	2	6	40
16	75	3	3	6	50
17	75	6.5	2	6	50
18	75	6.5	2	6	50
19	85	6.5	2	7	50
20	75	10	2	6	60
21	75	6.5	3	5	50
22	85	6.5	3	6	50
23	65	6.5	2	6	40
24	75	3	2	6	40
25	75	6.5	1	6	40
26	65	3	2	6	50
27	75	3	2	6	60
28	75	10	3	6	50
29	75	6.5	1	7	50
30	75	6.5	1	5	50
31	65	6.5	2	7	50
32	65	6.5	1	6	50
33	65	6.5	2	6	60
34	75	3	1	6	50
35	65	6.5	2	5	50
36	75	10	2	7	50
37	75	6.5	2	6	50
38	75	6.5	2	6	50

Ru n	A: Moisture Content, %	B:Diameter of stick, mm	E:Age of Rootstock, days	C:Operating air pressure, kg/cm²	D:Operating Rotational Speed, rpm
39	85	3	2	6	50
40	75	6.5	2	5	40
41	75	6.5	3	7	50
42	75	6.5	3	6	60
43	85	6.5	2	6	40
44	65	6.5	3	6	50
45	75	6.5	2	5	60

2) Grafting Capacity, per hour

Grafting capacity is the number of grafts produced after cutting scion-rootstock and wrapping graft union per unit hour (Sun *et al.*, 2014).

$$\text{Grafting capacity, } G_c = (N_{gc} / T_{gc}) \quad \dots (3.17)$$

Where,

G_c = Grafting capacity, no./ h

N_{gc} = Total number of grafts prepared, no.

T_{gc} = Total time required for graft preparation, h

3) Energy Consumption, kWh

The sum of power required to operate cutting mechanism and wrapping mechanism per unit time for grafting by grafting machine is measured by Energy meter. The total number of units (kWh) consumed by developed bench grafting tool in unit time and measured by energymeter.

3.6.5 Cost of Operation

Cost of operation of developed bench grafting tool was determined by considering the fixed cost and variables cost. The cost of material for machine and the bench grafting tool was determined. Total cost of operation of machine was calculated by adding material cost and labour cost. The machine life was considered as 8 yrs and annul use of machine according to IS 9164:1979.

A) Fixed Cost

Fixed costs are those that are usually not directly related to the amount of use, they include Depreciation, Interest on the investment, housing and insurance.

i. Cost of machine

ii. Depreciation (Rs./h) = $(C - S) / (L \times H)$ Interest (Rs./h) = $[(C + S) / 2] \times I / H / 100$

iii. Insurance, taxes and shelter (Rs. / h)

=3.5 % of initial cost

Total fixed cost = 2 + 3 + 4

B) Variable Cost

Variable cost are those that are directly related to use of machine includes,

1. Operators cost = Wage of operator / Working hour
2. Repair and maintenance (Rs. / h) = 10 % of initial cost
3. Electricity cost (Rs. / h)

Total variable cost = 1 + 2 + 3

Operating Cost

= Fixed cost + Variable cost

Where,

C = Initial cost or cost of machine, Rs.

H = Annual use of machine, h

I = Interest rate, %

L = Total life of machine, yr

S = Salvage value, Rs.

The details are given in Appendix H.

Table 3.18 The Following Instruments Were Used During the Test

Sr.No.	Instrument used	Description	Details
1.	Weighing balance	Weight of sample	Name: Contech Precision Blalance Capacity: up to 220 g Readability: 0.0001 g
2.	Micrometer	Measuring thickness	Name: Mitutoyo Micrometer Range: 0 - 25 mm

			Least Count: 0.01 mm
3.	Vernier calliper	Measuring dimension	Name: Mitutoyo Vernier Caliper Range: 0-150 mm Least Count: 0.02 mm
4.	Texture analyser	Measuring force, strength and hardness	Name: Perten Instrument, TEXVOL TVT 300XP Capacity: 50 kg Loadcell
5.	Tachometer	Measuring rotational speed	Name: Teclock Analog Tachometer Range: 0 – 10000 rpm Type: H type Accuracy : 0.5%
6.	Energy meter	Electricity consumption	Name: Maxwell 40 Static Watthour Meter Standard: IS 13779 Phase: Single phase two wire



Plate 3.8 Weighing Balance



Plate 3.9 Micrometer

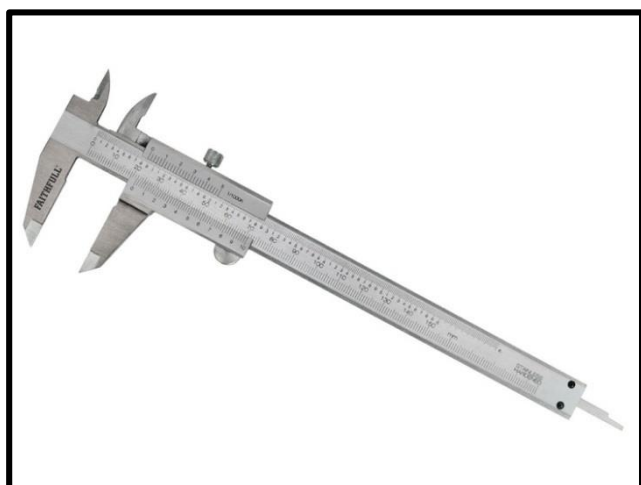


Plate 3.10 Vernier Calliper



Plate 3.11 Texture Analyser



Plate 3.12 Tachometer

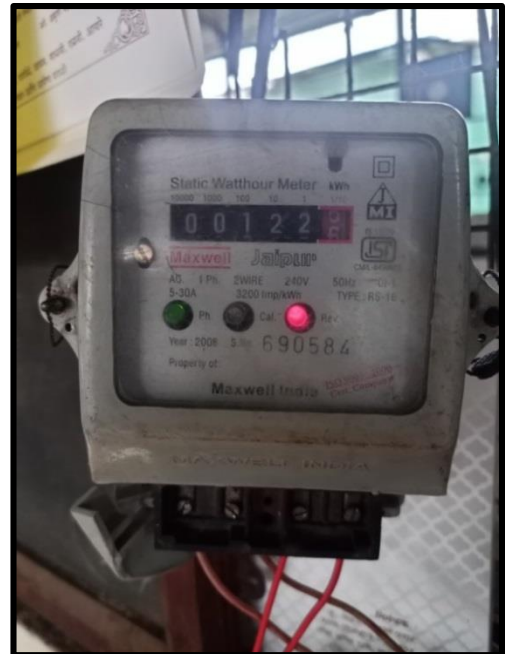


Plate 3.13 Energy Meter

CHAPTER IV

RESULTS AND DISCUSSION

This chapter deals with the results obtained from the performance evaluation of the developed bench grafting tool for Cashew. The machine performance under the laboratory condition and field performance of developed bench grafting tool was tested. After satisfactory operation of the machine in the laboratory, separately for cutting mechanism and wrapping mechanism, the performance of the developed bench grafting tool was tested for field condition at Farm Machinery Workshop, College of Agricultural Engineering and Technology, Dr. BSKKV, Dapoli. The results are presented below.

4.1 Study of Existing Grafting Technique

The study of existing grafting technique was done at Nursery, College of Horticulture, Dr. BSKKV, Dapoli. The average time required for scion cutting, rootstock cutting, wrapping and cutting length during the grafting of cashew by different skilled grafters was studied. The manual grafted cashew grafts by skilled grafter were evaluated for success rate of grafting. The success rate of grafting was found to be 60 % - 80 % for grafts grafted by different grafter. The results are presented in Table 4.1. The similar results were also reported by researcher studied cashew grafting in Konkan region for grafting in all season and the success of grafting in November was found as 63.33 % (Kadam, 1992). The mean time required for grafting by skilled grafter was 57.8 seconds per graft. The mean cutting length during scion and rootstock cutting by skilled grafter was 60.4 mm.

Table 4.1 Mean scion and rootstock cutting, wrapping time and cutting length during grafting by different grafters

Sr.No.	Grafter	Scion cutting time, second	Rootstock cutting time, second	Wrapping time, second	Total time, sec/graft	Cutting length, mm
1	Grafter 1	15	11	34	60	63
2	Grafter 2	13	15	32	60	61
3	Grafter 3	14	12	40	66	55
4	Grafter 4	11	12	27	50	60
5	Grafter 5	15	16	25	56	65
6	Grafter 6	12	14	35	61	56
7	Grafter 7	13	13	26	52	59
8	Grafter 8	10	12	28	50	63
9	Grafter 9	14	10	32	56	60
10	Grafter 10	12	13	42	67	62

Mean	12.9 sec	12.8 sec	32.1 sec	57.8 sec	60.4 mm
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4.2 Engineering Properties of Scion and Rootstock

Engineering properties of scion and rootstock were studied at different diameter, moisture content and age of sticks. Engineering properties of scion and rootstock, and properties related to stick cutting were measured and presented in Appendix - A and Appendix - B.

4.2.1 Diameter of scion and rootstock

The diameter of scion and rootstock was measured as per standard procedure given in 3.2.3. The average diameter of scion was found to be approximately 6 mm, 8 mm and 10 mm. The detailed observations for diameter of scion are presented in Appendix A (Table A-1). The average diameter of rootstock was 4 mm, 6 mm and 8 mm for rootstock of age 90 days. The average diameter of rootstock was 6 mm, 8 mm and 10 mm for rootstock of age 240 days. The detailed observations for diameter of rootstock of age 90 and 240 days are presented in Appendix A (Table A-2 and A-3).

4.2.2 Moisture Content scion and rootstock

The moisture content (wb) of scion was determined as per the procedure given in 3.2.4 and presented in Appendix - B. The mean moisture content for scion of diameter class of 6 mm, 8 mm and 10 mm was 68.4 %, 65.94 % and 63.67 % respectively. The moisture content of scion was found to be 58.13 % to 82.58 %. The mean moisture content for rootstock of age 90 days and diameter class of 4 mm, 6 mm and 8 mm was 85.30 %, 86.16 % and 86.17 % respectively. The mean moisture content for rootstock of age 240 days and diameter of 6 mm, 8 mm and 10 mm was 77.98 %, 81.63 % and 74.44 % respectively. The moisture content for rootstock was found to be 67.08 % to 90.09 %. The detailed observations are presented in Appendix B.

4.2.3 Hardness

Hardness of the scion and rootstock were measured using Texture analysis as per standard procedure described in 3.2.5. The hardness of different scion and rootstock of size D₁, D₂ and D₃ diameter class were determined. The mean hardness of scion diameter class D₁, D₂ and D₃ was 35.65 N/mm², 38.65 N/mm² and 38.14 N/mm² respectively. The maximum hardness of scion was found to be 51.83 N/mm². The hardness of scion was found to be 16.62 – 51.83 N/mm². The mean hardness of rootstock of age A1 for diameter class R₁, R₂ and R₃ is 13.23 N/mm², 9.71 N/mm² and 10.34 N/mm². The mean hardness of rootstock of age A2 for diameter class S₁, S₂ and S₃ was

23.12 N/mm², 19.68 N/mm² and 22.61 N/mm² respectively. The maximum hardness of rootstock A1 and A2 was found to be 21.28 N/mm² and 33.24 N/mm² respectively. The hardness was found to be 2.01 – 33.24 N/mm². The hardness of stick for class 2 was found to be lower than class 1 and 3, probably due to the vigorous swelling (Softwood) of scion of class D₂ offers low resistance to indentation of probe (Kadam, 1992). The results are presented in Appendix C.

4.2.4 Cutting Strength

The cutting strength of scion and rootstock were measured using Texture Analysis as per standard procedure described in 3.2.6. The maximum cutting strength of scion was 7.06 N/mm². The mean cutting strength of the scion observed for diameter class D₁, D₂ and D₃ was 5.49 N/mm², 4.16 N/mm² and 3.60 N/mm² respectively. The maximum cutting strength of rootstock was found to be 6.53 N/mm². The mean cutting strength of the rootstock A1 observed for diameter class R₁, R₂ and R₃ was 7.77 N/mm², 4.39 N/mm² and 3.15 N/mm² respectively. The mean cutting strength of the scion observed for diameter class S₁, S₂ and S₃ is 5.57 N/mm², 3.83 N/mm² and 3.33 N/mm² respectively. The cutting strength of scion and rootstock diameter class decreases as diameter increases, probably due to maturity of sticks has not increased much with diameter due to this less resistance to cutting was observed as compared to lower diameter. (Adams, 2016). The results are given in Appendix D.

4.3 Developed Bench Grafting Tool

The bench grafting tool was developed for bench grafting of cashew by considering agronomic considerations and machine requirements as per 3.3.1 and 3.3.2. The machine developed worked properly for cutting of stick and wrapping of graft union steps in grafting operation as shown in Plate 4.1. The developed machine consisted of two systems,

1. Cutting Mechanism
2. Wrapping Mechanism

4.3.1 Cutting Mechanism

The cutting mechanism was developed to cut the scion and rootstock in ‘V’ shape to form wedge shape and ‘V’ notch respectively. The developed machine cut the scion in wedge shape (V) at bottom (stem side) of scion with clean surface cut as shown in Plate 4.2. Three blades of different size for cutting three different diameter class sticks were developed. Different blades made cuts in

proper shape in the scion and rootstock as per required cutting length. The cutting mechanism consisted of different parts as shown in fig. 3.1. The cutting mechanism consisted of pneumatic cylinder, pedal lever (control lever), air filter regulator, polyurethane tube for connecting pneumatic system, rootstock placing platform, blade holder and stand for pneumatic cylinder.

Operation:

The compressor was switched ON and after reaching the optimum air pressure in pneumatic system, the cutting mechanism was operated. To cut the stick, the stick is placed on base under cutting blade. The operator operates the lever with foot. The cutting blade mounted on pneumatic cylinder rod cuts the stick by moving downward. After cut was made, the pedal was released, this causes return of blade. The wedge shaped scion was removed and kept for further operation of grafting. The same procedure was followed to cut the rootstock and the notched stem side rootstock was kept for further operation of grafting.

4.3.2 Wrapping Mechanism

The wrapping mechanism was developed by considering the tightly wrapping of graft union with grafting tape. The wrapping mechanism was developed by considering the wrapping of graft union without air gap i.e. moisture proof at the graft joining area. The developed machine works very well for considerations of wrapping of the graft union as shown in Plate 4.3. The developed machine wraps the graft union tightly, without any air space in graft union joining area. The wrapping mechanism is consist of DC gear motor, power transmission, grafting tape holder, sliding platform for rootstock bag placing as shown in Fig. 3.9.

Operation:

The DC motor was turned ON by pressing switch. The power transmission drives the driven wheel on which the grafting tape holder was fixed. The rootstock was placed in sliding platform, such that the notched end of rootstock was inside the driven gear wheel. The wedge shape scion was inserted in split of rootstock from opposite side of rootstock bag. After insertion, the graft union was wrapped with grafting tape by revolving grafting tape holder around the graft union. The wrapped graft was removed from wrapping mechanism and kept in polyshed for post graft care as shown in Plate 4.4.

The schematic view of developed cutting mechanism and wrapping mechanism of bench grafting tool is shown in Fig. 3.9 and specification is given Table 4.2.

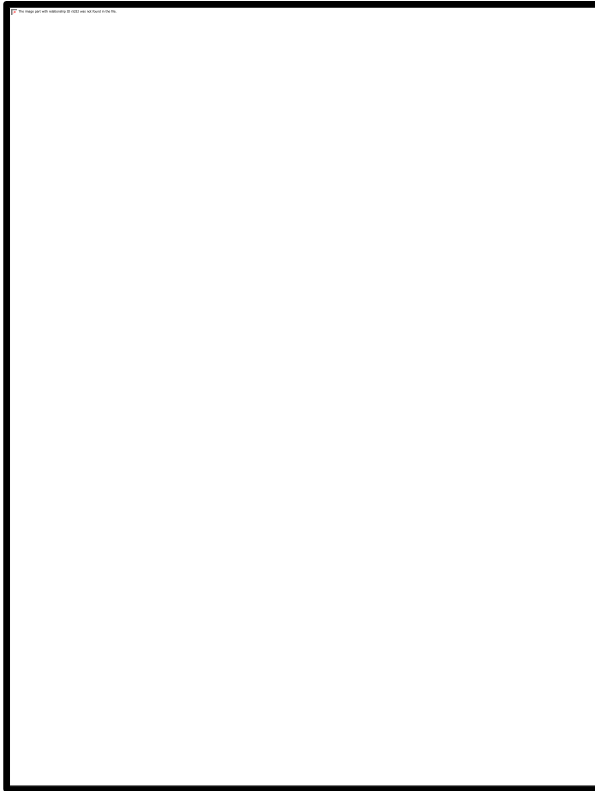


Plate 4.1 Operation of developed bench grafting tool

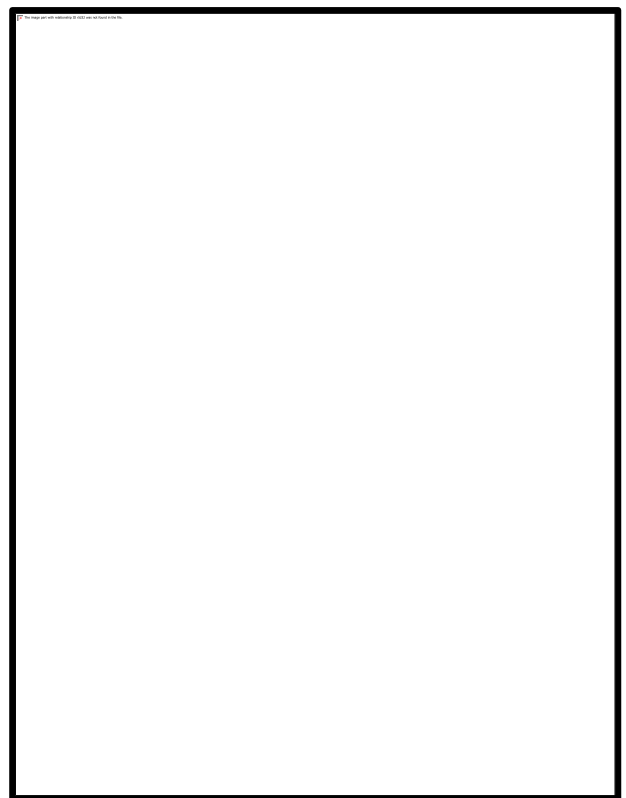


Plate 4.2 Scion cut in 'V' shape with cutting mechanism

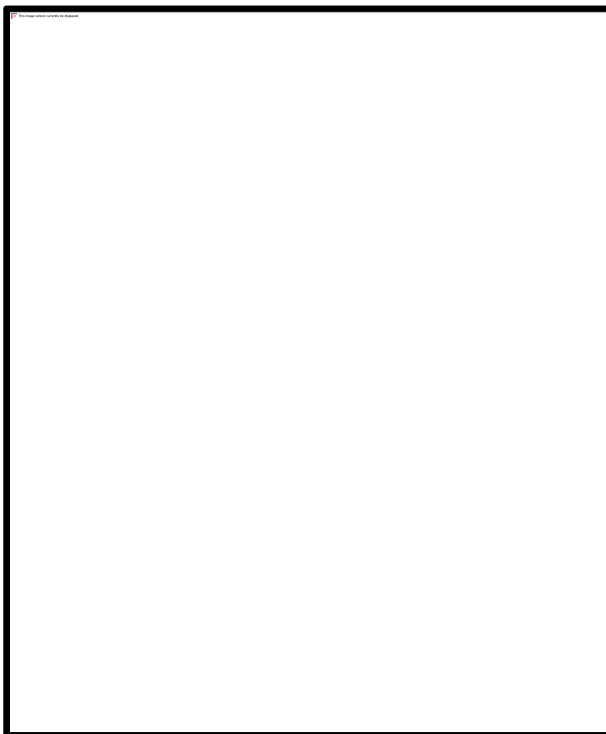


Plate 4.3 Wrapped Graft union using wrapping mechanism

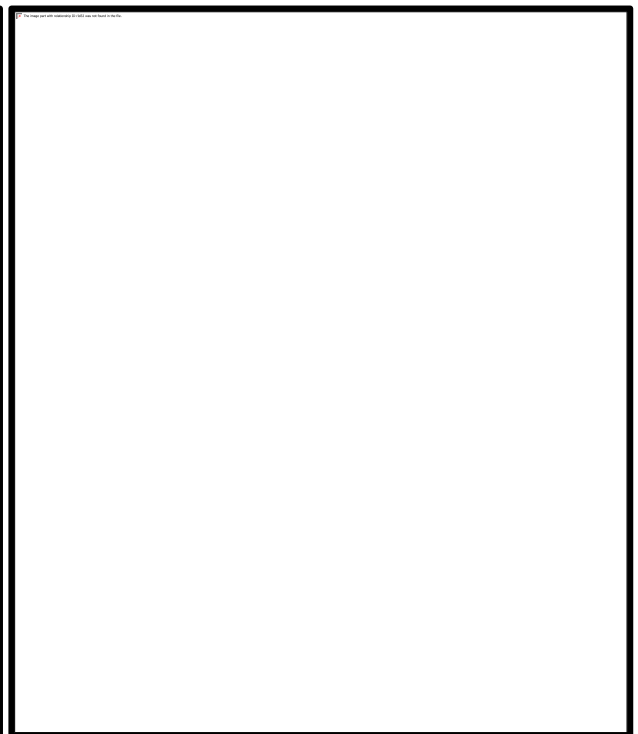


Plate 4.4 Grafts prepared using developed bench grafting tool

Table 4.2 Specifications of developed bench grafting tool.

Sr.No.	Components	Specification	Material
1	Pneumatic cylinder	Bore Ø: 32 mm, Stroke length: 50 mm	Pressure die cast Aluminium
2	Cutting stand	Height 271 mm × Width 260 mm,	MS Square pipe
3	Cutting platform	260 mm × 260 mm, height 110 mm	Wooden, hard rubber sheet
4	Rootstock platform	Tray 500 mm × 120 mm.	22 SWG GI sheet
5	Cutting blade	22 mm × 120 mm, Thickness 0.8 mm.	D2 steel
6	Blade holder	40 mm × 16 mm × 65 mm, 6 mm grooved.	MS Flat
7	Grafting tape holder	Bolt 8 mm × 100 mm length, bush Ø10 mm × 15 mm.	MS
8	Sliding platform	1. 265 mm × 100 mm × 40 mm wooden block, 2. Tray 120 mm × 200 mm × height 20 mm. 3. Slider 250 mm long with steel ball (6 mm).	1. Wood, 2. 22 SWG GI sheet 3. Cold rolled steel
9	Power transmission	Spur gear Ø 135 mm, 66 teeth and 15 mm pitch, Ø 50 mm, 26 teeth and 15 mm pitch.	High density steel
10	Safety cover	Box cover 217 mm × 180 mm × 44 mm	22 SWG GI sheet
11	Supporter block	50 mm × 15 mm × 10 mm	Nylon plastic sheet
12	Base frame	1. Channel 300 mm × 95 mm × 50 mm, 2. Frame 460 mm × 380 mm, height 540 mm	1. MS channel 2. GI square pipe 32 mm

4.4 Study of Parameters in Laboratory

The effect of moisture content, diameter of stick and age of rootstock on cutting strength and hardness has carried out as per 3.5.1. The experiments were conducted following scheme obtained by Design Expert Software Package Trial Version 13.0.0.

4.4.1 Engineering Properties Studies of Scion and Rootstock

4.4.1.1 Properties Studies of Scion

The effect of independent parameters of scion stick on dependent engineering properties was studied as described in Table 3.8.

The experiment was conducted with five levels Center Composite Design (CCD). The test was carried out using five diameter class scion sticks with five moisture content range as given in Table 4.3. A cutting force was measured using texture analyser and cutting strength (N/mm²) was determined. Hardness (N/mm²) of scion stick was also measured. The Response Surface Methodology was used and effect of independent parameter on dependent parameter was carried out and graphs drawn depicted at Fig. 4.1 and Fig. 4.2.

Table 4.3 Effect of moisture content and diameter on cutting strength and hardness of scion

Run	A:Moisture Content, %	B:Diameter of scion, mm	Cutting Strength, N/mm ²	Hardness, N/mm ²
1	62	11	4.45	31.30
2	67	8	2.96	40.71
3	67	12	4.68	43.75
4	67	8	5.83	36.73
5	67	8	4.96	48.27
6	67	8	2.72	34.50
7	67	4	3.79	41.53
8	60	8	6.84	40.63
9	72	5	4.48	27.59
10	74	8	4.14	40.41
11	72	11	3.77	16.61
12	62	5	4.35	36.86
13	67	8	3.87	40.08

1) Effect of moisture content and diameter on cutting strength

As shown in Fig. 4.1, the cutting strength of scion is inversely proportional to moisture content of scion. The cutting strength decreases with increase in moisture content of scion, which indicates that high moisture content scion were vigorous in nature than woody scion and provide less resistance to cutting. The decrease in cutting strength with increasing moisture content may be due to the behaviour of plant material. The similar results were reported by Sessiz *et al.*, 2013. The cutting strength is directly proportional to diameter of scion. The cutting strength increases with increase in diameter of scion gradually, probably due to the increase in woodiness the resistance to cutting is increases with increase in diameter. The similar results were also reported by Sessiz *et al.*, 2013. The maximum cutting strength found for scion with low moisture content 60 % and 8 mm diameter was 6.84 N/mm². The minimum cutting strength was found to be 2.72 N/mm² for scion of diameter 8 mm at 67 % moisture content.

2) Effect of moisture content and diameter on hardness

As shown in Fig. 4.2, the hardness of scion is inversely proportional to moisture content of scion as scion with low moisture content were hard to indent than scion with high moisture content. The hardness increases with decrease in moisture content of scion but the maturity of scion also affects the hardness of scion. The increase in hardness indicates the woodiness or high lignin of scion at low moisture content due to this resistance to indentation increases. The hardness of scion slightly increases with increase in diameter of scion as larger scion may be more mature or woody than smaller one and offer greater resistance to indentation. The researcher characteristic behaviour of plants used for grafting was described (Adams, 2016). The large size scion is harder than the scion with small diameter. The maximum hardness found for 67 % moisture content of 8 mm diameter scion was 48.27 N/mm². The minimum hardness was found to be 16.61 N/mm² for scion of diameter 11 mm at 72 % moisture content.



Fig. 4.1 Effect of moisture content and diameter of scion on cutting strength of scion



Fig. 4.2 Effect of moisture content and diameter of scion on hardness of scion

4.4.1.2 Property Studies of Rootstock

The effect of independent parameters of rootstock on dependent engineering properties was studied as per 3.5.1 and scheme of test given in Table 3.9. The experiment was conducted following test scheme obtained by Design Expert Software Trial Version 13.0.0 and presented in Table 4.4. The experiment was conducted with five level Center Composite Design (CCD) using three independent parameter moisture content (%), Diameter of rootstock (mm) and age of rootstock (days) as categoric factor on dependent parameter, cutting strength (N/mm²) and Hardness (N/mm²). The age of rootstock used as A1: 90 days and A2: 240 days.

Table 4.4 Effect of moisture content, diameter for age A1 and A2 of rootstock on cutting strength and hardness of rootstock

Run	A:Moisture Content, %	B:Diameter of Rootstock, mm	C:Age of Rootstock, days	Cutting Strength, N/mm²	Hardness, N/mm²
1	70	3	A1	5.11	26.55
2	90	3	A1	3.34	22.40
3	70	9	A1	4.05	18.02
4	90	9	A1	3.13	20.40
5	66	6	A1	2.68	33.24
6	94	6	A1	2.93	18.89
7	80	2	A1	1.90	26.44
8	80	10	A1	4.03	17.34
9	80	6	A1	3.45	26.18
10	80	6	A1	3.68	27.76
11	80	6	A1	3.92	29.82
12	80	6	A1	4.01	5.99
13	80	6	A1	3.98	17.14
14	70	3	A2	4.24	15.27
15	90	3	A2	3.89	8.74
16	70	9	A2	3.11	2.01
17	90	9	A2	2.49	11.39
18	66	6	A2	4.13	14.17
19	94	6	A2	3.64	10.16
20	80	2	A2	2.60	13.14
21	80	10	A2	4.99	8.65
22	80	6	A2	4.09	11.68
23	80	6	A2	4.03	11.81
24	80	6	A2	3.99	9.97
25	80	6	A2	3.74	8.10
26	80	6	A2	4.18	14.48

1) Effect of moisture content, diameter for age A1 and A2 of rootstock on cutting strength of rootstock

The effect of moisture content, diameter on cutting strength of rootstock of age A1 and A2 were shown in Fig. 4.3 and Fig. 4.5 respectively. The cutting strength for rootstock of age A1, increases with decrease in moisture content, and the cutting strength is proportional to moisture content. The cutting strength is proportional to diameter of rootstock A1. The cutting strength increases with increase in size of diameter of rootstock gradually, due to increase in resistance to cutting because of increase in woodiness. Cutting strength is directly proportional to diameter of rootstock of age A2. As moisture content increases, cutting strength decreases probably due to vigour rootstock, the resistance to cutting was decreases. The same trends in result were reported by Sessiz, 2016. The highest cutting strength of rootstock A2 was found to be 4.99 N/mm² for the rootstock of diameter 10 mm at 80 % moisture content. Whereas the highest cutting strength of rootstock A1 was found to be 5.11 N/mm² for 3 mm diameter rootstock at 70 % moisture content. This indicates that moisture content of rootstock has more significant effect on cutting strength than diameter.

2) Effect of moisture content, diameter for age A1 and A2 of rootstock on hardness

The effect of moisture content, diameter of age A1 and A2 on hardness of rootstock were shown in Fig. 4.4 and Fig. 4.6. The hardness of rootstock A1 increases with decrease in moisture content, which indicates the hardness, was proportional to moisture content. The woodiness of stick increases with decrease in moisture content due to this the resistance to indentation of probe in rootstock increases. The hardness was also proportional to diameter of rootstock A1. The hardness increases with decrease in size may be due to decrease in the woodiness of stick, the rootstock was compressed initially by probe and then probe intended because of insufficient strength of small diameter rootstock. The similar effects of woodiness and moisture content of stick was also reported by Adams, 2016. The hardness of rootstock A2 increases with increase in diameter of rootstock A2 and also increases with increase in moisture content of rootstock. The maximum hardness of rootstock A1 was found to be 33.24 N/mm² for 6 mm diameter at 67 % moisture content. The minimum hardness of rootstock was found to be 5.99 N/mm² for 6 mm diameter at 80 % moisture content. The maximum hardness of rootstock A2 was found to be 15.27 N/mm² for 3 mm diameter at 70 % moisture content. The minimum hardness of rootstock A2 was found to be 2.01 N/mm² for 9 mm diameter at 70 % moisture content.

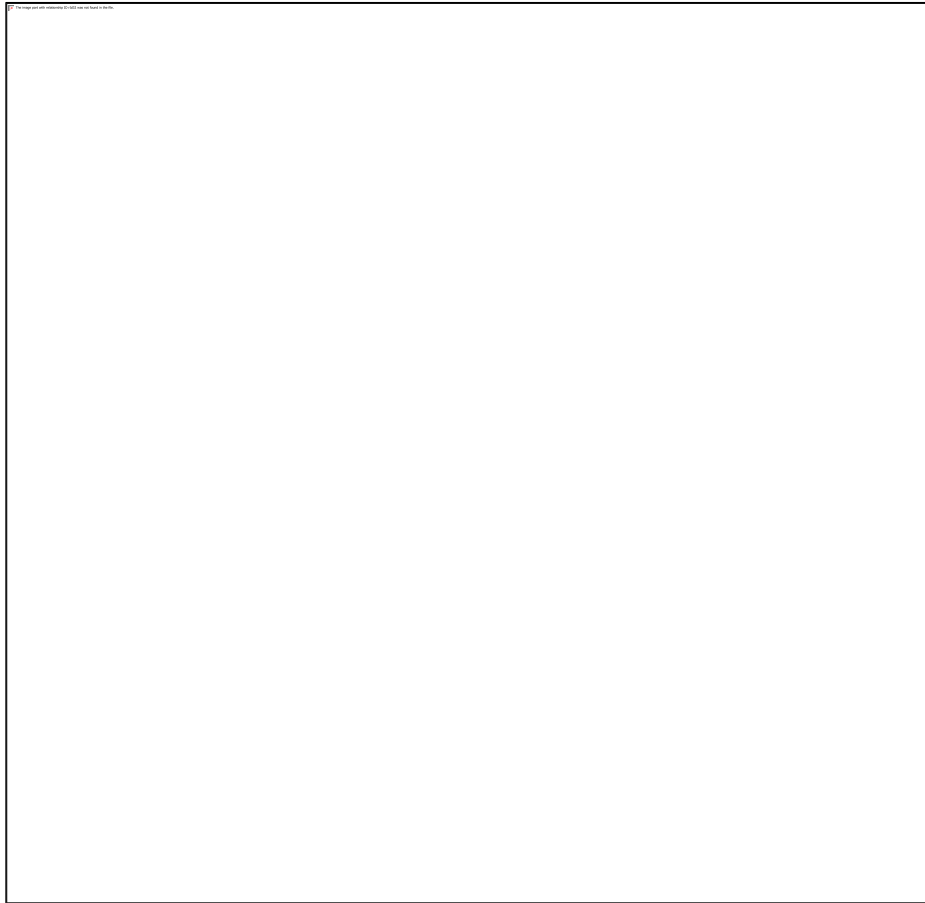


Fig. 4.3 Effect of moisture content and diameter on cutting strength for A1



Fig. 4.4 Effect of moisture content and diameter on hardness for A1



Fig. 4.5 Effect of moisture content and diameter on cutting strength for A2

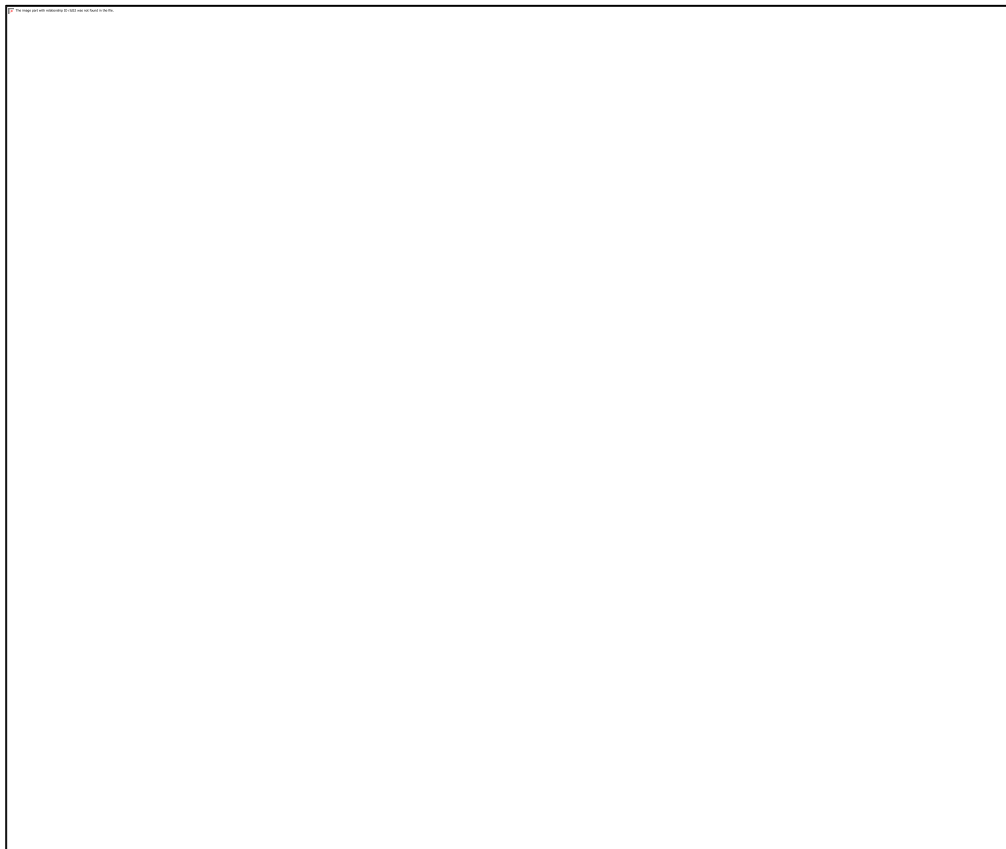


Fig. 4.6 Effect of moisture content and diameter on hardness for A2

4.4.2 Machine Performance Evaluation

To evaluate the performance of developed cutting mechanism and wrapping mechanism experiment has been carried out as per procedure given in 3.5.2.2, 3.5.2.3, 3.5.2.5 and 3.5.2.6. The developed machine mechanism was tested as per the standard procedure. Testing of cutting mechanism was done to determine cutting success rate (%), cutting capacity (no./h) and energy consumption (kWh). The developed wrapping mechanism was tested to determine wrapping success rate (%), wrapping capacity (no./h) and energy consumption (kWh).

4.4.2.1 Performance of Cutting Mechanism for Scion Cutting

The test was conducted as per the standard procedure given in 3.5.2.2 and 3.5.2.3. The test was conducted with different level of moisture content (%), diameter of scion (mm) and operating air pressure (kg/cm²) and its effect was studied. The effect of independent parameters on operation of cutting mechanism are presented in Table 4.5.

Table 4.5 Effect of moisture content, diameter and operating air pressure on cutting mechanism performance for scion cutting

Ru n	A: Moistur e Content, %	B: Diameter of Scion, mm	C: Operating Air Pressure, kg/cm²	Scion Cutting Success Rate, %	Scion Cutting Capacity, no./h	Energy Consumptio n, kWh
1	67	11	7	75	800	0.84
2	67	5	5	80	818	0.825
3	67	5	7	80	900	0.838
4	62	5	6	75	857	0.832
5	72	5	6	80	878	0.827
6	72	8	5	75	783	0.822
7	62	8	5	75	766	0.821
8	67	11	5	70	720	0.824
9	72	11	6	75	766	0.829
10	62	11	6	70	750	0.83
11	72	8	7	85	900	0.835
12	62	8	7	75	837	0.838
13	67	8	6	80	800	0.827
14	67	8	6	80	783	0.826
15	67	8	6	80	800	0.828
16	67	8	6	85	818	0.827
17	67	8	6	80	800	0.829

1) Effect of moisture content and diameter on scion cutting success rate

The effect of moisture content and diameter of scion on scion cutting success rate was shown in Fig. 4.7. The result shows that scion cutting success rate was proportional to moisture content. The scion cutting success rate increases with increase in moisture content, probably due to increase in moisture content offer clean surface cut properly without burr. The scion cutting success rate was found maximum for 6 mm – 8 mm diameter at 70 % moisture content. Scion cutting success rate decreases with increase in diameter from 8 mm onwards, may be due to increase in woodiness (towards hardwood) the scion cutting may not be clean surface cut and burred cut; which decrease the scion cutting success rate. The similar trends were also reported by Sun *et al.*, 2014. The effect of diameter (mm) and operating air pressure (N/mm²) on scion cutting success rate (%) is shown in Fig. 4.8. The scion cutting success rate was maximum for scion of 6 mm – 7 mm diameter at higher operating air pressure between 6 and 7 kg/cm². The maximum scion cutting success rate was found to be 85 % for stick of 8 mm diameter at 67 % moisture content and 6 kg/cm² operating air pressure. The minimum scion cutting success rate of 70 % was found for scion of diameter 11 mm at moisture content of 62 % and 67 % at 6 kg/cm² and 5 kg/cm² respectively.

2) Effect of moisture content and diameter on scion cutting capacity

The effect of moisture content (%) and diameter (mm) of scion on scion cutting capacity is shown in Fig. 4.9. The effect of diameter of scion and operating air pressure (kg/cm²) of pneumatic system on scion cutting capacity (no./h) is shown in Fig. 4.10. The scion cutting capacity was high for small diameter of around 5 - 6 mm at around 72 % moisture content of scion. The scion cutting capacity increases with increase in operating air pressure. The small diameter scion (5 – 6 mm) and higher moisture content provide less resistance to cutting, thus speed of work i.e. cutting capacity per hour increases. The scion cutting capacity is directly proportional to operating air pressure of pneumatic system. The increase in pressure of pneumatic system increases the speed of cylinder rod, causes to fast cutting of scion i.e. the scion cutting capacity increases. The similar effects were also reported by Sun *et al.*, 2014. The maximum cutting capacity was found to be 900/h for scion of diameter 5 mm and 8 mm at operating air pressure of 7 kg/cm².

3) Effect of moisture content and diameter on Energy Consumption for scion cutting

The effect of moisture content (%) and diameter (mm) of scion on energy consumption (kWh) of cutting mechanism is shown in Fig. 4.11. The effect of diameter of scion (mm) and operating pressure (kg/cm²) on energy consumption (kWh) is shown in Fig. 4.12. The cutting of

medium range diameter of scion (8 mm - 9 mm) shows that slight decrease in energy consumption. The marginal decrease in energy consumption was observed with increase in moisture content due to the reduction in cutting energy (less resistance to cutting) required for scion cutting. The energy consumption increases with increase in operating air pressure, because of providing high air pressure to pneumatic system with the help of air compressor consumes more energy as compared to low pressure. The similar trends were reported by Sun *et al.*, 2014. The maximum energy consumption was found to be 0.84 kWh for 11 mm diameter scion at operating air pressure of 7 kg/cm².

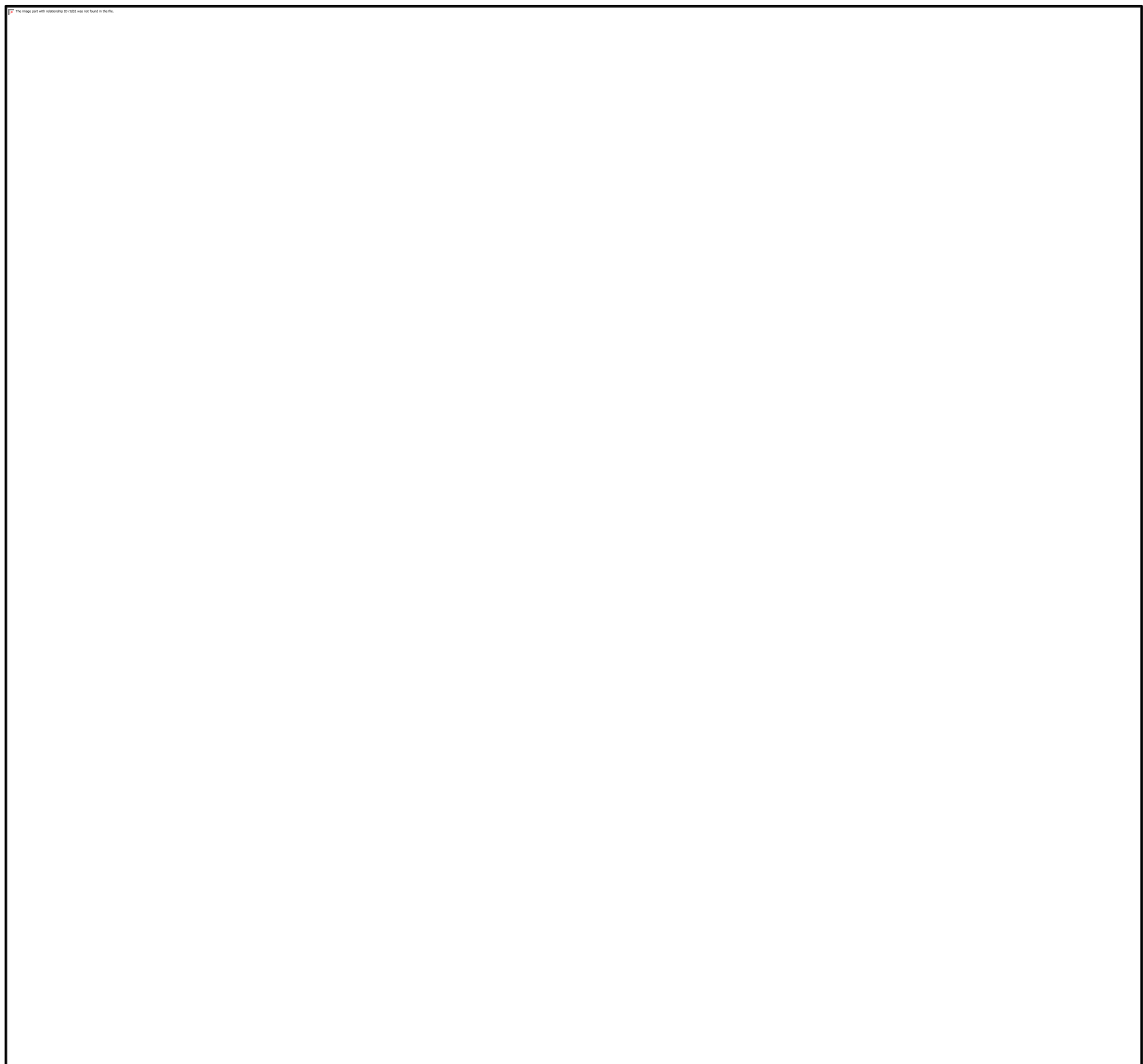


Fig. 4.7 Effect of moisture content and diameter on scion cutting success rate

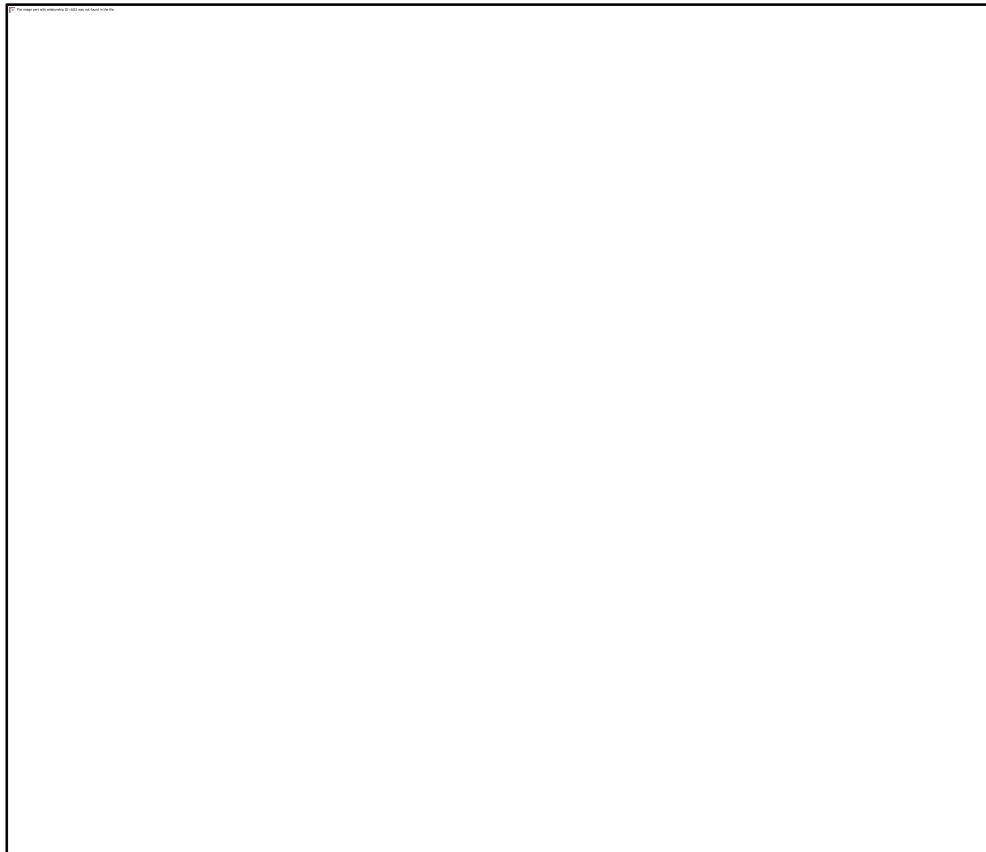


Fig. 4.8 Effect of diameter and operating air pressure on scion cutting success rate

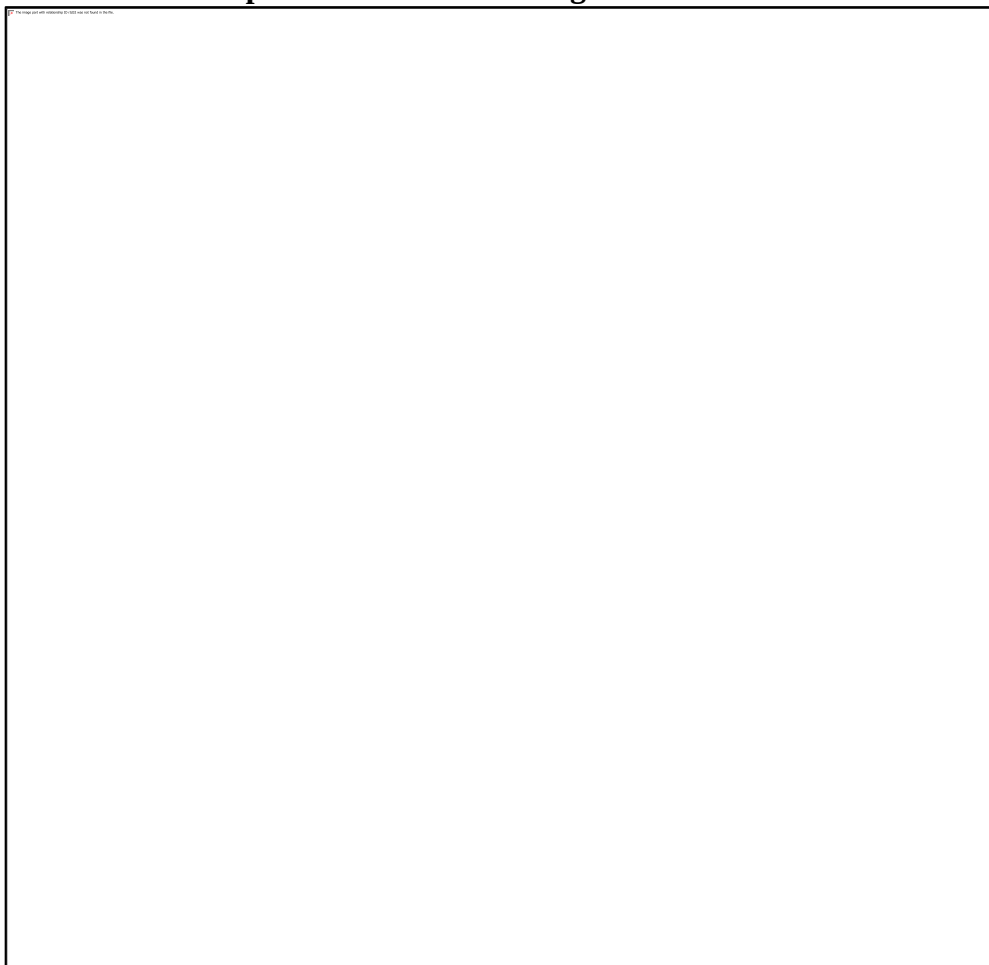


Fig. 4.9 Effect of moisture content and diameter on scion cutting capacity

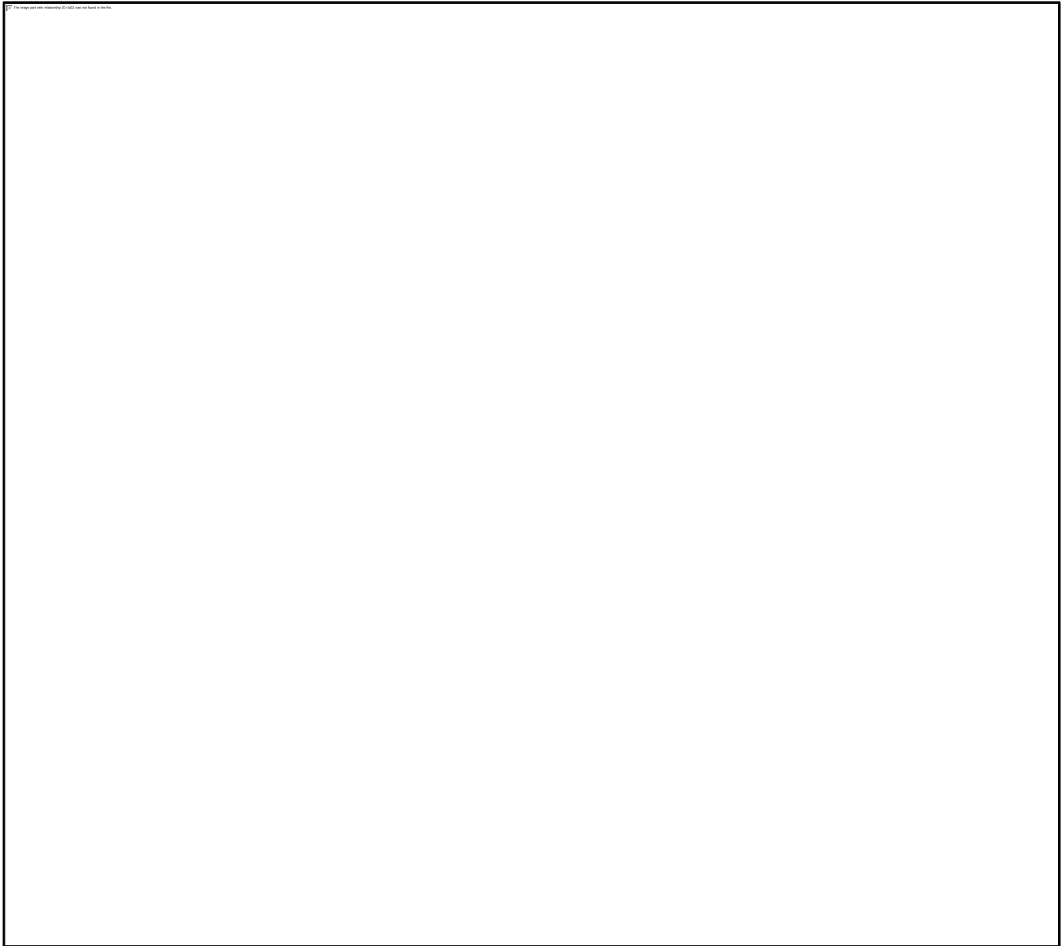


Fig. 4.10 Effect of diameter and operating air pressure on scion cutting capacity

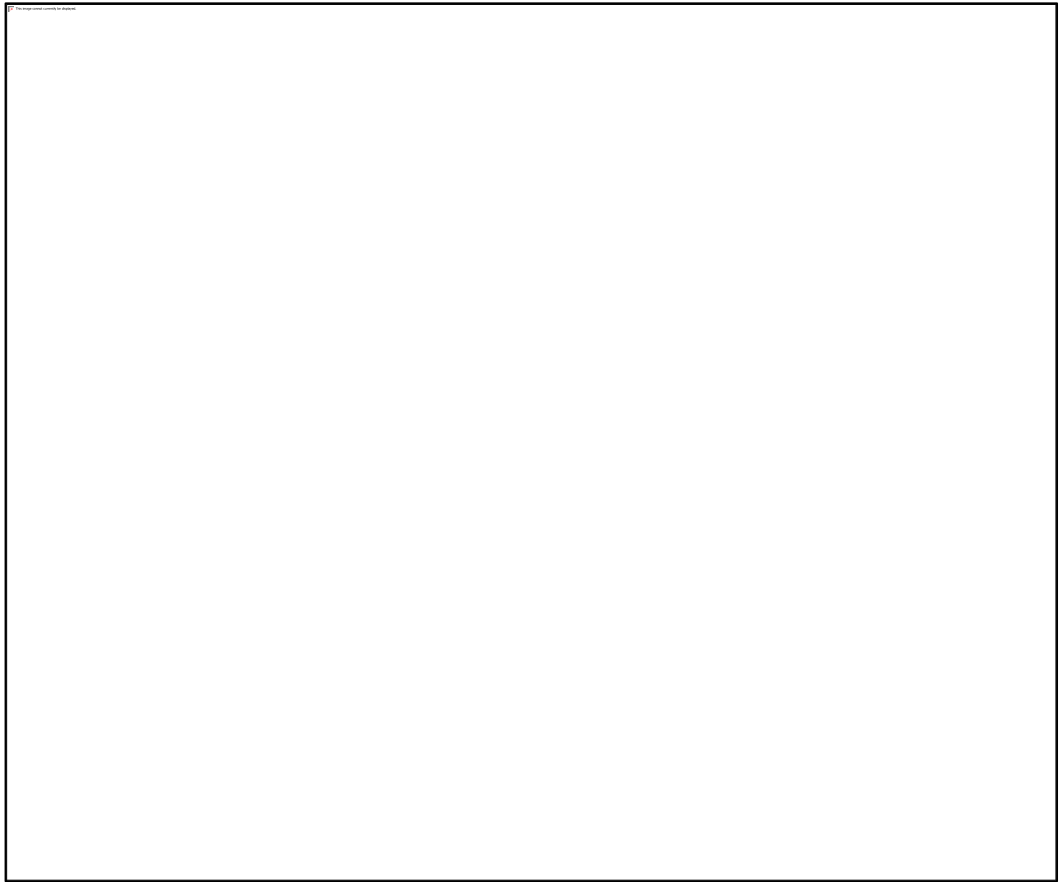


Fig. 4.11 Effect of moisture content and diameter on energy consumption

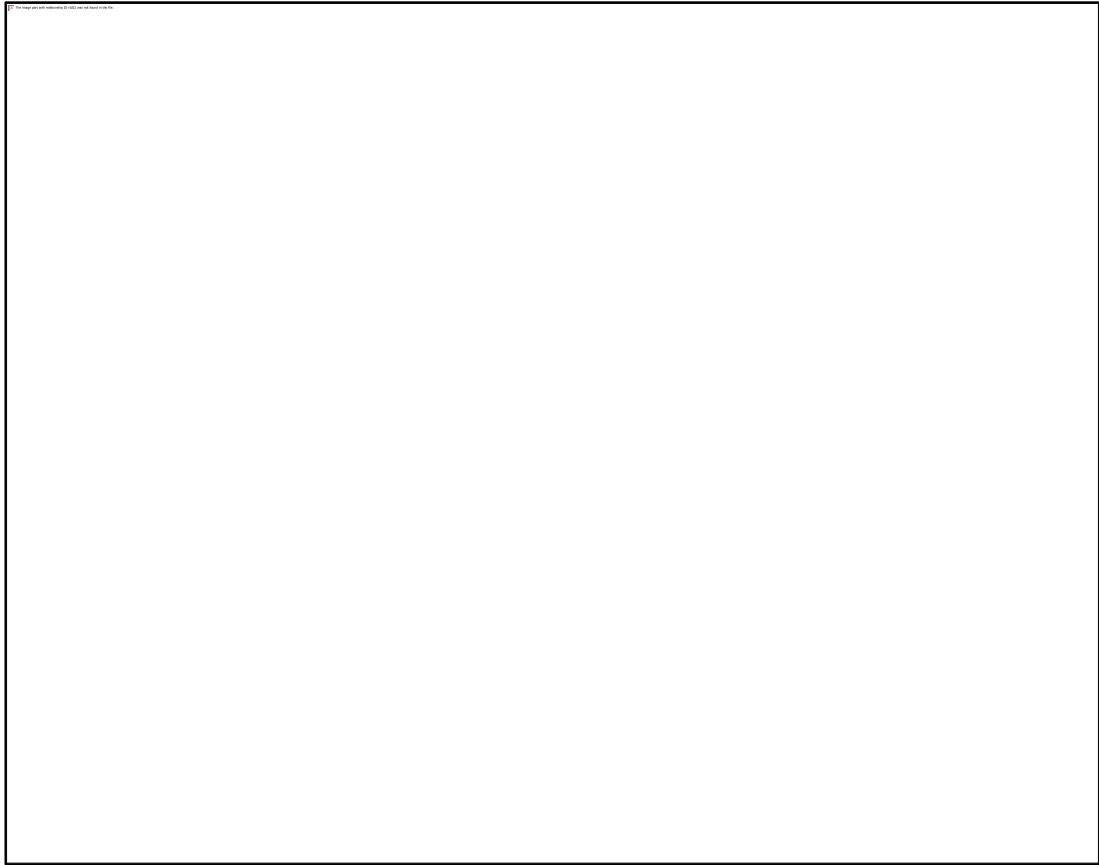


Fig. 4.12 Effect of diameter and operating air pressure on energy consumption

4.4.2.2 Performance evaluation of Cutting Mechanism for Rootstock

The test was conducted as per the standard procedure in 3.5.2.3 and experiment design in Table 3.13 was given. The rootstock 1 (A1), 2 (A2) and 3 (A3) used in experiments denotes the age of rootstock as used was 90 days (3 months), 150 days (5 months) and 240 days (8 months) respectively. The test was conducted at different moisture content of rootstock (%), diameter of rootstock (mm) and operating air pressure (kg/cm^2) and the results are presented in Table 4.6. The effect of these parameters on rootstock cutting success rate (%), rootstock cutting capacity (no./h) and energy consumption (kWh) was discussed below.

Table 4.6 Effect of moisture content, diameter and operating air pressure on cutting mechanism performance for rootstock cutting

Run	A: Moisture Content, %	B: Diameter of Rootstock, mm	C: Age of Rootstock, days	D: Operating Air Pressure, kg/cm^2	Rootstock Cutting Success Rate, %	Rootstock Cutting Capacity, no./h	Energy Consumption, kWh
1	75	9	3	6	75	485	0.831
2	85	9	2	6	70	477	0.829
3	85	6	1	6	60	459	0.827

Run	A: Moisture Content, %	B: Diameter of Rootstock, mm	C: Age of Rootstock, days	D: Operating Air Pressure, kg/cm²	Rootstock Cutting Success Rate, %	Rootstock Cutting Capacity, no./h	Energy Consumption, kWh
4	75	3	2	5	55	399	0.815
5	65	6	1	6	65	442	0.826
6	85	6	3	6	70	459	0.828
7	65	3	2	6	65	401	0.82
8	65	6	2	5	70	425	0.819
9	75	6	1	5	65	432	0.822
10	85	3	2	6	60	413	0.823
11	85	6	2	5	65	410	0.818
12	75	6	2	6	80	460	0.828
13	65	9	2	6	75	490	0.832
14	75	6	3	5	70	430	0.812
15	75	6	2	6	70	467	0.829
16	75	6	2	6	70	463	0.831
17	75	3	3	6	65	417	0.822
18	75	6	2	6	75	460	0.829
19	75	9	1	6	65	493	0.832
20	75	6	2	6	65	457	0.828
21	75	3	1	6	60	405	0.823
22	65	6	2	7	70	470	0.838
23	75	9	2	5	70	508	0.841
24	75	6	3	7	75	458	0.84
25	75	3	2	7	55	409	0.836
26	75	6	1	7	65	462	0.839
27	65	6	3	6	75	452	0.827
28	85	6	2	7	70	448	0.837
29	75	9	2	7	75	514	0.844

1) Effect of moisture content, diameter and operating air pressure on rootstock cutting success rate

The effect of moisture content, (%) and diameter (mm) of rootstock on rootstock cutting success rate (%) is shown in Fig. 4.13. The effect of age of rootstock and operating air pressure of pneumatic system on rootstock cutting success rate is shown in Fig. 4.14. The rootstock cutting success rate increases with increase in diameter due to optimum thick cambium retained at outward after notch 'V' cut and clean surface cut without burr. The similar trend was also reported by researcher Sun *et al.*, 2014. For 3 mm diameter, the rootstock cutting success rate was minimum may be due to outward remains of rootstock notched are very thin and the bark of such rootstock damages which is unsuitable for grafting. The rootstock of moisture content of 65 % - 75 % shows good results for rootstock cutting. The rootstock of age 5 months and 8 months were shown good results for cutting success rate may due to the presence of optimum cambium layer, due to this the cut made is clean surface cut, without burr and thus increase the rootstock cutting success rate. The maximum rootstock cutting success rate was found to be 80 % for rootstock (150 days) of diameter 6 mm at operating air pressure of 6 kg/cm². The minimum rootstock cutting success rate of 55 % for rootstock of diameter 3 mm at operating air pressure 5 kg/cm².

2) Effect of moisture content, diameter and operating air pressure on rootstock cutting capacity

The effect of moisture content (%) and diameter (mm) of rootstock on rootstock cutting capacity (no./h) is shown in Fig. 4.15. The effect of age of rootstock (days) and operating air pressure (kg/cm²) on rootstock cutting capacity (no./h) is shown in fig. 4.16. The cutting capacity increases with increase in diameter of rootstock due to softwood characteristic of large diameter rootstock which offers proper cutting characteristic with optimum cutting strength and the speed of rootstock cutting increases. The maximum rootstock cutting capacity was found at 70 % moisture content. The rootstock cutting capacity slightly increases with increase in operating air pressure may be due to increase in speed of cylinder rod at high pressure. The similar trends were also reported by Chen *et al.*, 2010. Rootstock of 150 days age, with small

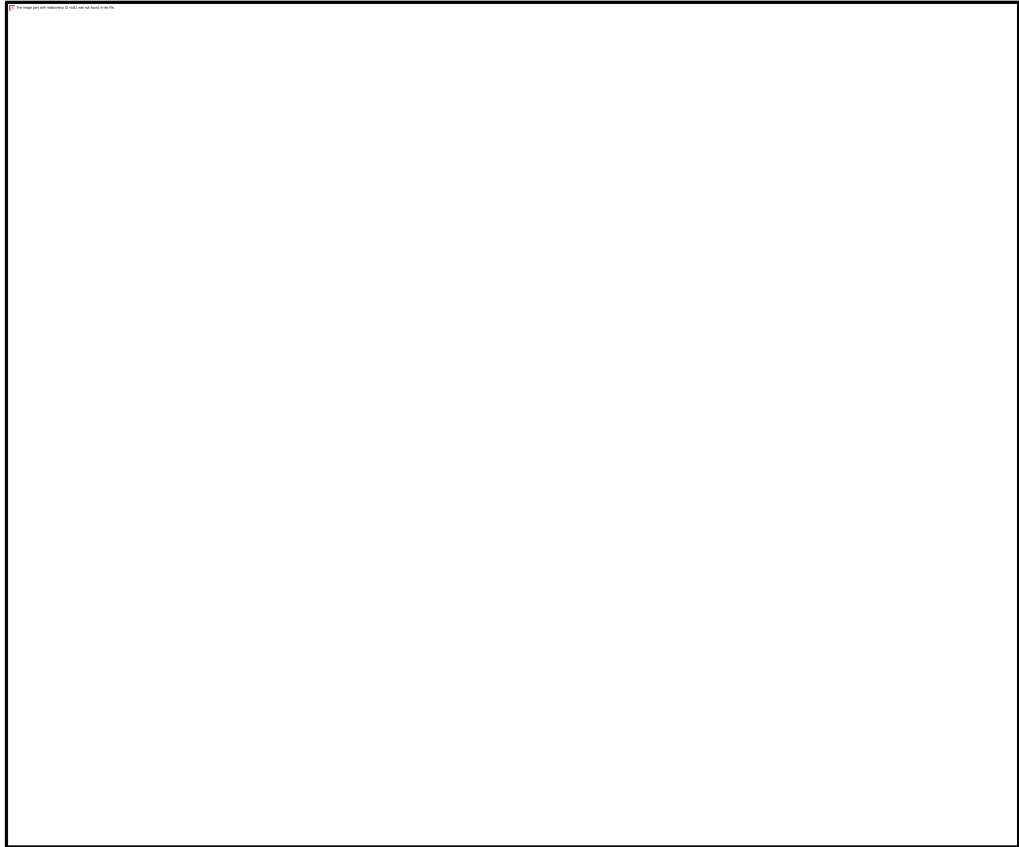


Fig. 4.13 Effect of moisture content and diameter of rootstock on rootstock cutting success rate

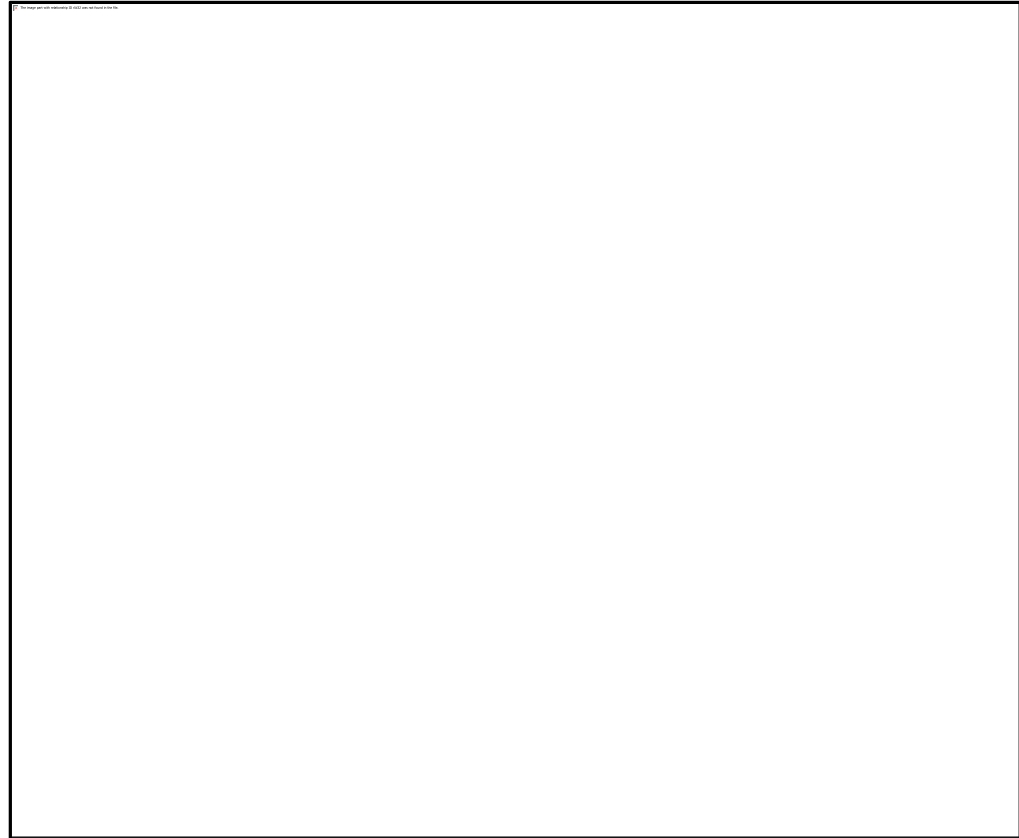


Fig. 4.14 Effect of age of rootstock and operating air pressure on rootstock cutting success rate

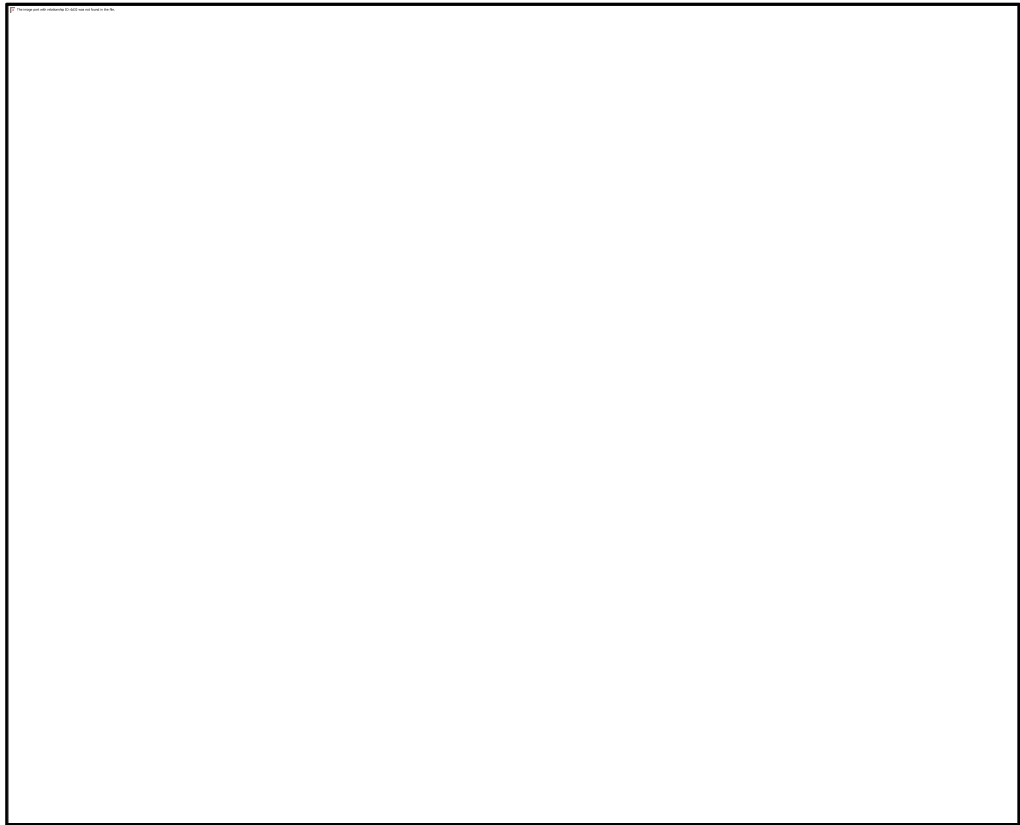


Fig. 4.15 Effect of moisture content and diameter of rootstock on rootstock cutting capacity

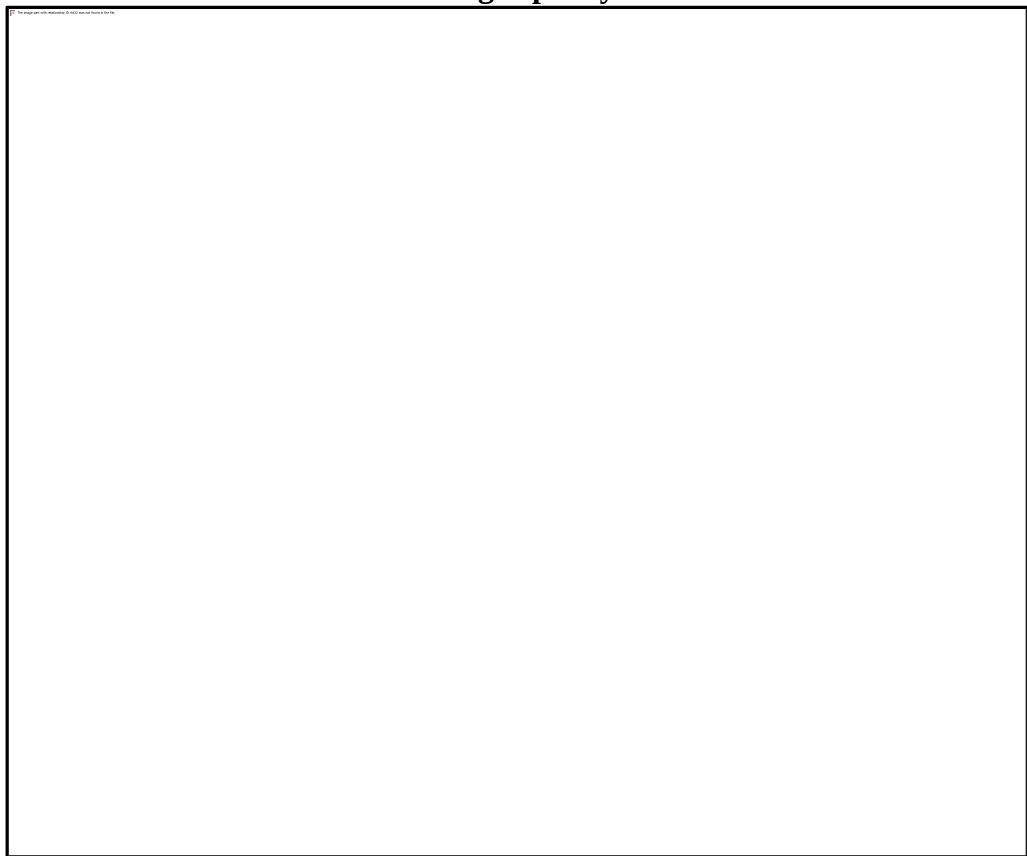


Fig. 4.16 Effect of age of rootstock and operating air pressure on rootstock cutting capacity

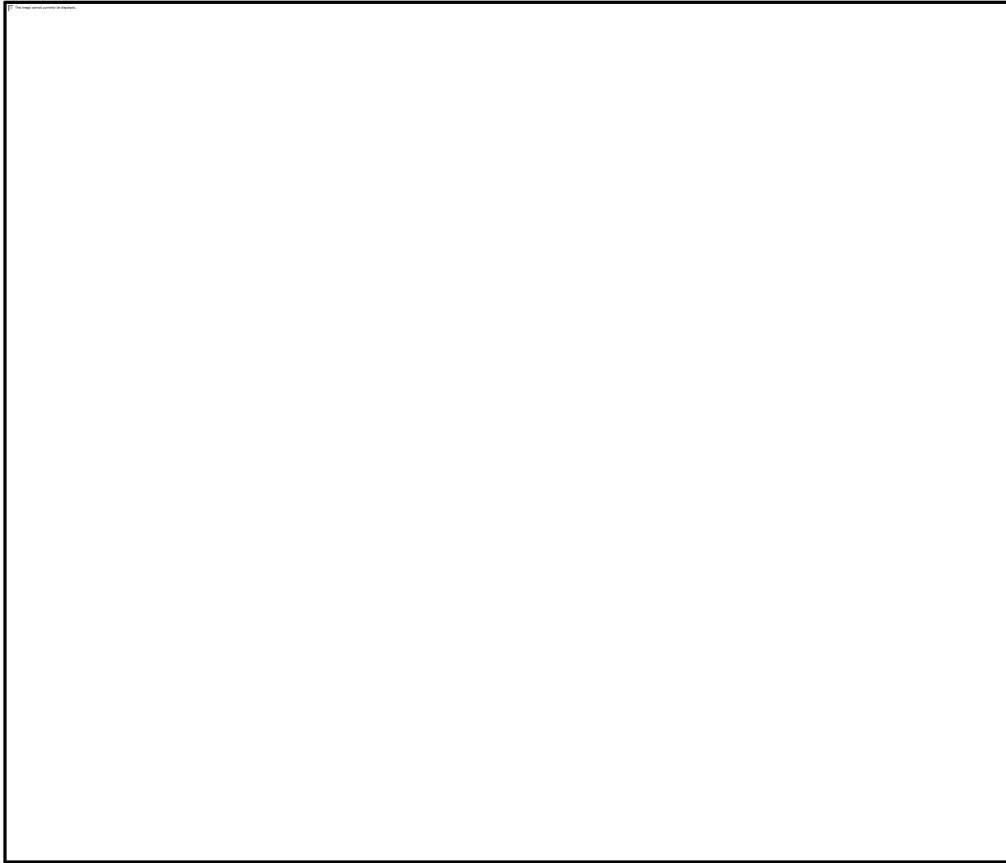


Fig. 4.17 Effect of moisture content and diameter energy consumption

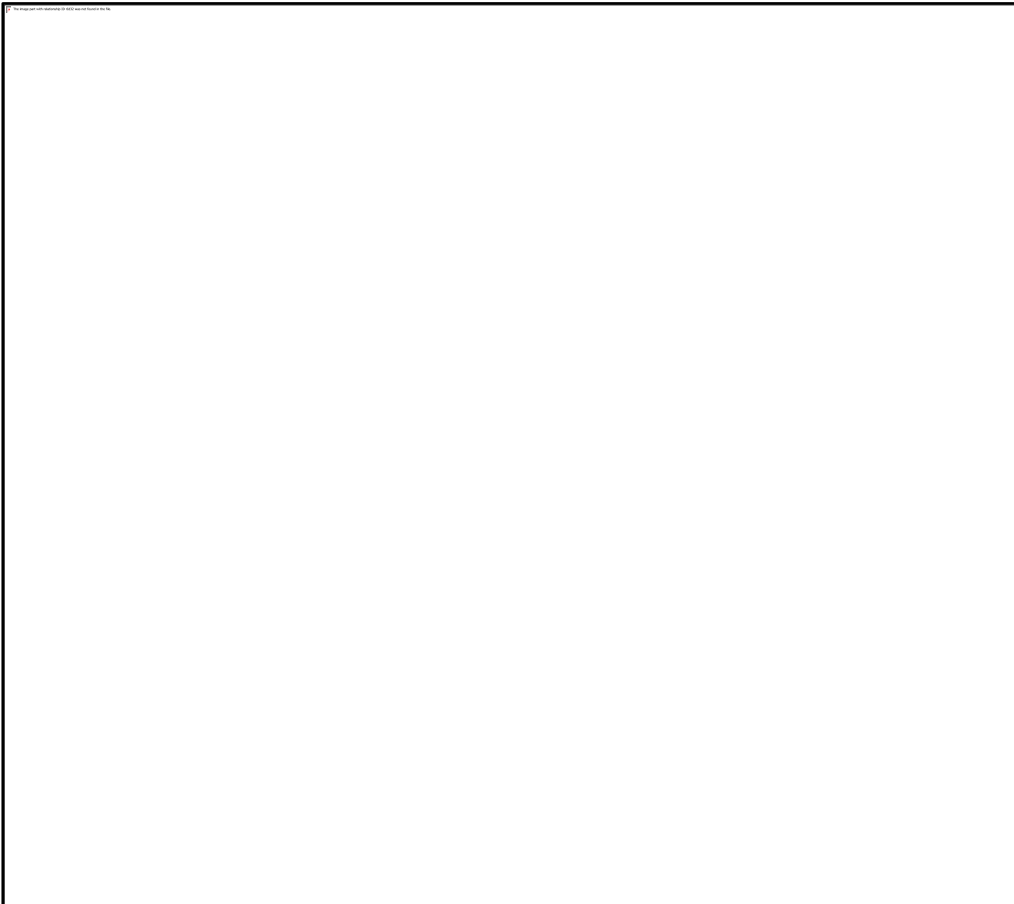


Fig. 4.18 Effect of age of rootstock and operating air pressure on energy consumption

diameter gives slightly low cutting capacity. The maximum rootstock cutting capacity of 514/h for rootstock (150 days) of diameter 9 mm at 7 kg/cm² operating air pressure.

3) Effect of moisture content, diameter and operating air pressure on energy consumption

The effect of moisture content (%) and diameter (mm) of rootstock on energy consumption (kWh) is shown in Fig. 4.17. The effect of age of rootstock (days) and operating air pressure (kg/cm²) on energy consumption (kWh) is shown in Fig. 4.18. The energy consumption increases with increase in diameter of rootstock marginally. Low moisture content, rootstock cutting require slightly more energy consumption. The cutting of lower diameter class rootstock at high moisture content requires less cutting energy (low cutting resistance), so the energy consumption of cutting mechanism was lower. The similar effects were also reported by Sessiz *et al.*, 2015. The energy consumption increases with increase in operating air pressure of cutting mechanism may be due to more energy required to operate cutting mechanism with higher air pressure as compared to low air pressure. Results indicate that the age of rootstock has no significant effect on energy consumption of cutting mechanism. The maximum energy consumption of 0.844 kWh was required at 7 kg/cm² operating air pressure for 9 mm diameter at 75 % moisture content.

4.4.3 Performance of Wrapping Mechanism

The test was conducted as per the standard procedure described in 3.5.2.6 and experiment design in Table 3.15 was given. The rootstock 1 (A1), 2 (A2) and 3 (A3) used in experiments represent the age of rootstock used was 90 (3 months), 150 (5 months) and 240 (months) days after placing in bags. The test was conducted using properties like moisture content of rootstock (%), diameter of rootstock (mm) and operating rotational speed (rpm). The effect of these parameter on graft union wrapping success rate (%), graft union wrapping capacity (no./h) and energy consumption (kWh) was described below. The results are presented in Table 4.7.

Table 4.7 Results of graft union wrapping mechanism performance

Run	A: Moisture Content, %	B: Diameter of stick, mm	C: Age of Rootstock, days	D: Operating Rotational Speed, rpm	Graft union wrapping success, rate%	Graft wrapping capacity, no./h	Energy Consumption, kWh
1	75	6.5	3	40	95	123	0.0219
2	75	10	2	60	85	182	0.0267
3	75	6.5	3	60	85	180	0.0265
4	75	3	2	60	70	186	0.0270
5	65	6.5	2	60	75	179	0.0268
6	75	3	3	50	70	147	0.0251

Run	A: Moisture Content, %	B: Diameter of stick, mm	C: Age of Rootstock, days	D: Operating Rotational Speed, rpm	Graft union wrapping success, rate%	Graft wrapping capacity, no./h	Energy Consumption, kWh
7	75	3	2	40	80	121	0.0224
8	75	3	1	50	70	153	0.0248
9	75	10	2	40	95	115	0.0221
10	85	6.5	2	60	80	181	0.0263
11	75	6.5	2	50	90	149	0.0249
12	75	6.5	1	60	70	177	0.0263
13	75	10	1	50	70	146	0.0254
14	85	6.5	2	40	85	119	0.0223
15	85	10	2	50	85	143	0.0257
16	65	10	2	50	90	151	0.0253
17	75	6.5	2	50	90	148	0.025
18	65	3	2	50	75	154	0.0252
19	85	6.5	1	50	75	147	0.0256
20	75	6.5	2	50	85	145	0.0251
21	75	6.5	2	50	90	150	0.026
22	75	6.5	2	50	85	152	0.0259
23	65	6.5	2	40	90	125	0.0226
24	65	6.5	3	50	95	148	0.0246
25	85	6.5	3	50	90	146	0.0257
26	85	3	2	50	70	157	0.0245
27	75	10	3	50	95	143	0.0244
28	65	6.5	1	50	80	152	0.0249
29	75	6.5	1	40	85	123	0.0227

1) Effect of moisture content, diameter and operating rotational speed on graft union wrapping success rate

The effect of moisture content (%) and diameter (mm) of stick on graft union wrapping success rate (%) is shown in Fig. 4.19. The effect of age of rootstock and operating rotational speed (rpm) on graft union wrapping success rate (%) is shown in Fig. 4.20. The wrapping success rate increases with increase in diameter of stick. The large diameter class stick graft joint were easy to hold and has optimum strength against the stretching of grafting tape around stick by wrapping mechanism, due to this, the wrapping success rate increased. The effect of diameter of stick on its strength was reported by Adams, 2016. The maximum wrapping success rate was found for stick of diameter 6.5 mm – 10 mm. The wrapping success rate marginally increases with decrease in moisture content, probably due to increase in strength of graft joint with decrease in moisture

content. The maximum wrapping success rate was found to be 95 % at low operating rotational speed rpm (40 rpm) and for rootstock of age 240 days. Wrapping success rate depends on operating rotational speed of wrapping mechanism; it increases with decrease in operating speed. This was probably due to proper and tightly wrapping of grafting tape at low speed. The minimum wrapping success rate was found to be 70 % for rootstock of age 90 – 150 days and diameter 3 mm at high operating rotational speed of 50 – 60 rpm at 75 % moisture content.

2) Effect of moisture content, diameter and operating rotational speed on graft union wrapping capacity

The effect of moisture content (%) and diameter (mm) of stick on graft union wrapping capacity (no./h) is shown in Fig. 4.21. The effect of age of rootstock and operating rotational speed (rpm) on graft union wrapping capacity (no./h) is shown in Fig. 4.22. The moisture content and diameter of stick does not show any significant effect on wrapping capacity may be due to the moisture content and diameter of stick does not affect the rotational speed of wrapping mechanism or time required to wrap the graft joint. The graft union wrapping capacity increases with increase in operating rotational speed and was found proportional to operating rotational speed. This may due to the increase in speed of revolving of grafting tape covers the more area of stick in less time. The maximum graft union wrapping capacity was found to be 186/h for rootstock of age 150 days and 3 mm diameter at operating rotational speed of 60 rpm.

3) Effect of moisture content, diameter and operating rotational speed on energy consumption

The effect of moisture content (%) and diameter (mm) of stick on energy consumption (kWh) of graft union wrapping mechanism is shown in Fig. 4.23. The effect of age of rootstock and operating rotational speed (rpm) on energy consumption (kWh) of graft union wrapping mechanism is shown in Fig. 4.24. The diameter and moisture content of stick was shown minute effect on energy consumption of graft union wrapping mechanism. The energy consumption increases with increase in operating rotational speed of graft union wrapping mechanism. The energy consumption was found directly proportional to operating rotational speed of graft union wrapping mechanism. To increase the speed of wrapping mechanism, the voltage supply to DC motor was increased, so more energy was consumed by wrapping mechanism. The similar effect of increase in motor speed on energy consumption was reported by researcher (Belforte *et al.*, 2018). The age of rootstock has no significant effect on energy consumption of graft union wrapping mechanism. The maximum energy consumption was found to be 0.027 kWh for wrapping of 3 mm diameter stick (240 days) operating with rotational speed of 60 rpm at moisture content of 75 %. The minimum energy consumption was found to be 0.0221 kWh for wrapping 10 mm diameter stick (150 days) wrapped with operating rotational speed of 40 rpm at 75 % moisture content.

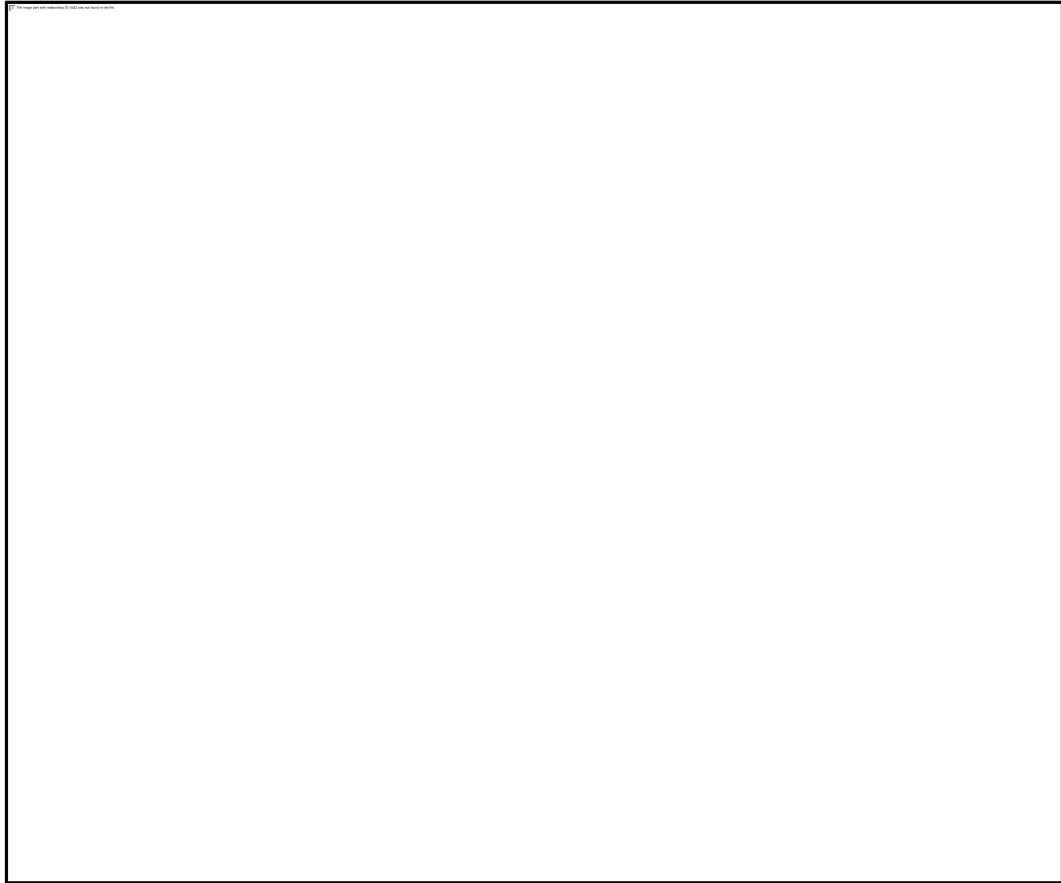


Fig. 4.19 Effect of diameter and moisture content on wrapping success rate

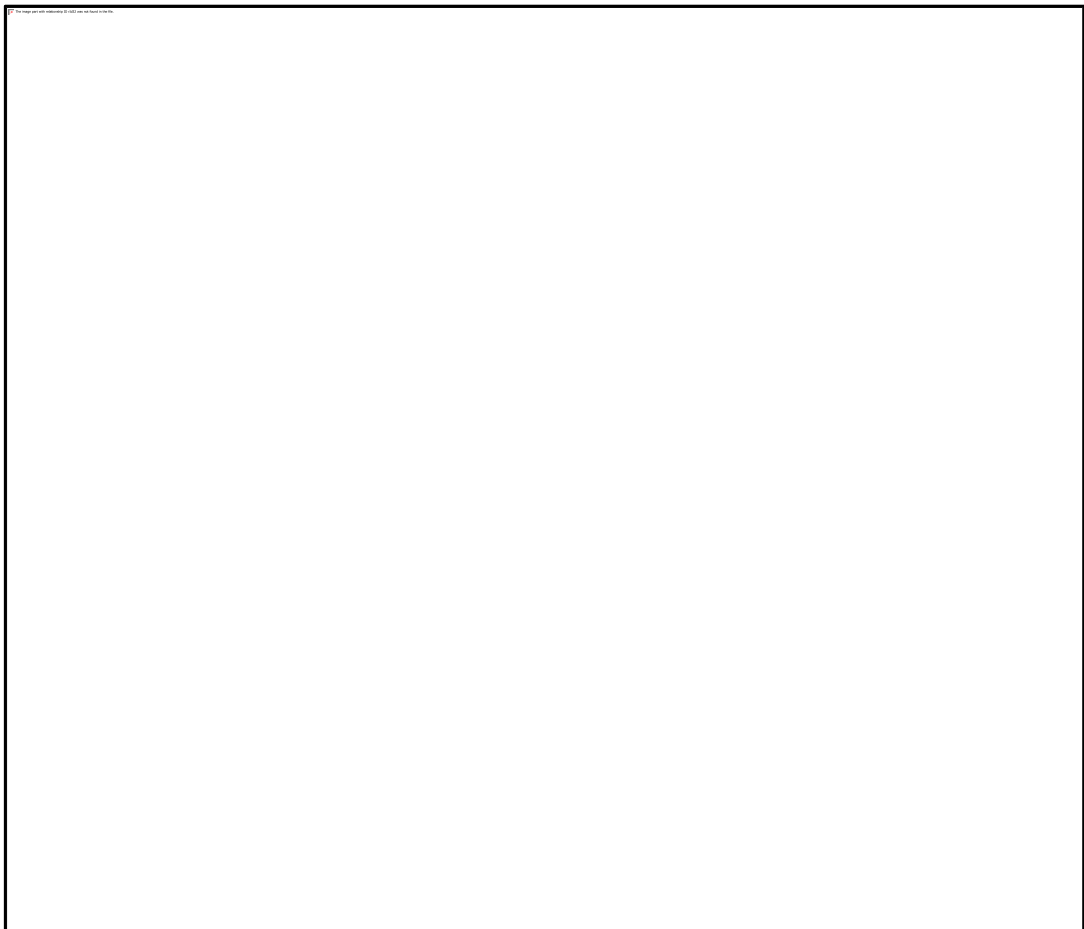


Fig. 4.20 Effect of age of rootstock and operating rotational speed on wrapping success rate

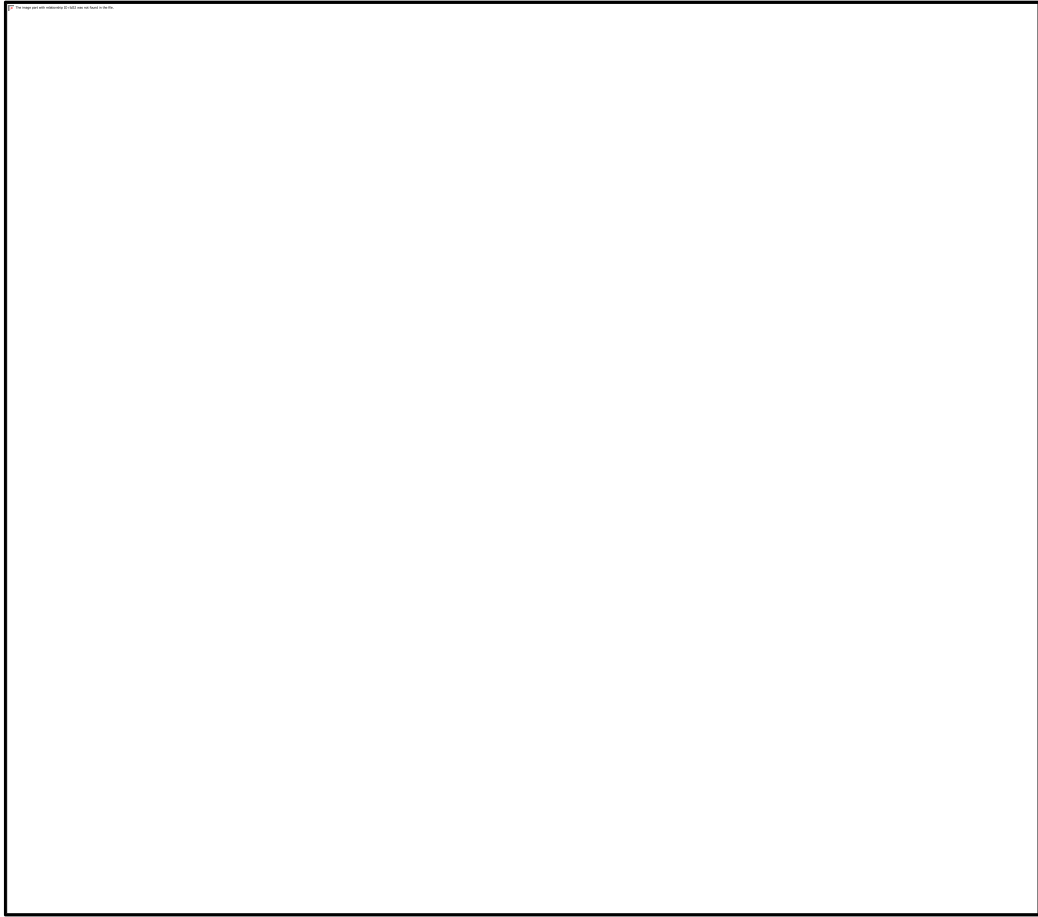


Fig. 4.21 Effect of diameter and moisture content on wrapping capacity



Fig. 4.22 Effect of age of rootstock and operating rotational speed on wrapping capacity

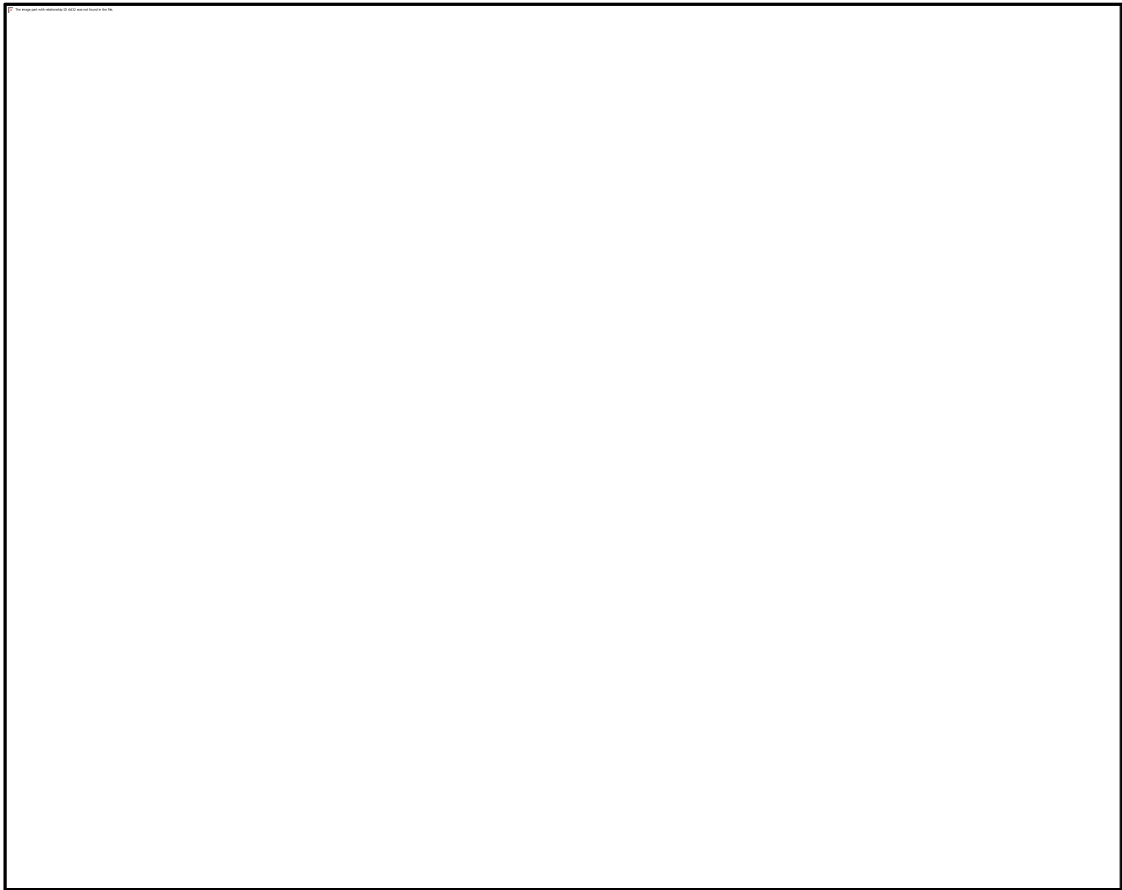


Fig. 4.23 Effect of diameter and moisture content on energy consumption

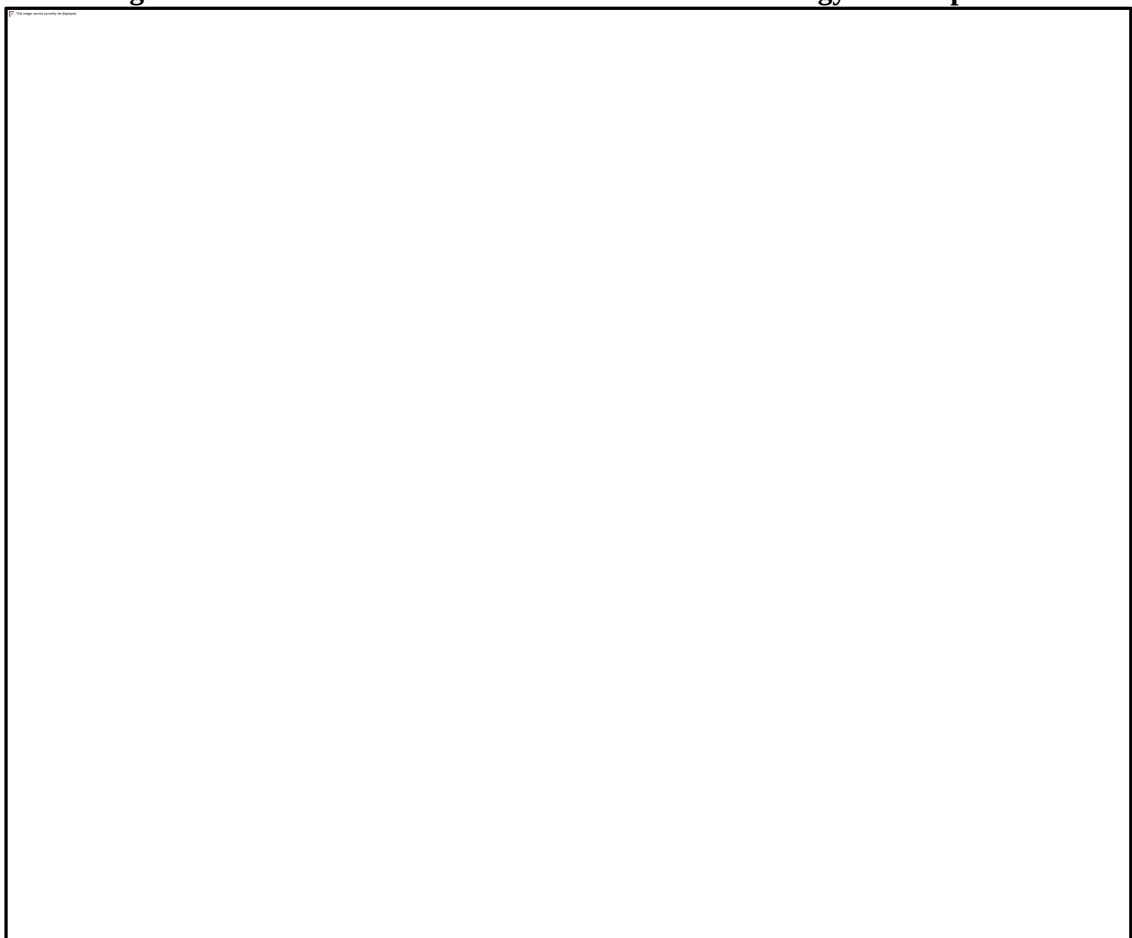


Fig. 4.24 Effect of age of rootstock and operating rotational speed on energy consumption

4.5 Field Performance Evaluation

The developed bench grafting tool was tested in field condition by completing whole process of grafting operation as described in 3.6.3. The grafting nursery condition was maintained during field evaluation of developed bench grafting tool. The grafted plants were kept in postgraft care polyhouse and readings for success of grafting were measured. The experiment was conducted using 20 plants per run and evaluated.

4.5.1 Experimental Design and Statistical Analysis

The experimental design of field evaluation of developed bench grafting tool was as per standard procedure as described in Table 3.16. The statistical experiment design was described in Table 3.17. The effect of moisture content (%), diameter (mm) of stick, age of rootstock (days), operating air pressure (kg/cm²) and operating rotational speed (rpm) on success of grafting (%) and grafting capacity (no./h) was evaluated below. The results are presented in Table 4.8.

Table 4.8 Effect of independent parameters on performance of developed bench grafting tool by RSM

Run	A: Moisture Content, %	B: Diameter of stick, mm	C: Age of Rootstock, days	D: Operating Air Pressure, kg/cm ²	E: Operating Rotational Speed, rpm	Success of Grafting, %	Grafting Capacity, no./h
1	85	6.5	2	6	60	75	104
2	75	6.5	3	6	40	80	83
3	75	3	2	5	50	60	99
4	75	6.5	2	7	40	80	85
5	85	10	2	6	50	75	90
6	75	6.5	2	6	50	80	94
7	85	6.5	2	5	50	75	96
8	75	3	2	7	50	65	98
9	65	10	2	6	50	75	92
10	75	10	2	5	50	70	89
11	75	6.5	2	7	60	70	105
12	75	6.5	1	6	60	70	103
13	75	10	1	6	50	75	91
14	85	6.5	1	6	50	80	95
15	75	10	2	6	40	75	79
16	75	3	3	6	50	60	97
17	75	6.5	2	6	50	75	94
18	75	6.5	2	6	50	80	97

Run	A: Moisture Content, %	B: Diameter of stick, mm	C: Age of Rootstock, days	D: Operating Air Pressure, kg/cm²	E: Operating Rotational Speed, rpm	Success of Grafting, %	Grafting Capacity, no./h
19	85	6.5	2	7	50	75	98
20	75	10	2	6	60	65	104
21	75	6.5	3	5	50	65	93
22	85	6.5	3	6	50	75	95
23	65	6.5	2	6	40	75	85
24	75	3	2	6	40	65	87
25	75	6.5	1	6	40	75	86
26	65	3	2	6	50	60	96
27	75	3	2	6	60	55	110
28	75	10	3	6	50	70	91
29	75	6.5	1	7	50	75	94
30	75	6.5	1	5	50	70	92
31	65	6.5	2	7	50	75	94
32	65	6.5	1	6	50	75	95
33	65	6.5	2	6	60	70	106
34	75	3	1	6	50	70	98
35	65	6.5	2	5	50	65	95
36	75	10	2	7	50	70	90
37	75	6.5	2	6	50	75	93
38	75	6.5	2	6	50	80	92
39	85	3	2	6	50	70	98
40	75	6.5	2	5	40	65	83
41	75	6.5	3	7	50	75	96
42	75	6.5	3	6	60	70	106
43	85	6.5	2	6	40	70	88
44	65	6.5	3	6	50	65	97
45	75	6.5	2	5	60	65	105

4.5.1.1 Effect of moisture content, diameter, age of rootstock, operating air pressure and operating rotational speed on Success of Grafting

The success of grafting was calculated as per standard procedure described in 3.6.4 (1) and the results are presented in Table 4.8. The effect of moisture content (%) and diameter (mm) of stick on success of grafting (%) is shown in Fig. 4.25. The maximum success of grafting was found for sticks of diameter of around 6 mm to 8 mm. The success of grafting increases with increase in diameter of stick from 4 mm to 8 mm and decreases slightly for stick of diameter 8 mm onward. The stick of size 4 mm to 8 mm with softwood, vigorous and mature characteristics at a time, which gives the maximum success of grafting in softwood grafting technique. The similar effect was also reported by researcher (Kadam, 1992). The minimum success of grafting was found for stick of diameter less than 4 mm. The maximum success of grafting was found to be 80 % for stick of 6.5 mm diameter, rootstock of age 150 days at 75 – 85 % of moisture content at operating rotational speed of 40 rpm. The minimum success of grafting was found to be 55 % for stick of diameter 3 mm, rootstock of age 150 days at operating rotational speed of 60 rpm at 6 kg/cm² operating air pressure. The success of grafting slightly increases with increase in moisture content of stick. The use of optimum moisture content of sticks increases the chances of successful joining of scion and rootstock to form graft union and grow as single plant. The similar effect of moisture content on graft union formation was also reported by Adams, 2016. The effect of age of rootstock (days) and operating air pressure (kg/cm²) on success of grafting (%) is shown in Fig. 4.26. The success of grafting slightly decreases with increase in age of rootstock. The rootstock of age 3 months (1) to 5 months (2) shows better results for softwood grafting as the rootstock of this age group has perfect softwood stem characteristics. The similar recommendation was reported by researcher Kadam, 1992. The success of grafting increases with increase in operating air pressure of cutting mechanism. The effect of moisture content (%) and operating rotational speed (rpm) on success of grafting is shown in Fig. 4.27. The success of grafting slightly increases with increase in moisture content of stick. The success of grafting increases with decrease in operating rotational speed of graft union wrapping mechanism. The wrapping of graft joint with lower speed will ensure the proper wrapping by stretching grafting tape on joint without much disturbance to graft joint. In contradictory, the high speed of wrapping than optimum operating rotational speed may disturb or damage the graft joint (surface contact between scion and rootstock). This success of grafting increases with decrease in operating rotational speed.

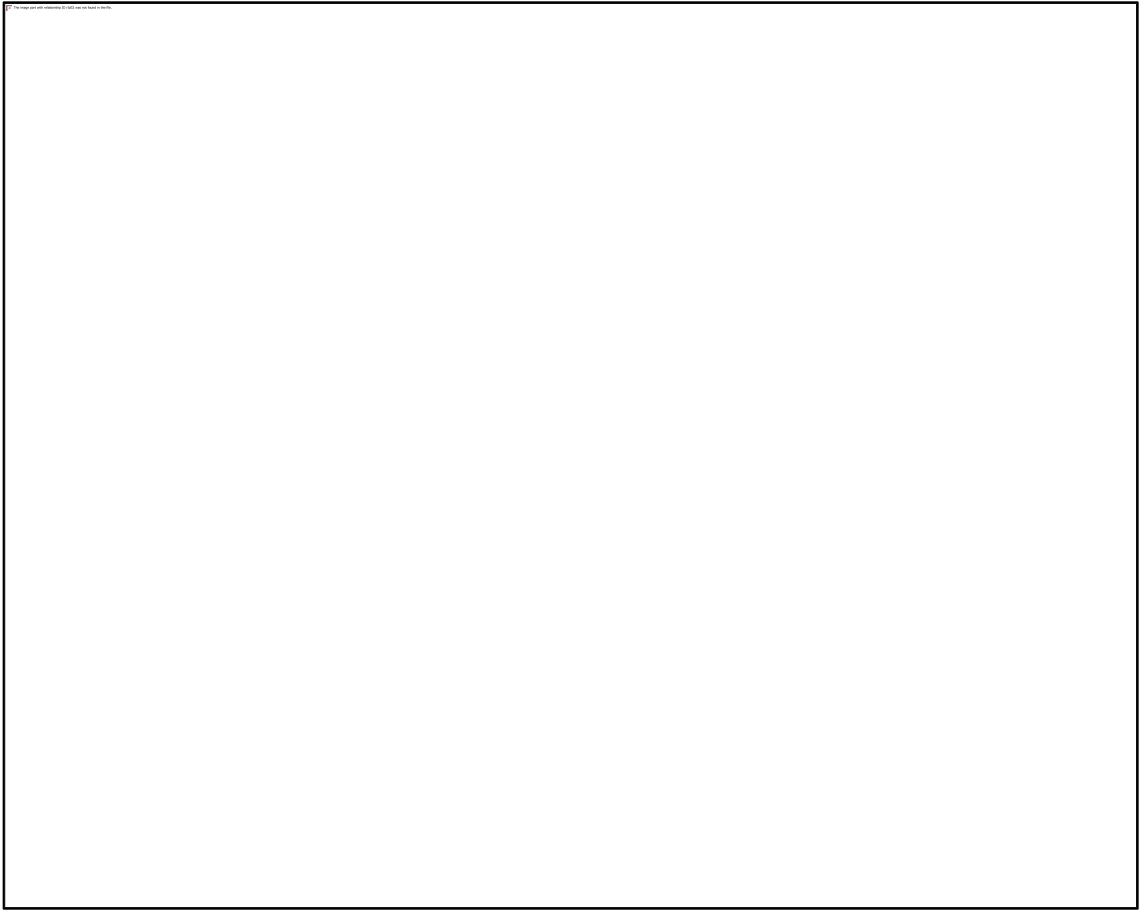


Fig. 4.25 Effect of moisture content and diameter of stick on success rate of grafting

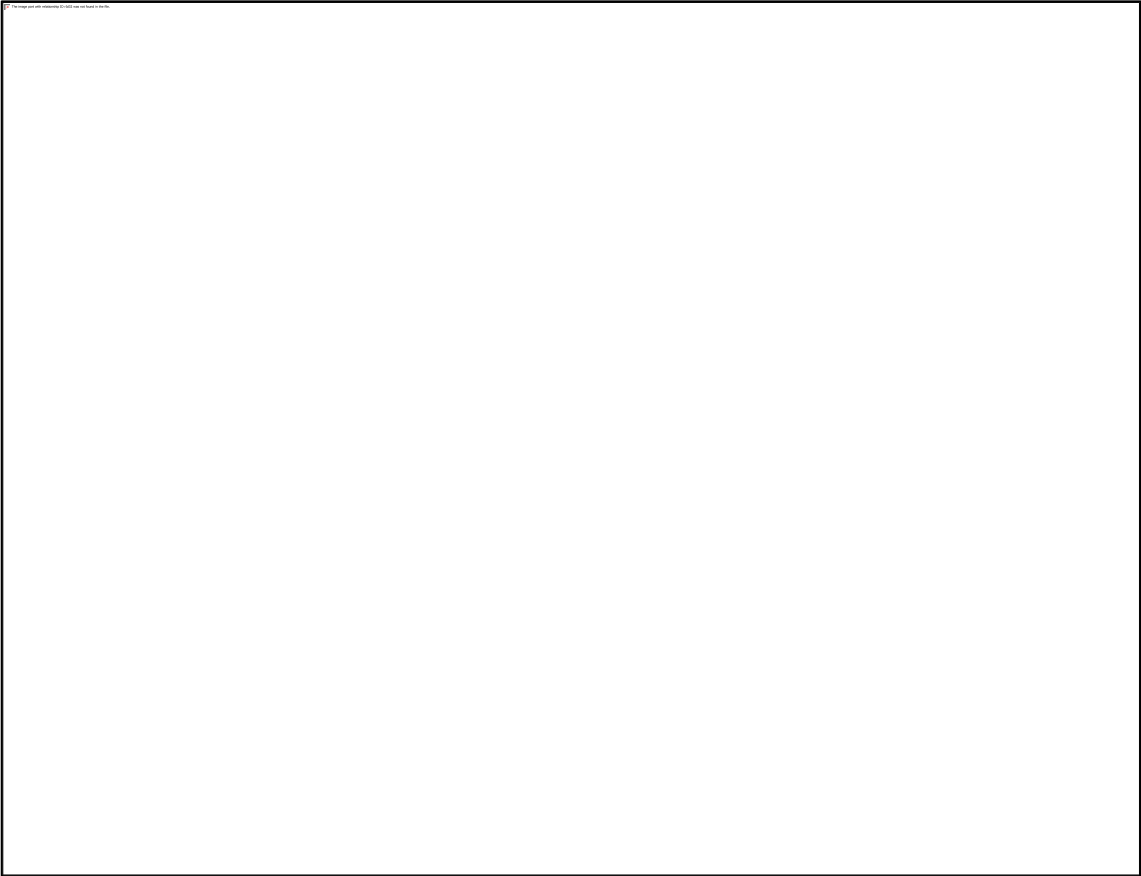


Fig. 4.26 Effect of age of rootstock and operating air pressure on success rate of grafting

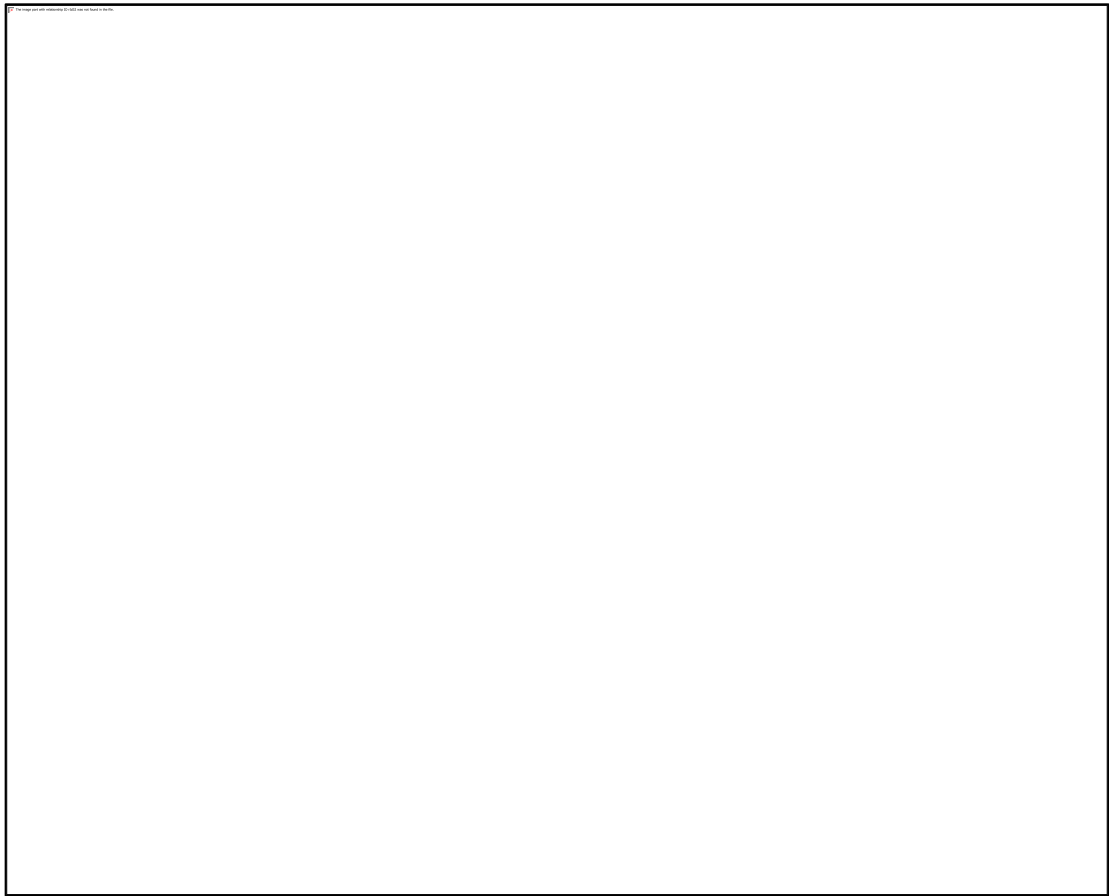


Fig. 4.27 Effect of moisture content and operating rotational speed on success rate of grafting

4.5.1.2 ANOVA for success of grafting

The ANOVA shown in Table 4.9 indicated that, The Model F-value of 6.80 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. The model value F (6.80) suggesting quadratic model could be successfully used to fit experimental data (<0.001) as per F-values indicated in Table 4.9. P-values less than 0.0500 indicate model terms are significant. In this case A, B, C, D, E, B^2 , D^2 , E^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve model. The Lack of Fit F-value of 1.46 implies, the Lack of Fit is not significant relative to the pure error. There is a 38.98 % chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good, the model to fit. The predicted R^2 of (0.4439) is not as close to the adjusted R^2 of (0.7249) as one might normally expect; i.e. the difference is more than 0.2. Things to consider are model reduction, response transformation, outliers, etc. All empirical models should be tested by doing confirmation runs. Adequate precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 9.520 indicates an adequate signal. The value of R^2 is 0.8499. This model can be used to navigate the design space.

The regression equation representing variation of success of grafting (%) with different independent parameters were fitted in polynomial form given as,

$$\text{Success of Grafting (\%)} = 78 + 2.1875 A + 4.375 B - 1.875 C + 3.125 D - 2.8125 E - 2.5 AB + 1.25 AC - 2.5 AD + 2.5 AE + 1.25 BC - 1.25 BD + 6.45317e^{-16} BE + 1.25 CD - 1.25 CE - 2.5 DE - 1.39583 A^2 - 7.64583 B^2 + 1.8125 C^2 - 4.3125 D^2 - 3.89583 E^2 \dots(4.1)$$

$$R^2 = 0.8499$$

Where,

A = Moisture content (%)

B = Diameter of rootstock (mm)

C = Age of rootstock (days)

D = Operating pressure (kg/cm²)

E = Operating rotational speed (rpm)

Table 4.9 ANOVA for study effect of moisture content, diameter, age of rootstock, operating pressure and operating rotational speed on success of grafting

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1409.03	20	70.45	6.80	< 0.0001	Significant
A-Moisture Content	76.56	1	76.56	7.39	0.0120	Significant
B-Diameter of stick	306.25	1	306.25	29.55	< 0.0001	Significant
C-Age of Rootstock	56.25	1	56.25	5.43	0.0286	Significant
D-Operating Air Pressure	156.25	1	156.25	15.08	0.0007	Significant
E-Operating Rotational Speed	126.56	1	126.56	12.21	0.0019	Significant
AB	25.00	1	25.00	2.41	0.1335	Not Significant
AC	6.25	1	6.25	0.6030	0.4450	Not Significant
AD	25.00	1	25.00	2.41	0.1335	Not Significant
AE	25.00	1	25.00	2.41	0.1335	Not Significant
BC	6.25	1	6.25	0.6030	0.4450	Not Significant
BD	6.25	1	6.25	0.6030	0.4450	Not Significant
BE	0.0000	1	0.0000	0.0000	1.0000	Not Significant

Source	Sum of Squares	df	Mean Square	F-value	p-value	
CD	6.25	1	6.25	0.6030	0.4450	Not Significant
CE	6.25	1	6.25	0.6030	0.4450	Not Significant
DE	25.00	1	25.00	2.41	0.1335	Not Significant
A ²	15.85	1	15.85	1.53	0.2282	Not Significant
B ²	475.60	1	475.60	45.89	< 0.0001	Significant
C ²	26.73	1	26.73	2.58	0.1214	Not Significant
D ²	151.30	1	151.30	14.60	0.0008	Significant
E ²	123.48	1	123.48	11.91	0.0021	Significant
Residual	248.75	24	10.36			
Lack of Fit	218.75	20	10.94	1.46	0.3898	not significant
Pure Error	30.00	4	7.50			
Cor Total	1657.78	44				
Std. Dev.	3.22					
R ²	0.8499					
Mean	71.22					
Adjusted R ²	0.7249					
C.V. %	4.52					
Predicted R ²	0.4439					
Adeq Precision	9.5202					

4.5.1.3 Effect of moisture content, diameter, age of rootstock, operating air pressure and operating rotational speed on grafting capacity

The grafting capacity was calculated as per the standard procedure described in 3.6.4 (2) and results were given in Table 4.6. The effect of moisture content (%) and diameter (mm) of stick on grafting capacity (no./h) of developed bench grafting tool was shown in Fig. 4.28. The grafting capacity increases a little with increase in moisture content and decrease in diameter of stick. The moisture content and diameter of stick has a little significant effect on grafting capacity probably due to the decrease in cutting resistance with increase in moisture content and decrease in diameter causes to increase the cutting capacity. The moisture content and diameter of stick does not affect the wrapping capacity of wrapping mechanism. The effect of age of rootstock (days) and operating air pressure (kg/cm²) of cutting mechanism on grafting capacity (no./h) of developed bench grafting tool is shown in Fig. 4.29. The grafting capacity slightly increases with increase in operating air

pressure of cutting mechanism as increase in operating air pressure, increases the cutting capacity of cutting mechanism. The age of rootstock has no effect on grafting capacity of developed bench grafting tool. The effect of moisture content (%) and operating rotational speed (rpm) on grafting capacity (no./h) of developed bench grafting tool is shown in Fig. 4.30. The grafting capacity increases with increase in operating rotational speed of wrapping mechanism as increase in operating rotational speed of wrapping mechanism increases the wrapping capacity so, the ultimately grafting capacity of developed bench grafting tool increases. The similar effects were also reported by researcher (Belforte *et al.*, 2018). The grafting capacity is directly proportional to operating rotational speed of wrapping mechanism. The moisture content of stick had a little effect on grafting capacity of developed bench grafting tool. The maximum grafting capacity was found to be 110 grafts /h for 3 mm scion at 6 kg/cm² operating air pressure and 60 rpm speed. The minimum grafting capacity was found to be 79 grafts/h for 10 mm diameter stick (age 150 days) at operating pressure of 6 kg/cm², at operating rotational speed of 40 rpm at 75 % moisture content.



Fig. 4.28 Effect of moisture content and diameter of stick on grafting capacity

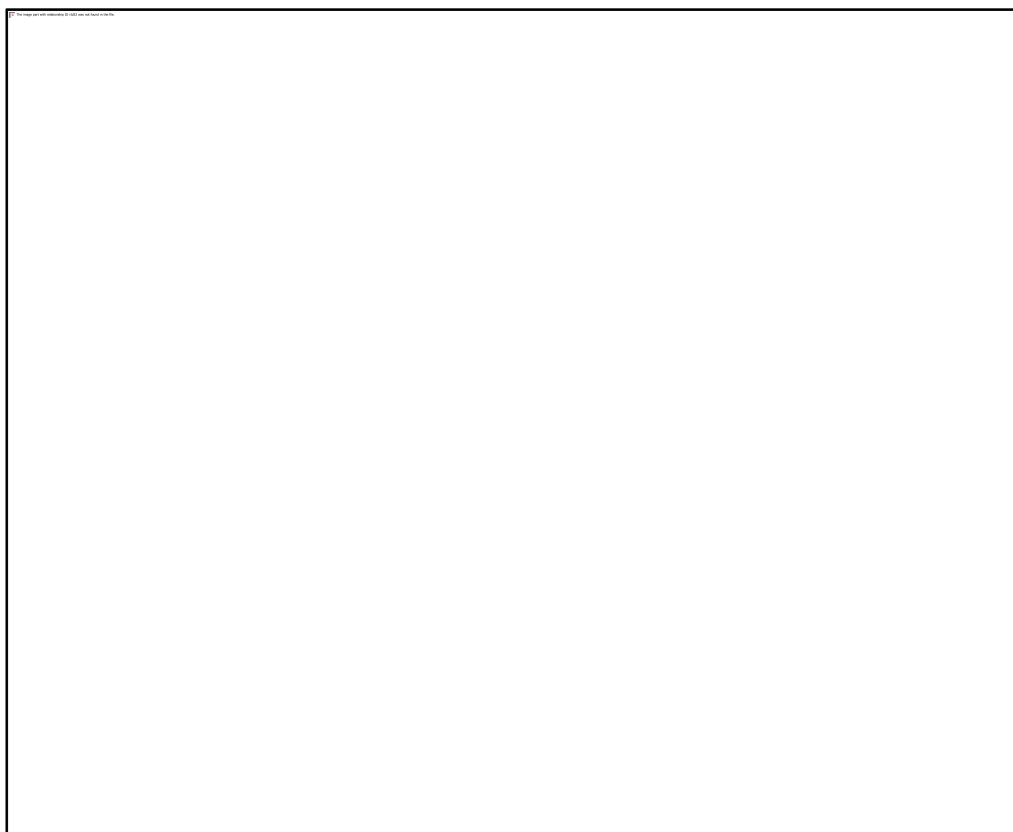


Fig. 4.29 Effect of age of rootstock and operating air pressure on grafting capacity

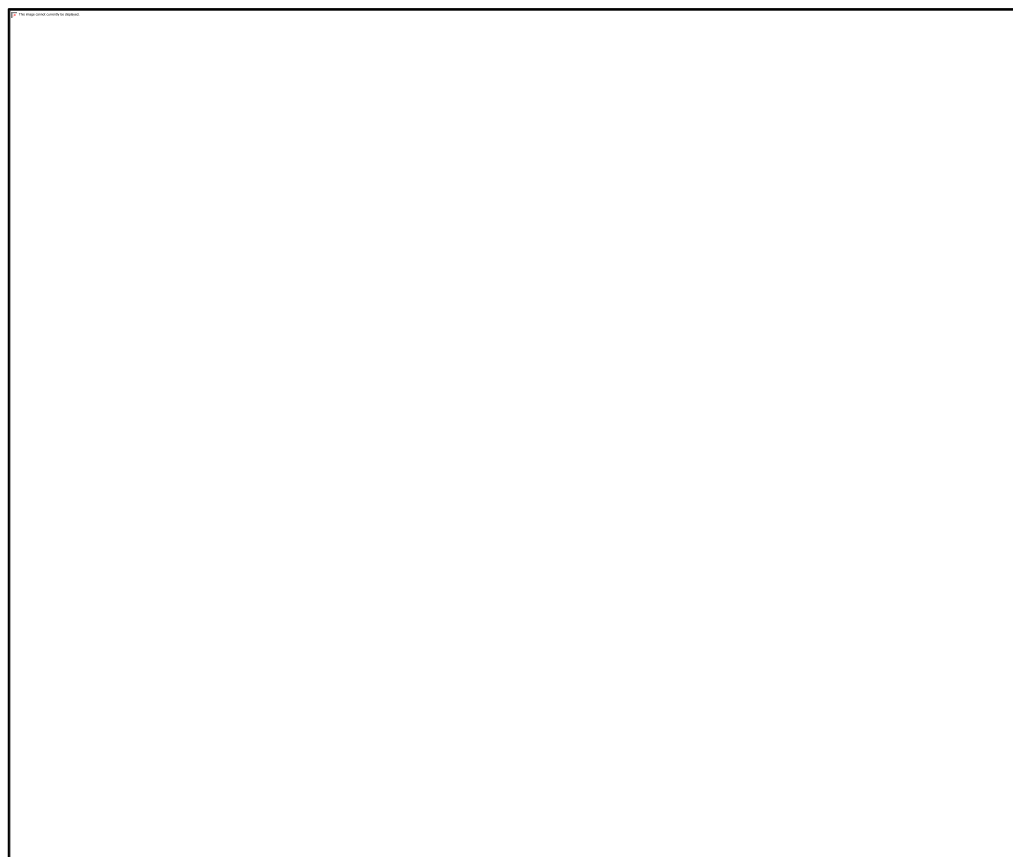


Fig. 4.30 Effect of moisture content and operating rotational speed on grating capacity

4.5.1.4 ANOVA for Grafting Capacity

The ANOVA shown in Table 4.10 indicates that, the Model F-value of 42.93 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case B and E are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 0.60 implies the Lack of Fit is not significant relative to the pure error. There is a 80.56% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good. The predicted R² of 0.9079 is in reasonable agreement with the adjusted R² of 0.9501; i.e. the difference is less than 0.2. The R² (0.9728) for these model is good. Adequate precision measures the signal to noise ratio. A ratio greater than 4 is desirable. This model ratio of 26.903 indicates an adequate signal. This model can be used to navigate the design space. The regression equation representing variation of grafting capacity (no./h) with different independent parameters were fitted in polynomial form given below,

$$\begin{aligned} \text{Grafting Capacity (no./h)} = & 94 + 0.25 A + -3.5625 B + 0.25 C + 0.5 D + 10.4375 E - 1 AB - 0.5 \\ & AC + 0.75 AD - 1.25 AE + 0.25 BC + 0.5 BD + 0.5 BE + 0.25 CD + 1.5 CE - 0.5 DE + 1.08333 \\ & A^2 - 0.166667 B^2 + 0.0833333 C^2 + 0.0833333 D^2 + 0.666667 E^2 \end{aligned} \quad \dots(4.2)$$

$$R^2 = 0.9728$$

Where,

A = Moisture content (%)

B = Diameter of rootstock (mm)

C = Age of rootstock (days)

D = Operating pressure (kg/cm²)

E = Operating rotational speed (rpm)

Table 4.10 ANOVA for study effect of moisture content, diameter, age of rootstock, operating pressure and operating rotational speed on success of grafting

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1992.87	20	99.64	42.93	< 0.0001	Significant
A-Moisture Content	1.0000	1	1.0000	0.4308	0.5178	Not Significant
B-Diameter of stick	203.06	1	203.06	87.48	< 0.0001	Significant
C-Age of Rootstock	1.0000	1	1.0000	0.4308	0.5178	Not Significant
D-Operating Air Pressure	4.00	1	4.00	1.72	0.2017	Not Significant
E-Operating Rotational Speed	1743.06	1	1743.06	750.94	< 0.0001	Significant
AB	4.00	1	4.00	1.72	0.2017	Not Significant

Source	Sum of Squares	df	Mean Square	F-value	p-value	
AC	1.0000	1	1.0000	0.4308	0.5178	Not Significant
AD	2.25	1	2.25	0.9693	0.3347	Not Significant
AE	6.25	1	6.25	2.69	0.1139	Not Significant
BC	0.2500	1	0.2500	0.1077	0.7456	Not Significant
BD	1.0000	1	1.0000	0.4308	0.5178	Not Significant
BE	1.0000	1	1.0000	0.4308	0.5178	Not Significant
CD	0.2500	1	0.2500	0.1077	0.7456	Not Significant
CE	9.00	1	9.00	3.88	0.0606	Not Significant
DE	1.0000	1	1.0000	0.4308	0.5178	Not Significant
A ²	9.55	1	9.55	4.11	0.0538	Not Significant
B ²	0.2260	1	0.2260	0.0974	0.7577	Not Significant
C ²	0.0565	1	0.0565	0.0243	0.8773	Not Significant
D ²	0.0565	1	0.0565	0.0243	0.8773	Not Significant
E ²	3.62	1	3.62	1.56	0.2240	Not Significant
Residual	55.71	24	2.32			
Lack of Fit	41.71	20	2.09	0.5958	0.8056	Not significant
Pure Error	14.00	4	3.50			
Cor Total	2048.58	44				
Std. Deviation	1.52					
R ²	0.9728					
Mean	94.62					
Adjusted R ²	0.9501					
C.V. %	1.61					
Predicted R ²	0.9079					
Adequate Precision	26.9030					

4.6 Optimization of Parameters of Stick and Developed Bench Grafting Tool

The performance of developed bench grafting tool was evaluated as per standard procedure and statistical experiments. The numerical multi response optimizing technique in Design Expert 13 software was used. Parameters were selected in combination for optimization of values i.e. moisture content, diameter, age of rootstock, operating pressure and operating rotational speed were in range, success of grafting and grafting capacity. The optimized combinations of selected parameters by using Response Surface Method are shown in Fig. 4.31. The optimized value of various parameters for developed bench grafting tool predicted by software is shown in Table 4.11.

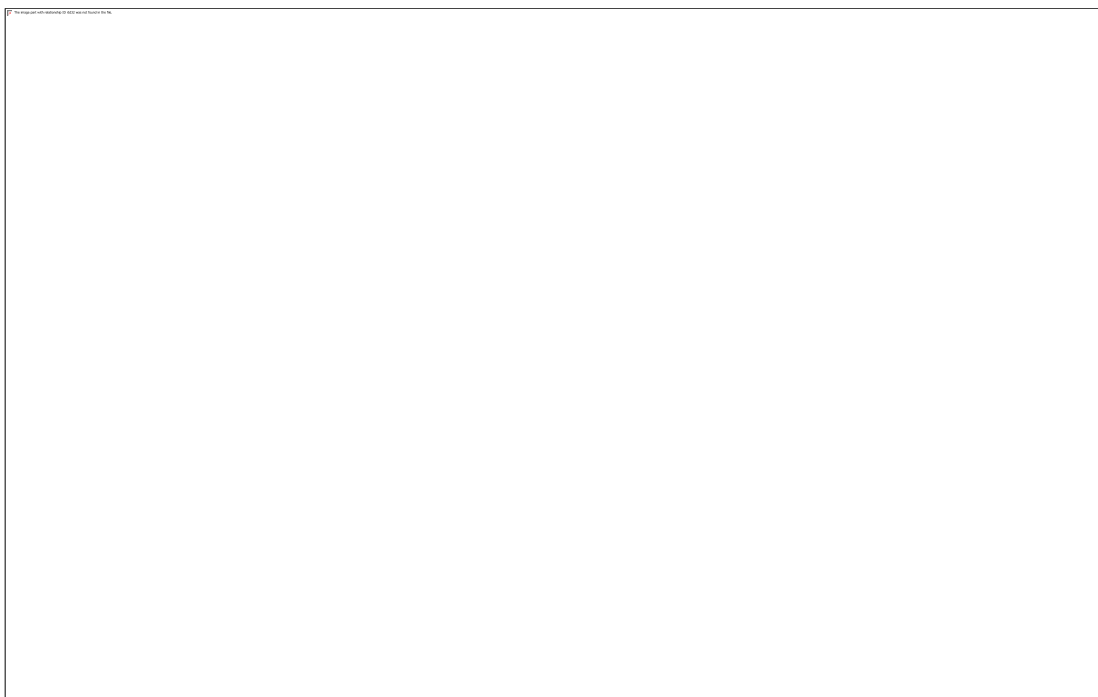


Fig. 4.31 Optimized combinations of selected parameter for operation of bench grafting tool by using RSM

The moisture content of stick has significant effect on success of grafting. The optimization to optimum moisture content for better results of success of grafting is 67.79 %. The actual observed moisture content nearest to optimized value is 65 %. The diameter of stick is important factor in success of grafting. The optimized diameter of stick for better success of grafting is 6.32 mm. The observed value 6.5 is nearest to optimized value of diameter of stick. The three age of rootstock 1 (90 days), 2 (150 days) and 3 (240 days) were observed in field evaluation of developed bench grafting tool. The optimized age of rootstock shows age value of 2.6 (211 days), which is nearest to rootstock age 3 (240 days). The predicted operating air pressure of cutting mechanism is 6.14 kg/cm², which is nearest to the observed value 6 kg/cm². The predicted operating rotational speed of wrapping mechanism for better results of success of grafting and grafting capacity is 52.4 rpm, which is nearest to the observed value 50 rpm. The predicted success of grafting found to be 71.72 %. The observed value of success of grafting is nearest to the predicted values of independent parameters discussed above is 65 %. The predicted grafting capacity is found to be 97.97/h. The observed value of grafting capacity with operation near to predicted independent parameters discussed above is 97/h.

Table 4.11 Optimization of selected parameter by using Response Surface Method

Parameters	Optimized Value	Observed Value	Variation
Moisture Content, %	67.692	65	2.692
Diameter, mm	6.323	6.5	- 0.177
Age of Rootstock, days	2.674 (211)	3 (240)	- 29
Operating Pressure, kg/cm ²	6.135	6	0.135
Operating Rotational Speed, rpm	52.408	50	2.0408
Success of Grafting, %	71.719	65	6.719
Grafting Capacity, no./h	97.970	97	0.9712

4.7 Cost of Operation

The cost of developed bench grafting tool was found to be Rs. 10260. The cost of operation of the developed bench grafting tool was calculated as per the standard procedure described in 3.6.5 and presented in Appendix H. The cost of operation of grafting by developed bench grafting tool is presented in Table 4.12. The traditional method of grafting is slow, costlier; require highly skilled person and drudgerous work. The developed bench grafting tool saves the time, eliminate dependence on highly skilled labour for grafting and grafting was done easily by labour with ease. The developed bench grafting tool saves 45 % time and 25 % cost as compared to traditional method of softwood grafting of cashew nut.

Table 4.12 Cost of operation of softwood grafting of Cashew

Sr.No.	Particulars	Traditional method	Developed machine
1.	Labour required, man days/1000 grafts	2	1.14
2.	Time required, man hours/1000 grafts	16	9.1
3.	Cost of operation for 1000 grafts production, Rs.	1000	774

CHAPTER V

SUMMARY AND CONCLUSIONS

The cashew tree (*Anacardium occidentale*) is a tropical evergreen tree that produces the cashew seed and cashew apple as accessory fruit. Cashew nut is eaten as snack, used in recipes, or processed into cashew cheese or cashew butter. The shell of the cashew seed yield derivatives that can be used in many applications including lubricants, waterproofing and paints. The traditional cashew tree is tall and takes three years from planting before it starts production, and eight years before economic harvest can begin. The dwarf breeds developed more recently of 6 m tall, and start producing after the first year, with economic harvest after the three years. Grafting and other modern tree management technologies are used to further improve and sustain cashew nut yields in commercial orchards. The requirement of grafted plants for plantation of cashew in commercial orchards was increased with increase in demand of cashew nut. So to fulfil demand of quality grafted plants, the development in grafting method and mechanization of grafting process is most important. The grafting process is the skill dependent success of grafting, season, drudgery work and unavailability of skilled labour during grafting season are the main problems in grafted plant production. Hence to reduce the cost of grafting operation, mechanise the operation and ease the process by removing dependency on skilled labour, the study on ‘Design, Development and Performance Evaluation of Bench Grafting Tool’ is undertaken.

The grafting process involves the cutting of scion and rootstock, inserting scion into rootstock and the wrapping graft union with polythene strip or grafting tape. The decapitated rootstock of diameter 4 mm – 8 mm was cut and split vertically to the depth of 50 – 60 mm. The scion (Vengurla – 4) was cut slanted at bottom end on both sides to form wedge shape (‘V’). The wedge shaped scion inserted in split of rootstock (Vengurla – 1). The graft union is wrapped air tightly with grafting tape.

The study of existing grafting method, physical properties of scion and rootstock need to be known. The study of existing grafting method, procedure and the results of grafting is needs to be known for mechanizing the grafting process. The softwood grafting of cashew by skilled labour at nursery, College of Horticulture, Dapoli was performed. The grafting process was observed for scion and rootstock cutting time, wrapping time, cutting length, total time per grafting and the success of grafting. The success of grafting was found to be 60 to 90 % and time per graft was 57.8 sec. Hence, it was planned to determine the physical and engineering properties of cashew scion and rootstock studied. The mean diameter of scion for diameter classes D₁, D₂ and D₃ were

found to be 6 mm, 8 mm and 10 mm respectively. The mean diameter of rootstock of age 90 days for diameter classes were found to be R_1 , R_2 and R_3 were found to be (4 mm, 6 mm and 8 mm) and 240 days for diameter classes S_1 , S_2 and S_3 were found to be (6 mm, 8 mm and 10 mm) respectively. The moisture content of scion were found to be 58.13 % to 82.58 %. The moisture content of rootstock were found to be 67.08 to 90.09 %. The hardness of scion were found to be 16.62 to 51.83 N/mm². The hardness of rootstock were found to be 2.01 to 33.24 N/mm². The maximum cutting strength found to be 7.06 N/mm². The effect of moisture content, diameter and age of rootstock on the cutting strength and hardness of sticks were studied using Texture Analyser and Design Expert 13.0.0 Software. It was observed that cutting strength is directly proportional to diameter and inversely proportional to moisture content of scion and rootstock. The hardness increases with increase in diameter and decrease in moisture content. The maximum force required for cutting scion and rootstocks was measured and was found to be 287.84 N.

The bench grafting tool was developed using the principal requirements of cutting scion and rootstock, graft union wrapping concepts. Success in grafting depends not only on a technically correct graft but in preparation of the scion and rootstock for grafting so, they should be prepared properly. The graft union should be wrapped tightly such that air should not enter at grafted area that will cause drying of the graft union area. The machine was designed to mechanise the softwood grafting process of cashew in nurseries. The developed grafting machine is consisted of stick cutting mechanism and wrapping mechanism.

The cutting mechanism is pneumatic powered, 'V' shape blade for cutting the scion into wedge shape from both sides at bottom end. The cutting mechanism consisted of pneumatic cylinder, polyurethane tube, blade holder, pedal control lever, cutting base, the base for rootstock bag during rootstock cutting, and air filter regulator. The air compressor was used to provide the compressed air to pneumatic system. The cutting mechanism was designed by considering maximum cutting force required to cut the stick which is determined as 300 N.

The wrapping mechanism was developed for wrapping the graft union with grafting tape. The wrapping mechanism consisted of slider mechanism platform, power transmission, 24 V DC motor, stick supporting block and grafting tape holder. The wrapping secures air tight space inside the wrap due to tight wrapping with stretchable grafting tape. The wrapping mechanism was operated at three different rotational speeds (40, 50 and 60 rpm) with the help of DC power source. The grafting tape is rotated around the center of driven wheel which wraps the graft union and the operator pushes back a slider mechanism platform continuously during the wrapping. The extra stick than joining area of graft union is wrapped for moisture proofing the grafted joint.

Performance was evaluated of cutting mechanism for scion cutting with three level stick parameters, moisture content (62 %, 67 % and 72 %), diameter (5 mm, 8 mm and 10 mm), operating air pressure (5, 6 and 7 kg/cm²) on scion cutting success rate (%), scion cutting capacity (no./h) and energy consumption (kWh). The performance evaluation of cutting mechanism for rootstock cutting with three level independent parameter moisture content (65 %, 75 % and 85 %), diameter (3 mm, 6 mm and 9 mm), age of rootstock (90, 150, 240 days) and dependent parameter, rootstock cutting success rate (%), rootstock cutting capacity (no./h) and energy consumption (kWh). The scion cutting success rate was maximum for scion of 6 mm – 8 mm diameter at high operating pressure between 6 to 7 kg/cm². The scion cutting capacity increases with increase in operating air pressure and was found maximum for 5 – 6 mm at 72 % moisture content. The maximum cutting capacity was found to be 900/h for scion 5 mm and 8 mm at operating air pressure of 7 kg/cm². The maximum energy consumption was found to be 0.84 kWh for 11 mm diameter scion at operating air pressure of 7 kg/cm². The rootstocks of age 5 months and 8 months were observed better for cutting success rate. The maximum rootstock cutting success rate was found to be 80 % for rootstock of age 150 days and diameter 6 mm at operating air pressure of 6 kg/cm². The maximum rootstock cutting capacity of 514/h for rootstock of age 150 days of diameter 9 mm at 7 kg/cm² operating air pressure.

The performance of wrapping mechanism in lab condition was also evaluated. Performance evaluated with three level independent parameters moisture content (65, 75 and 85 %), diameter of stick (3, 6.5 and 10 mm), age of rootstock (90, 150 and 240 days), operating rotational speed (40, 50 and 60 rpm), using dependent parameter wrapping success rate (%), wrapping capacity (no./h) and energy consumption (kWh). It was observed that, the wrapping success rate increases with increase in diameter of stick and decrease in operating rotational speed. The maximum wrapping success rate was found to be 95 % at lower operating rotational speed of 40 rpm for rootstock of age 240 days. The wrapping capacity increases with increase in operating rotational speed. The maximum wrapping capacity was found to be 186/h at rotational speed of 60 rpm. The maximum energy consumption was 0.027 kWh for wrapping of 3 mm diameter stick of age 240 days at operating rotational speed of 60 rpm.

The field performance of developed bench grafting tool was evaluated using moisture content of stick (65 %, 75 % and 85%), diameter of stick (3 mm, 6.5 mm and 10 mm), age of rootstock (90, 150 and 240 days), for success of grafting(%) and grafting capacity (n / h). The success of grafting of developed bench grafting tool was found 60 % – 80 %. The grafting capacity of developed machine was found 85 to 110 grafts/h. The numerical optimization of parameters

done using RSM technique of 'Design Expert 13' software. The cost economics of developed bench grafting tool was also done as compared to traditional method.

Based on results of developed bench grafting tool for cashew nut softwood grafting, following conclusions were drawn from the study,

Conclusions

1. The success of grafting was found 60 – 80 % for grafting by skilled labour using existing grafting technique.
2. The mean diameter of scion for three different size groups were found to be 6, 8 and 10 mm and for rootstock of age 90 days and 240 days was found to be (4, 6 and 8 mm) and (6, 8 and 10 mm) respectively. The moisture content of scion were found to be 58.13 to 82.58 % and for rootstock were found to be 67.08 to 90.09 %.
3. The maximum cutting strength of scion and rootstock was found to be 7.06 N/mm² and 6.53 N/mm² respectively. The maximum hardness of scion and rootstock was found to be 51.38 N/mm² and 33.24 N/mm² respectively.
4. The maximum cutting force for scion and rootstock cutting was found to be 287.84 N.
5. The maximum cutting success rate of scion and rootstock was found to be 85 % and 80 % respectively with 0.844 kWh energy consumption of cutting mechanism.
6. The maximum wrapping success rate was found to be 95 % at 40 rpm operating rotational speed. The maximum wrapping capacity was found to be 186/h at 60 rpm operating rotational speed with 0.0222 kWh energy consumption.
7. The success of grafting increases with increase in operating air pressure of cutting mechanism and decrease in operating rotational speed of wrapping mechanism. The success of grafting using developed bench grafting tool was found to be 60 – 80 % with grafting capacity 83 - 110 grafts/h.
8. The cost of operation of bench grafting tool is Rs. 85.14/h. The developed bench grafting tool saves 45 % time and 25 % cost as compared to manual method.

Thus, the developed bench grafting tool was found effective for 'V' shape scion cutting and wrapping of graft union for Cashew softwood grafting in konkan region. The performance of the developed bench grafting tool was found satisfactory for cutting selectively classified sticks into three classes according to diameter and using three different blades for cutting as per class.

Suggestions:

The following suggestions are given for further research related to present study.

1. The different shape of the scion and rootstock cutting blade like 'U' and 'Ω' shape may be used for cutting mechanism.
2. The tool needs testing with different grafting tape for wrapping mechanism.
3. The transport wheel for portability may be provided.
4. The other system for powering cutting mechanism instead of pneumatic system may be used

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APPENDICES

APPENDIX A

Size of the scion and rootstocks

Table A-1 Diameter of scion of Vengurla – 4 variety of Cashew

Sr.No.	Diameter class 1, mm	Diameter class 2, mm	Diameter class 3, mm
1	4.1	7.6	8.5
2	4.3	7.6	8.5
3	4.6	7.6	8.5
4	4.8	7.8	8.6
5	5	7.8	8.6
6	5.2	7.8	8.6
7	5.5	7.9	8.7
8	5.8	7.9	8.7
9	5.9	7.9	8.7
10	5.9	8	8.8
11	6	8	8.8
12	6	8	8.8
13	6	8.1	9.3
14	6.1	8.1	9.3
15	6.1	8.1	9.3
16	6.2	8.2	9.6
17	6.4	8.2	9.6
18	6.4	8.2	9.6
19	6.5	8.2	10
20	6.6	8.2	10
21	6.7	8.2	10
22	6.7	8.3	10.2
23	6.7	8.3	10.2
24	6.8	8.3	10.2
25	6.8	8.4	10.5
26	6.8	8.4	10.5
27	6.9	8.4	10.5
Mean	6 mm	8 mm	10 mm
Max.	6.9 mm	8.40 mm	10.50 mm
Std. Deviation	0.81	0.25	0.72

Table A-2 Diameter of rootstock of age A1 (90 days) of Vengurla – 1 variety of Cashew

Sr.No.	Diameter class 1, mm		Diameter class 2, mm	Diameter class 3, mm
1	3.5		5	7
2	3.7		5.3	7.4
3	3.8		5.7	7.6
4	3.9		5.9	7.9
5	4		6	8
6	4.1		6	8.1
7	4.3		6.1	8.2
8	4.5		6.3	8.4
9	4.7		6.4	8.5
10	4.8		6.7	8.5
Mean	4 mm		6 mm	8 mm
Max.	4.80 mm		6.70 mm	8.50 mm
Std. Deviation	0.43		0.51	0.50

Table A-3 Diameter of rootstock of age A2 (240 days) of Vengurla – 1 variety of Cashew

Sr.No.	Diameter class 1, mm		Diameter class 2, mm	Diameter class 3, mm
1	5.7		6.6	8.5
2	5.8		6.7	9.5
3	5.9		6.9	9.8
4	6		7	10
5	6		8	10
6	6		8	10.1
7	6.1		8.2	10.3
8	6.2		8.3	10.3
9	6.4		8.4	10.4
10	6.4		8.5	10.5
Mean	6 mm		8 mm	10 mm
Max.	6.40 mm		8.50 mm	10.50 mm
Std. Deviation	0.23		0.76	0.59

APPENDIX B

Moisture content of the scion and rootstock

Table B-1 Moisture content of scion of three different diameter class (6 mm, 8 mm and 10 mm) of Vengurla - 4 variety of cashew

Sr.No.	Moisture Content for D ₁ , %	Moisture Content for D ₂ , %	Moisture Content for D ₃ , %
1	70.29	70.94	64.83
2	68.45	69.14	62.66
3	66.50	67.23	60.35
4	68.27	66.97	62.86
5	66.31	64.93	60.57
6	64.22	62.76	58.13
7	66.76	68.28	63.71
8	64.71	66.32	61.46
9	62.52	64.23	59.08
10	82.58	68.87	64.83
11	81.50	66.94	62.66
12	80.36	64.90	60.35
13	67.68	68.36	65.32
14	65.68	66.41	63.17
15	63.56	64.33	60.90
16	70.83	73.54	66.71
17	69.03	71.91	64.65
18	67.11	70.17	62.47
19	70.19	64.25	63.13
20	68.34	62.04	60.85
21	66.39	59.69	58.43
22	68.55	65.32	73.52
23	66.60	63.18	71.88
24	64.53	60.90	70.15
25	71.05	65.20	67.52
26	69.26	63.04	65.51
27	67.36	60.76	63.38
Mean	68.84 %	65.95 %	63.67 %
Max.	82.58 %	73.54 %	73.52 %
Std. Deviation	5.05	3.48	3.80

Table B-2 Moisture content of rootstock A1 (90 days) of three different diameter class (4 mm, 6 mm and 8 mm) of Vengurla - 1 variety of cashew

Sr.No.	Moisture Content for R ₁ , %	Moisture Content for R ₂ , %	Moisture Content for R ₃ , %
1	87.27	86.39	85.14
2	86.48	85.55	84.22
3	85.64	84.66	83.25
4	84.48	86.92	85.74
5	83.52	86.12	84.86
6	82.50	85.26	86.17
7	86.78	87.61	90.09
8	85.96	86.84	89.48
9	86.20	86.15	88.83
10	84.20	86.02	83.93
Mean	85.30 %	86.15 %	86.17 %
Max.	87.27 %	87.61 %	90.09 %
Std. Deviation	1.55	0.86	2.44

Table B-3 Moisture content of rootstock A2 (240 days) of three different diameter class (6 mm, 8 mm and 10 mm) of Vengurla - 1 variety of cashew

Sr.No.	Moisture Content for S ₁ , %	Moisture Content for S ₂ , %	Moisture Content for S ₃ , %
1	79.96	84.92	70.81
2	78.72	83.98	69.00
3	77.98	82.99	67.08
4	80.98	84.37	80.72
5	79.81	81.63	79.53
6	78.56	82.38	78.26
7	76.93	78.87	76.33
8	75.50	77.56	74.40
9	73.98	76.18	73.31
10	77.41	83.41	74.87
Mean	77.98 %	81.63 %	74.44 %
Max.	80.98 %	84.92 %	80.72 %
Std. Deviation	2.13	3.04	4.50

APPENDIX C

Table C-1 Hardness of scion (Cashew Vengurla–4 variety) for three different diameter class (6 mm, 8 mm and 10mm) using Texture Analyser with 2 mm diameter probe

Sr.No.	Hardness for D ₁ class, N/mm ²	Hardness for D ₂ class, N/mm ²	Hardness for D ₃ class, N/mm ²
1	39.71	36.86	41.92
2	36.60	39.33	48.32
3	38.16	38.10	45.12
4	31.30	40.41	40.77
5	31.30	42.91	35.66
6	31.30	41.66	38.21
7	37.23	27.59	27.24
8	35.09	16.61	17.78
9	36.16	22.10	22.51
10	40.63	48.27	44.79
11	34.28	43.75	40.46
12	37.45	46.01	42.63
13	38.69	41.10	43.57
14	36.68	40.45	41.38
15	37.68	40.77	42.47
16	38.05	40.08	42.04
17	39.67	36.20	41.30
18	38.86	38.14	41.67
19	29.99	35.16	43.57
20	28.52	47.90	40.46
21	29.26	41.53	38.21
22	30.89	39.52	40.71
23	35.06	42.51	34.50
24	32.97	41.02	37.61
25	39.10	43.38	41.54
26	38.89	33.58	51.83
27	39.00	38.48	46.68
Mean Force	35.65 N/mm ²	38.65 N/mm ²	38.14 N/mm ²
Max. Force	40.63 N/mm ²	48.27 N/mm ²	40.63 N/mm ²
Std. Deviation	3.66	7.03	7.29

Table C-2 Hardness of rootstock of age A1 (90 days) Cashew Vengurla-1 variety for three different diameter class (4 mm, 6 mm and 8 mm) using Texture Analyser with 2 mm diameter probe

Sr.No.	Hardness for R ₁ class, N/mm ²	Hardness for R ₂ class, N/mm ²	Hardness for R ₃ class, N/mm ²
1	6.25	10.16	10.34
2	8.30	10.57	15.27
3	10.83	11.45	14.48
4	8.65	8.74	14.17
5	9.99	9.97	11.39
6	11.82	11.68	13.14
7	13.23	11.81	15.36
8	20.90	8.10	4.34
9	20.41	9.71	2.93
10	21.88	4.87	2.01
Mean Force	13.23 N/mm ²	9.71 N/mm ²	10.34 N/mm ²
Max. Force	21.88 N/mm ²	11.81 N/mm ²	15.36 N/mm ²
Std. Deviation	5.75	2.09	5.28

Table C-3 Hardness of rootstock of age A2 (240 days) Cashew Vengurla-1 variety for three different diameter class (6 mm, 8 mm and 10 mm) using Texture Analyser with 2 mm diameter probe

Sr.No.	Hardness for S ₁ class, N/mm ²	Hardness for S ₂ class, N/mm ²	Hardness for S ₃ class, N/mm ²
1	25.84	19.61	26.44
2	26.60	19.68	29.60
3	27.84	20.80	22.61
4	20.78	16.17	17.14
5	23.12	10.84	17.34
6	26.55	5.99	18.02
7	21.35	26.18	22.40
8	18.87	27.76	20.40
9	16.86	29.82	18.89
10	23.42	19.97	33.24
Mean Force	23.12 N/mm ²	19.68 N/mm ²	22.61 N/mm ²
Max. Force	27.84 N/mm ²	29.82 N/mm ²	33.25 N/mm ²
Std. Deviation	3.64	7.38	5.52

Appendix D

Table D-1 Cutting strength of scion (Cashew Vengurla-4 variety) for three different diameter class (6 mm, 8 mm and 10mm) using Texture Analyser

Sr.No.	Cutting strength for D ₁ class, N/mm ²	Cutting strength for D ₂ class, N/mm ²	Cutting strength for D ₃ class, N/mm ²
1	7.06	4.35	4.16
2	6.67	4.52	4.51
3	6.87	4.44	4.34
4	4.45	4.14	3.90
5	4.45	4.30	3.62
6	4.45	4.22	3.76
7	5.95	4.48	4.33
8	5.71	3.77	3.83
9	5.83	4.12	4.08
10	6.84	4.96	4.25
11	6.13	4.68	4.02
12	6.49	4.82	4.14
13	6.08	4.14	3.79
14	5.87	4.10	3.69
15	5.98	4.12	3.74
16	4.58	3.87	3.18
17	4.74	3.64	3.15
18	4.66	3.75	3.17
19	5.21	3.41	3.67
20	5.08	4.17	3.45
21	5.14	3.79	3.56
22	4.20	4.34	2.96
23	4.56	4.51	2.72
24	4.38	4.43	2.84
25	5.64	4.04	2.62
26	5.62	3.48	3.00
27	5.63	3.76	2.81
Mean Force	5.49 N/mm ²	4.16 N/mm ²	3.60 N/mm ²
Max. Force	7.06 N/mm ²	4.96 N/mm ²	4.51 N/mm ²
Std. Deviation	0.87	0.39	0.55

Table D-2 Cutting strength of rootstock of age A1 (90 days) Cashew Vengurla-1 variety) for three different diameter class (4 mm, 6 mm and 8 mm) using Texture Analyser

Sr.No.	Cutting strength for R ₁ class, N/mm ²	Cutting strength for R ₂ class, N/mm ²	Cutting strength for R ₃ class, N/mm ²
1	6.44	4.56	1.90
2	7.77	4.62	2.29
3	6.84	4.69	2.68
4	7.72	4.39	4.01
5	8.38	4.87	4.03
6	9.04	4.01	3.15
7	8.89	3.45	3.34
8	8.29	3.68	3.13
9	7.70	3.92	2.93
10	6.64	5.72	4.05
Mean Force	7.77 N/mm ²	4.39 N/mm ²	3.15 N/mm ²
Max. Force	9.04 N/mm ²	5.72 N/mm ²	4.05 N/mm ²
Std. Deviation	0.96	0.70	0.79

Table D-3 Cutting strength of rootstock of age A2 (240 days) Cashew Vengurla-1 variety) for three different diameter class (6 mm, 8 mm and 10 mm) using Texture Analyser

Sr.No.	Cutting strength for S ₁ class, N/mm ²	Cutting strength for S ₂ class, N/mm ²	Cutting strength for S ₃ class, N/mm ²
1	5.57	3.87	4.24
2	6.52	3.79	4.18
3	6.54	3.61	3.33
4	4.99	3.89	2.49
5	5.14	3.99	2.60
6	5.29	3.83	2.71
7	5.37	4.03	3.28
8	5.09	3.74	3.20
9	4.69	3.46	3.11
10	6.50	4.09	4.13
Mean Force	5.57 N/mm ²	3.83 N/mm ²	3.33 N/mm ²
Max. Force	6.54 N/mm ²	4.09 N/mm ²	4.24 N/mm ²
Std. Deviation	0.74	0.20	0.70

APPENDIX – E

Table E-1 Manual speed of rotation of grafting tape for wrapping of softwood graft union by skilled labour

Sr. No.	Skilled labour (Grafter)	Wrapping rotational speed, rpm
1	Grafter 1	35
2	Grafter 2	40
3	Grafter 3	38
4	Grafter 4	43
5	Grafter 5	41
6	Grafter 6	39
7	Grafter 7	42
8	Grafter 8	40
9	Grafter 9	42
10	Grafter 10	36
Mean		39.6 ~ 40 rpm

Table F-1 Peak cutting Force for cutting of scion (Vengurla – 4 variety) for three different diameter (6 mm, 8 mm and 10 mm) using Texture Analysis

Sr.No.	Peak Cutting Force for D ₁ class, N	Peak Cutting Force for D ₂ class, N	Peak Cutting Force for D ₃ class, N
1	173.89	197.34	235.89
2	164.12	205.09	255.98
3	169.01	201.21	245.94
4	121.62	197.69	226.40
5	121.62	205.55	210.34
6	121.62	201.62	218.37
7	162.65	219.31	257.40
8	155.94	184.86	227.69
9	159.29	202.09	242.55
10	193.28	249.17	258.19
11	173.34	234.99	244.60
12	183.31	242.08	251.40
13	183.54	213.48	257.49
14	177.21	211.42	250.62
15	180.37	212.45	254.05
16	151.98	204.26	230.42
17	157.09	192.08	228.10
18	154.53	198.17	229.26
19	178.16	179.91	287.84
20	173.54	219.91	270.95
21	175.85	199.91	279.39
22	152.55	234.66	241.49
23	165.62	244.04	221.98
24	159.08	239.35	231.74
25	204.63	223.72	227.09
26	203.98	192.94	259.40
27	204.30	208.33	243.24
Mean Force	167.49 N	211.69 N	243.99 N
Max. Force	204.63 N	249.17 N	287.84 N
Std. Deviation	22.50	18.73	18.67

Table F-2 Peak cutting force for cutting of rootstock (Vengurla – 1 variety and age 90 days) for three different diameter (4 mm, 6 mm and 8 mm) using Texture Analysis

Sr.No.	Peak Cutting Force for R ₁ class, N	Peak Cutting Force for R ₂ class, N	Peak Cutting Force for R ₃ class, N
1	76.90	82.54	48.44
2	79.28	85.78	58.37
3	81.67	84.75	68.30
4	96.90	112.25	113.22
5	97.98	95.51	113.86
6	113.51	78.76	114.50
7	117.26	73.24	100.85
8	109.46	78.20	94.57
9	101.65	83.15	88.93
10	105.21	83.64	88.29
Mean Force	97.98 N	85.78 N	88.93 N
Max. Force	117.26 N	112.24 N	114.49 N
Std. Deviation	14.42	10.97	23.66

Table F-3 Peak cutting force for cutting of rootstock (Vengurla – 1 variety and age 240 days) for three different diameter (6 mm, 8 mm and 10 mm) using Texture Analysis

Sr.No.	Peak Cutting Force for S ₁ class, N	Peak Cutting Force for S ₂ class, N	Peak Cutting Force for S ₃ class, N
1	165.82	132.27	182.37
2	172.26	133.53	158.35
3	178.71	134.80	177.39
4	140.98	146.40	125.06
5	145.19	153.42	130.54
6	149.41	157.26	136.02
7	157.06	163.90	169.04
8	153.72	152.25	164.62
9	150.65	140.61	160.20
10	156.78	149.57	179.88
Mean Force	157.06 N	146.40 N	158.35 N
Max. Force	178.71 N	163.90 N	182.37 N
Std. Deviation	11.96	10.81	20.92

APPENDIX G

Motor speed at different voltage supply using DC power supply unit

Table G-1 Rotational speed of motor shaft at different voltage supply to DC motor using DC power supply unit

Sr.No.	Voltage, V	Current, A	Speed, rpm
1	24 V	0.72	152
2	21 V	0.73	128
3	18 V	0.73	103
4	12 V	0.75	64
5	9 V	0.75	51

Table G-2 Rotational speed of driven wheel at different voltage supply to DC motor using DC power supply unit

Sr.No.	Voltage, V	Current, A	Speed, rpm	Energy consumption, kWh
1	24	1.11	60	0.0266
2	21	1.19	50	0.0250
3	18	1.24	40	0.0223

APPENDIX H

I. Cost estimation of developed bench grafting tool for cashew grating.

Table H-1 Cost of material required for fabrication of bench grafting tool

Sr.No.	Particular	Material and specification	Qty.	Rate, Rs	Amount Rs.
1	Pneumatic Cylinder	Pressed die cast Aluminium	01	1278	1278
2	5/2 Lever Valve	¼”	01	500	500
3	Polyurethrene Tube	8 × 6 mm	10 m	48	480
4	Air Filter Regulator		01	900	900
5	Straight Fitting	¼”, 1/8”	08	42.50	340
6	Gear	135 mm, 50 mm, pitch 15 mm	02	200	400
7	Cutting stand	MS Square pipe 30 mm, 2100 mm length	3.7 kg	75	276
8	Base frame	MS square pipe MS channel	10.879 kg	75	816
9	Flat for mounting	12 × 150 ×120 mm, 80 × 80 mm, 60 × 120 mm (2)	2 kg	60	120
10	Slider	Cold rolled steel, 250mm	01	150	150
11	DC Motor	24 V DC gear motor	01	1500	1500
12	Miscillaneous	Wooden block, nylon block, nut bolt, blades	-	-	1000
13	Fabrication cost				2500
Total material cost, Rs					10260

II. Cost of operation of developed bench grafting tool**A. Fixed cost**

$$1. \text{ Depreciation /h} = \frac{C-S}{L \times H}$$

$$= (10260 - 1026) / (10 \times 400)$$

$$= \text{Rs. } 2.31/\text{h}$$

$$2. \text{ Interest /h @10 \%} = \frac{C + S}{2} \times \frac{i}{100 \times H}$$

$$= \frac{10260 + 1026}{2} \times \frac{10}{100 \times 400}$$

$$= \text{Rs. } 1.41/\text{h}$$

3. Housing cost, Insurance cost, Taxes @ 3.5 % of the initial cost

$$\text{Housing cost /h} = \frac{10260 \times 0.035}{400}$$

$$= \text{Rs. } 0.9/\text{h}$$

$$\text{Total fixed cost} = 2.31 + 1.41 + 0.9$$

$$= 4.62/\text{h}$$

B. Operating cost

$$1. \text{ Electricity cost /h} = \text{Energy consumption (kWh)} \times \text{Rs / kWh}$$

$$= 0.847 \times 5$$

$$= \text{Rs. } 4.24/\text{h}$$

$$2. \text{ Repair and maintenance cost @ 5 \%} = \frac{10260 \times 5}{100 \times 400}$$

$$= \text{Rs. } 1.28$$

$$3. \text{ Wages of operator / h @300 /day} \quad \dots (2 \text{ operator})$$

$$= 600/8$$

$$= \text{Rs. } 75/\text{h}$$

Total cost of operation of developed bench grafting tool per hour

$$= \text{Fixed cost} + \text{operating cost}$$

$$= 4.62 + 80.52$$

$$= \text{Rs. } 85.14/\text{h}$$

THESIS ABSTRACT

The current shortage of farm labour and unavailability of skilled grafter during grafting season has made more apparent, the need of a machine for bench grafting to eliminates the need of grafting skill improve efficiency for small scale nursery. The existing manual (hand) grafting technique was studied. The success of grafting for manual method by skilled grafter was found 60 to 80 % and time required per graft was 57.8 sec. The moisture content of scion (Vengurla - 4) of diameter 3 -12 mm was found 58.13 % to 82.58 %. The moisture content of rootstock of diameter 3 – 10 mm was found 67.08 to 90.09 %. The hardness of scion was found 16.62 to 51.83 N/mm². The hardness of rootstock was found 2.01 to 33.24 N/mm². The maximum cutting strength of scion and rootstock was found 7.06 N/mm². The bench grafting tool for softwood grafting of cashew was developed consists of cutting mechanism and wrapping mechanism. The maximum cutting success rate of scion and rootstock cutting was found to be 85 % with scion cutting capacity 818 grafts/hr and 80 % respectively, and maximum 0.844 kWh energy consumption. The maximum wrapping success rate was found to be 95 % with wrapping capacity of 145 wraps/hr at operating rotational speed 50 rpm. The success of grafting using developed bench grafting tool was found to be 60 – 80 % with grafting capacity 83 - 110 grafts/hr.

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