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RESEARCH ARTICLE

Comparative evaluation of manual and robotic grafting in brinjal (*Solanum melongena* L.)

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Abstract

The proposed research work introduces robotic and manual grafting methods of eggplant seedlings of same genetic characteristics with their keen observative comparisons for precision and optimum production. The manual and mechanical grafting process using a semi-automated ultra precision grafting robot AFGR-800CS. These experiments were conducted at NAHEP-CAAST-DFSRDA under Agri-bot division in 2021 in collaboration with College of Agriculture, Department of Horticulture, VNMKV, Parbhani (Maharashtra) for varieties of brinjal such as Krishna, Phule Arjun, Manjari Gota and Phule Harit. The purpose of the comparative evaluation is to observe an impact of automation technology in comparison with manual method for *Solanum torvum* and arranged in a CRBD (Completely Randomised Block Design). Considerable differences were identified in the experimental results for the many attributes. The lowest days for healing (4.258 days) with the highest grafting success (96.285 %) and leaf count per plant (6.503) detected in Phule Arjun joined on *Solanum torvum* using robotic grafting technique. The least days to emergent was noted for Krishna (6.705 days) attached on *Solanum torvum* through robotic technique. While, the supreme diameter of rootstock (2.898 mm) and diameter of scion (2.880 mm) noted in Phule Harit joined on *Solanum torvum* through physical grafting technique. Meaningfully, the highest height of plant (16.225 cm) and grafts per hour (689.50) were noticed in Phule Harit united on *Solanum torvum* through using robotic attaching technique. Based on the findings, it can be inferred that grafting technology shows a positive effect when *Solanum torvum* Sw. was used as rootstock.

Keywords: brinjal and manual grafting; eggplant; semi-automatic robotic grafting; *Solanum torvum*

Introduction

Solanum melongena L., (Brinjal (2n = 2x = 24)) is most extensively spread and grown species of Solanaceae. It is indigenous to India (1) and perhaps China is its secondary center of origin (2). Brinjal is called with different names as eggplant, poor man's cup and aubergine. In India, it covers an area of 0.73 MHa with production of 12.98 MMT and productivity of 19.10 t/ha (3). Eggplant rich in carbohydrates (6.4 %), fat (0.3 %), protein (1.3 %), phosphorus (0.02 %), calcium (0.02 %), iron (0.0013 %) and β-carotene (34 mg), ascorbic acid (0.9 mg) riboflavin (0.05 mg), thiamine (0.05 mg) and niacin (0.5 mg) per 100 g of fresh fruit. The brinjal fruit contains mostly water, low calories and fats, fiber, contains good amount of minerals, vitamins and rich in total water-soluble sugars, free reducing sugars, amide proteins among other nutrients (4). It is a highly productive crop with high nutritional value, used in pickle making and dehydration industries as a raw material and has many medicinal properties, beneficial for diabetic patients (5).

Climate change is the very important global constraint on plant growth and productivity. Numerous attempts have been made to improve brinjal production through breeding, biotechnological and other agronomical practices to face the climate change consequences (6). However, the success rate was less due to physiological and hereditary complexity of the traits (7). Therefore, it is very true in developing or accepting new methodologies for various stress environments. Garden egg is a moderately sensitive plant; consequently, more care is mandatory in its production. By using elite rootstocks in grafting can achieve sustainable vegetable production (8). This technology has been used to obtain plants with higher fruit yield and quality due to which this has gained popularity in many countries (9). It has been mainly used in Cucurbitaceae and Solanaceae families to defeat various stress conditions (10). It is best substitute to biotechnological and breeding approaches to speedily increase stress endurance in vegetable crops (11). Moreover, it is an ecologically friendly, sustainable and effective technique to enhance the performance of well-known cultivars (12). The most commonly, widely used rootstocks for brinjal grafting is *Solanum torvum* and *Solanum xanthocarpum* (13). However, the different graft combinations using different species of Solanaceae may impact the production by reason of interactive influence of scion and rootstocks on assimilate segmentation and nutrient uptake (14). Grafting vegetable crops is a simple procedure of multiplication where, preferred rootstocks are used to increase vigour, production, precocity, yield, quality and better survival ability, especially in intensive high input cropping systems under wide range of stress conditions. Grafts have been used to bring resistance in contrast to low (15) and high (16) temperature, in contrast to iron chlorosis in calcareous soils to improve water and nutrient uptake (17), to enhance biosynthesis of endogenous hormones (18), to progress water use efficiency (19), decrease uptake of persistent organic toxins from agricultural soil, enhance alkalinity tolerance, increase salt tolerance, bound the undesirable effect of heavy metal toxicity, extend the period of harvest time and enhance the fruit quality (20, 21).

For associates of the Solanaceae, the first grafting in eggplant was done on scarlet eggplant (*Solanum integrifolium* Poir.) in the late 1950's (22). In 1990, several agricultural machine industries were invented semi or fully automated grafting robots (23). First in the Japan in the 1980s research was began on grafting robots (24). Vegetable grafting has been amended over the last two decades, because of the implementation of new practices and materials. Grafting has limited facilities, laborious, requires time, space, materials, distribution prices and legal issues allied with contracting for grafted plant distribution have caused sluggish receipt of this choice (25). To overcome problems in manual grafting the substitute approach of robotic grafting bounces improved results in the form of decrease of higher worth of grafted seedlings (26). The absence of suppleness of the existing robots also restricts their extensive use (27).

Each grafting machine has different modes of operations, the more automatic the more expensive (26). Therefore, grafting farm needs to consider grafting machines price, grafting successful rate, working efficiency as well as their industrial scale and other factors in selecting the appropriate grafting machine. Keeping the research and development work for grafting machines is still a necessary endeavour in the future. By using the most sophisticated machine, grafting efficacy could be significantly amplified to two to three folds than the manual grafting (26). So, there is a much need to adopt robotic technology to supply large quantity of high-quality grafted seedlings to the farmers. This approach has the potential to improve the status of grafting as an alternative technique in the future, with numerous opportunities for further scientific advancement.

Recently, the use of grafting has been increasingly popular in Solanaceae crops such as brinjal, however, few recent reviews have been conducted on robotic grafting applications under commercial or nursery-scale conditions. More recent research has employed AI and machine vision-based systems to graft robot that achieve above 90% grafting success with the speed more than 700 grafts/hr (28, 29). These systems reduce the labor and manual work, rely on precision and contribute to reducing the variability between grafted seedlings. Additionally, the utilization of robotic grafting fits into smart agriculture procedures, such as IoT monitoring and data-driven nursery work. Some economic studies have predicted the benefits to be had from cutting down on labour and increasing the product flow, while on an environmental level the extraction of less waste and better energy use would be made possible (30). Nevertheless, similar technological comparisons in brinjal are limited, particularly under different stress conditions and scion-rootstock combinations. Therefore, this study aims to bridge this gap by evaluating the physiological, economic and operational performance of manual versus robotic grafting in brinjal, offering insights for future commercialization and automation in vegetable seedling production.

Materials and Methods

The examination was undertaken at the College of Agriculture, Department of Horticulture, VNMKV, Parbhani (Maharashtra) in collaboration with NAHEP-CAAST-DFSRDA under Agri-bot division in 2021. The investigational material for the existing study contained of *Solanum torvum* Swartz (Turkey Berry) (wild rootstock) and varieties/hybrids (Phule Arjun, Krishna, Phule Harit and Manjari Gota) were adopted and released at AICRP on vegetable crops (All India Co-ordinated Research Project), MPKV, Rahuri for the Maharashtra region, which were chosen as scions. *Solanum torvum* Swartz, an extremely vigorous wild species of eggplant that is commonly used as a rootstock for grafting, because it has proved to be tolerant for various stress conditions in the field. The characteristic features of rootstock and scion used in the investigation are mentioned in Table 1.

Solanum torvum seeds were extracted from fully matured and ripened fruits. Seeds were washed and cleaned to remove the adhering pulp and placed in vessel containing water. The floated seeds were discarded, while the sunken seeds were used. To address the issue of uneven germination, selected *Solanum torvum* seeds were soaked overnight in a 1000 ppm GA_3 solution before being used to raise rootstock seedlings. Seeds of rootstock were sown in January 2021 which was one month before the scion seeds. The well know varieties/cultivars of brinjal (Phule Arjun, Krishna, Phule Harit and Manjari Gota) (Fig. 1) sown in the month of February 2021 which was thirty days later drilling of seeds of rootstock to match with breadth of scion and rootstock. Together scion and rootstock seeds were sown in 60 celled portrays holding sterilized vermicompost and cocopeat in 1:3 ratio and watered frequently. Portrays remained protected with polythene sheet used for 96 hrs afterward sowing for quick and uniform germination. After four days of sowing, emergence of seedlings was observed and kept under a shade net. To obtain quality seedlings, seedlings were fertigated once a week with water soluble 19:19:19 NPK (5 g/L). Seedlings of rootstock were ready for grafting at two months after sowing, while scion seedlings took 30 to 35 days to attain desirable thickness. Grafting was done when scion as well as rootstock attained 3 to 4 true leaf stage. Upon grafting eight treatments comprising of four varieties joined on *Solanum torvum* by robotic technique and other four attached by manually were composed in a CRBD with thrice replicated in which twenty portrays were taken per treatment.

Table 1. Characteristic features of planting material used in the experiment

Rootstock	
Solanum torvum Swartz	It is a multi-branched, evergreen shrub with a maximum height of 4.8 m. (Fig. 1a)
Scions	
Phule Arjun (F_1 Hybrid)	Fruit is green with purple and white stripes, oval shape, tender and spiny and weighs about 60 g on average. (Fig. 1b)
Phule Harit	Fruit is pale green with white stripes at the tip, tender and less spiny and weighs approximately 190 g on average, making it ideal for roasting (Bharta). (Fig. 1c)
Krishna (F_1 Hybrid)	Plants are hardy and resistant to lodging, fruits are born solitary with spines on the pedicel, are egg shaped and are purple with white stripes (Fig. 1d)
Manjari Gota	Plants are medium in height and spread. Spines are observed on leaves, midribs and pedicel of fruits and round purple with white stripes (Fig. 1e)

Fig. 1. Planting material used in the experiment- (Fig. 1a) *Solanum torvum Swartz* (rootstock); (Fig. 1b) Phule Arjun (F_1 Hybrid) (Scion); (Fig. 1c) Phule Harit (Scion); (Fig. 1d) Krishna (F_1 Hybrid) (Scion); (Fig. 1e) Manjari Gota (Scion).

Manual grafting

Solanum torvum rootstock of brinjal grafted with four cultivated varieties (Phule Arjun, Krishna, Phule Harit and Manjari Gota) (Fig. 1) were through implementing cleft technique of grafting described in Fig. 2. This is the most usually used practice for Solanaceous member crops. It was done in the month of March 2021. The age of rootstock was 60 - 65 days (*i.e.* at three to four true leaf stage of seedlings), while the scion age was 30 to 35 days (*i.e.* at three to four true leaf stage). Grafting took place in the sun rise and set time under mist chambers built with 100-micron transparent polythene sheets. The process was started when stem diameters of scion and rootstock seedlings grew to 2~3 mm. Rootstock seedlings were pruned at 8-10 cm from the ground with all leaves removed from the stem. A sterilized razor blade was used to make a 1.0 to 1.5 cm depth longitudinal downward cut on the rootstock to serve as the groove into which the scion could be inserted. The scion portion was made into a tapered wedge, with two opposite surfaces and dimensions of approximately 2.0 mm in length, so that it could be exactly fitted into the cut.

Robotic grafting

The semi-automatic grafting robot was procured and installed at National Agriculture Higher Education Project, Centre of Excellence for Digital Farming Solutions, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani (Maharashtra) under Agri-bot division. This semi-automatic ultra-precision grafting robot (Model Name/No: AFGR-800CS) was developed by Helper Robotech Co. Ltd., Korea which was specially designed for the vegetable grafting of Solanaceae family to strengthen research work and teaching related to vegetable grafting. This semi-automatic grafting machine can cut scion and rootstock as well as join and fix the two plants cut surfaces to produce a complete plant by side grafting (Fig. 3).

Gripping device of rootstock and scion is to hold and take rootstock and scion apart. In the rootstock cutting device mentioned above, the bias cutting blade is used and cuts the upper part of the rootstock seedling to separate upward half of the seedling of rootstock and to slant the superior surface of rootstock in the perpendicular position and the slanted rootstock is prepared to graft on the upper part of seedling of scion. It is the task of the cutting unit for the scion to cut the scion off in its bottom area and to produce the oblique surface for the grafting. Two operators are required to operate this semi-automatic grafting machine. One is feeding the scion, while the other is feeding the rootstock. Both operators activate the process of grafting by clicking a foot pedal. Serving a robot unit third person also needs to take the grafted seedlings from the strip for settlement in the tray, which will be introduced into the healing tunnel. This semi-automatic vegetable grafting robot has the specifications shown in Table 2.

Grafted seedlings were instantly sited for ten days in mist chamber. Grafting chamber was protected for 2 days with black polythene and saplings remained positioned in dark. This process was performed to confirm high grafting achievement. Successful healing of grafts is achieved by lowered light strength, maximum air moisture content (85-95 %) and moderate temperature (25 -30 °C) for five days to permit the graft union to cure then light was slowly amplified and atmospheric moisture was lowered. The saplings then moved to the ordinary nursery (healing process) meant for 7 days, earlier planting in the field. Seedlings were hardened for 2-3 days under natural light prior to transplanting. 25 to 30 days after grafting, the plants were ready for transplanting. After successful grafting, clips were removed from the graft union.

Recording of data

10 arbitrarily chosen grafted plants from each treatment in each replication for recording the data. Days to curing were noted by take away the grafting clips after 72 hrs of grafting and average days were noted. Days to germination were visually noted every day and the count of germinated saplings was tallied and mean days were stated. The graft success rate was computed by number of plants dried to the total count of plants grafted

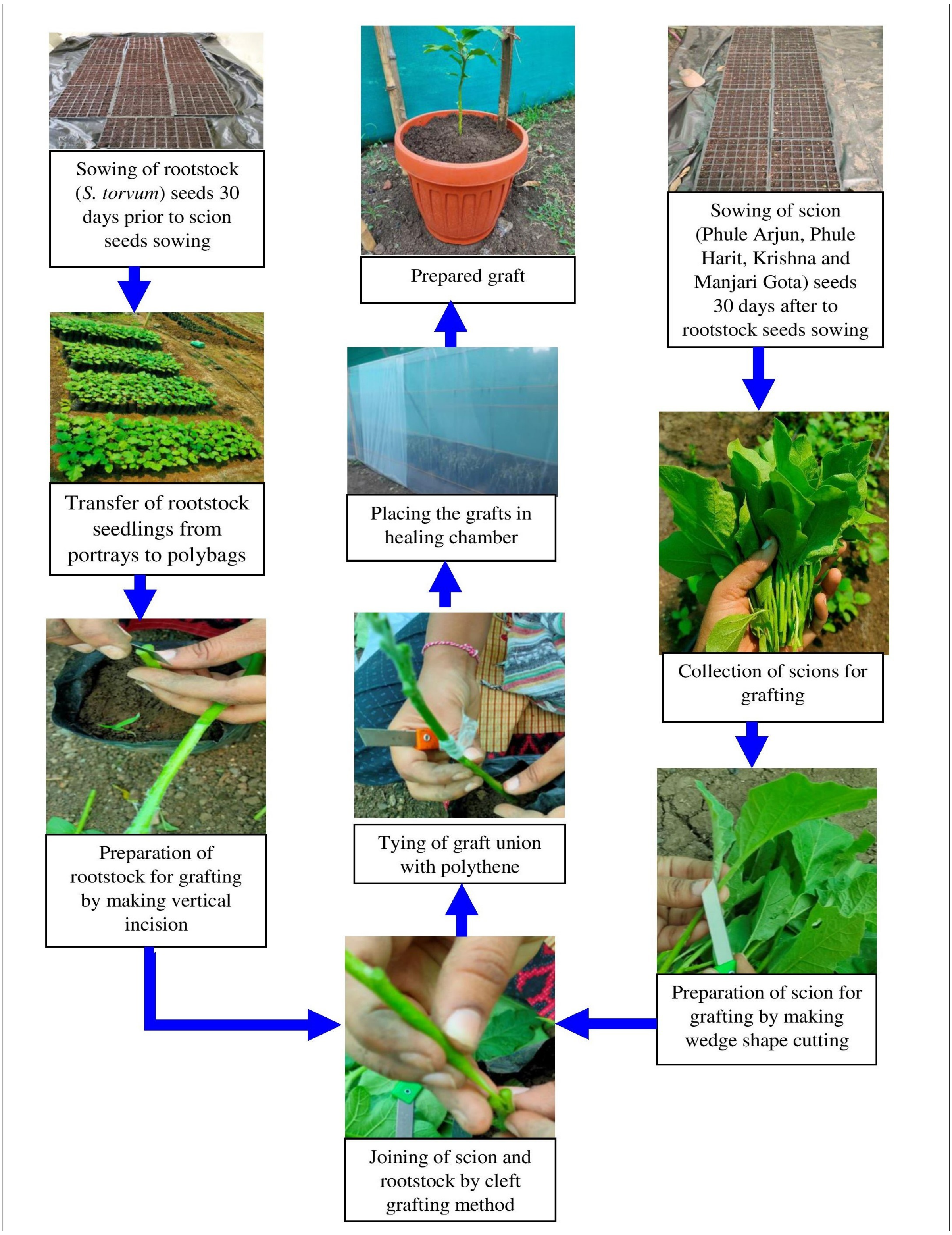

Fig. 2. Steps in manual grafting of brinjal varieties (Phule Arjun, Phule Harit, Krishna and Manjari Gota) on *Solanum torvum* rootstock.

Table 2. Specifications of semi-automatic grafting robot

S. No.	Specification	Description
1	Capacity	More than 800 plants per hr (If skillfully 800~900 plants per hr)
2	Size	1470 × 1630 × 1350 (L×W×H) mm
3	Weight	175 kg
4	Electric power supply	Grafting Robot: 1 phase, 220 VAC/110 VAC, 60 Hz/50 Hz Parts Feeder: 1 phase, 220 VAC/110 VAC, 60 Hz/50 Hz
5	Proper air pressure	5 ± 0.5 kg/cm^2 (minimize the content of water and oil)
6	Color	Helper Robotech Standard
7	Operation temperature	+5 °C~45 °C
8	Altitude (Max.)	Up to 1000 m sea level

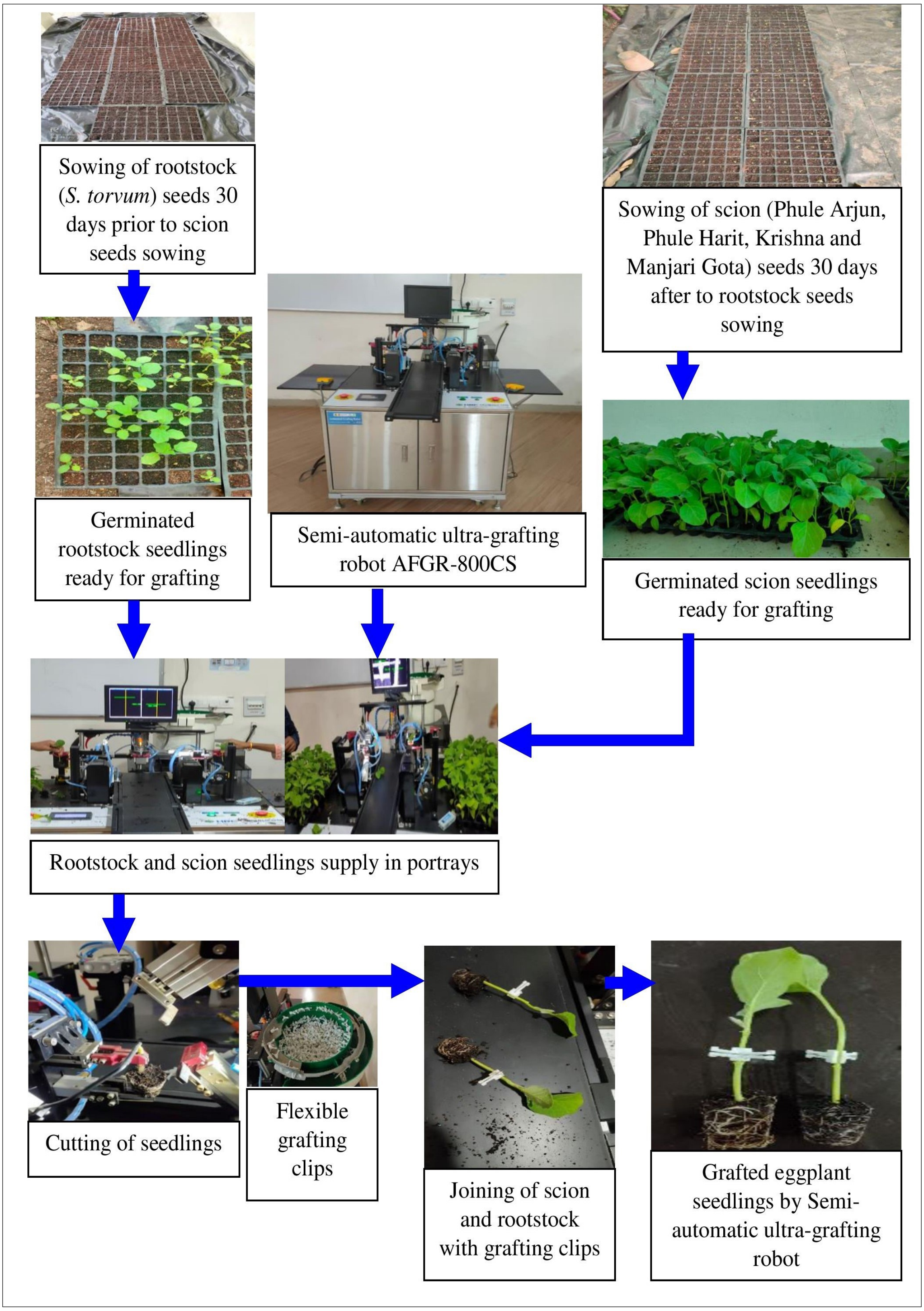

Fig. 3. Steps in robotic grafting of brinjal varieties (Phule Arjun, Phule Harit, Krishna and Manjari Gota) on *Solanum torvum* rootstock.

multiplied by hundred and written in percentage. Diameter of rootstock at 20 DAG 2 cm underneath the graft union of plant and diameter of scion at 20 DAG 2 cm above the graft union of plant were taken with digital Vernier Caliper and average was worked out and expressed in millimeter. Scion and rootstock ratio was calculated as per the values obtained from scion and rootstock by dividing scion by rootstock at 20 DAG on dry weight basis. The height of the plant at 20 DAG was measured from base of the plant to the growing tip of the plant and average was worked out, expressed in cm. A total number of leaves were recorded by counting individual leaves at 20 DAG and average was worked, expressed in numbers. Number of grafts per hour was recorded by counting the grafts prepared by manual and robotic grafting machines in 1 hr time period individually. The data gained all through experiments were examined as per the standard statistical methods (31). The S.Em. (standard error of mean) was calculated and the CD (Critical Difference) was worked out at 5 % probability level where the treatment differences were found significant after estimating the analysis of variance.

Results and Discussion

The effect of manual and robotic grafting methods on different parameters were found significant difference and furnished in Table 3 and 4 and graphically represented in Fig. 4 and 5. Significantly, the minimum days to healing were taken in Phule Arjun (4.258 days) followed by Krishna (4.365 days) and Phule Harit (4.628 days) joined on *Solanum torvum* through robotic grafting technique, whereas, the highest days to healing were taken to Manjari Gota (5.353 days) and Phule Harit (5.250 days) attached on *Solanum torvum* by manual technique (Table 3 and Fig. 4). Healing process depends on different factors during grafting, which might be type of fine cut made, environmental conditions during grafting, age of the seedlings of both scion and rootstock, microclimate conditions upon grafting and type of scion and rootstock. Quicker healing helps in better establishment of graft union. Healing process enables the formation of callus and thereby the connection between vascular systems of both scion and rootstock. The outcomes are in match with early findings in cucurbits (32). The count of days obligatory used for graft union is identified by the age of rootstock and scion in addition to the predominant atmospheric situations. Graft union took fewer days in a 20-days old scion attached to rootstock at 20 days old. The stage of growth may have been appropriate for cambium interlocking, resulting in a shorter period for graft union. Similar findings were reported in tomato with high graft success and graft healing time of five days (33). Healing could be accredited to the cambial region's quicker joining of stock and scion; it might also prompt meristematic movement through forming parenchymatic cells, which is interlock the callus tissues to fill the space among the rootstock and scion (34).

The least days to germinating were taken in Krishna (6.705 days) followed by Phule Harit (7.040 days) and Manjari Gota (7.295 days) joined on *Solanum torvum* by robotic grafting technique, while, the maximum days to germinating remained taken to Phule Arjun (8.935 days) and Phule Harit (7.793 days) attached on *Solanum torvum* via manual technique (Table 3 and Fig. 4). This study has proved the effect of different methods as well as scion and rootstock combinations yield significant differences in sprouting of grafted plants. The scions which sprouted early because of the early establishment of graft union upon vascular connection establishment. The connection between scion and rootstock was established for translocation of biochemical compounds for further growth and development.

The maximum grafting success rate was recorded in Phule Arjun (96.285 %) followed by Krishna (95.370 %) and Manjari Gota (94.260 %) attached to *Solanum torvum* through robotic grafting technique, while the minimum grafting success was recorded in Phule Harit (87.703 %) and Manjari Gota (89.983 %) joined on *Solanum torvum* by manual technique (Table 3 and Fig. 4). Grafting success is a significant concern when using novel scion-stock combinations (14). The various factors of conditions under which grafting is performed, the technique applied and the union compatibility among the scion and the rootstock, all impact the success of grafting. Other aspects such as the age of the saplings, the diameter of both the rootstock and scion, care provided later grafting and the culture and environment also have significant roles. There are also other factors such as anatomy, differences in physiology and biochemistry, plant growth stage, as well as the plant hormone's influence on graft partners that shape the outcome. Success of grafting stems from weather conditions which differ from one place to another as

Table 3. Effect of manual and robotic grafting methods on days to healing and sprouting, grafting success (%) and diameter of rootstock (mm) of brinjal varieties grafted on *Solanum torvum*

Treatments	Treatment details	Days to healing	Days to sprouting	Grafting success (%)	Diameter of rootstock (mm) 20 DAG
T_1	Phule Arjun grafted on *S. torvum* by manual method	4.855	8.935	92.345	2.623
T_2	Phule Harit grafted on *S. torvum* by manual method	5.25	7.793	87.703	2.898
T_3	Krishna grafted on *S. torvum* by manual method	5.113	7.598	91.148	2.528
T_4	Manjari Gota grafted on *S. torvum* by manual method	5.353	8.628	89.983	2.415
T_5	Phule Arjun grafted on *S. torvum* by robotic method	4.258	7.528	96.285	2.715
T_6	Phule Harit grafted on *S. torvum* by robotic method	4.628	7.04	93.533	2.893
T_7	Krishna grafted on *S. torvum* by robotic method	4.365	6.705	95.370	2.615
T_8	Manjari Gota grafted on *S. torvum* by robotic method	4.763	7.295	94.260	2.408
SE (m) ±		**0.009**	**0.017**	**0.163**	**0.008**
C.D at 5 %		**0.028**	**0.035**	**0.482**	**0.023**

DAG: Days After Grafting

Table 4. Effect of manual and robotic grafting methods on diameter of scion (mm), scion to stock ratio, plant height, number of leaves and number of grafts per hour of brinjal varieties grafted on *Solanum torvum*

Treatments	Treatment details	Diameter of scion (mm) 20 DAG	Scion to stock ratio 20 DAG	Plant height at 20 DAG	No of leaves at 20 DAG	Number of grafts per hour
T_1	Phule Arjun grafted on *S. torvum* by manual method	2.608	0.994	12.848	6.218	126.00
T_2	Phule Harit grafted on *S. torvum* by manual method	2.880	0.994	13.255	5.245	135.75
T_3	Krishna grafted on *S. torvum* by manual method	2.508	0.992	12.735	5.977	121.75
T_4	Manjari Gota grafted on *S. torvum* by manual method	2.413	0.999	12.323	5.423	120.00
T_5	Phule Arjun grafted on *S. torvum* by robotic method	2.665	0.982	15.845	6.503	680.75
T_6	Phule Harit grafted on *S. torvum* by robotic method	2.850	0.985	16.225	6.273	689.50
T_7	Krishna grafted on *S. torvum* by robotic method	2.500	0.956	13.845	6.425	650.75
T_8	Manjari Gota grafted on *S. torvum* by robotic method	2.375	0.987	13.353	6.320	654.50
SE (m) ±		**0.029**	**0.011**	**0.011**	**0.003**	**0.472**
C.D at 5 %		**0.086**	**NS**	**0.034**	**0.010**	**1.399**

DAG: Days After Grafting; NS: Non-significant at 5 % Level of significance

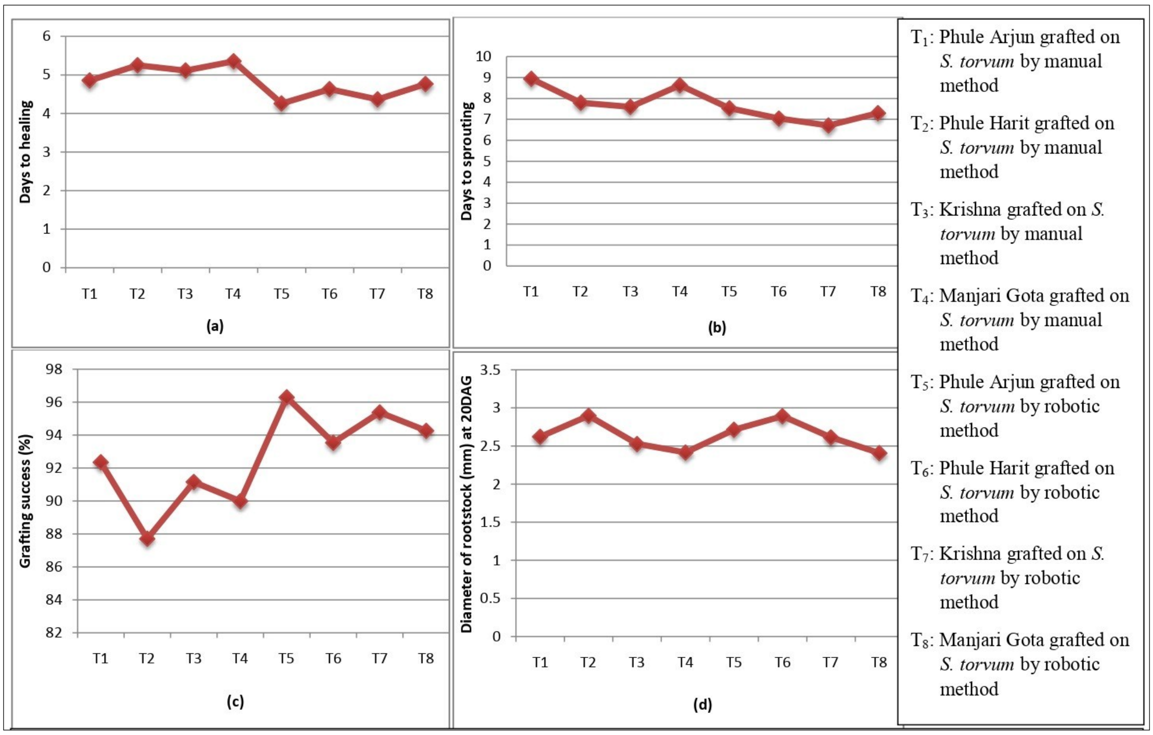

Fig. 4. Effect of manual and robotic grafting methods on days to healing (a), days to sprouting (b), grafting success (%) (c) and diameter of rootstock (mm) (d) of brinjal varieties grafted on *S. torvum.*

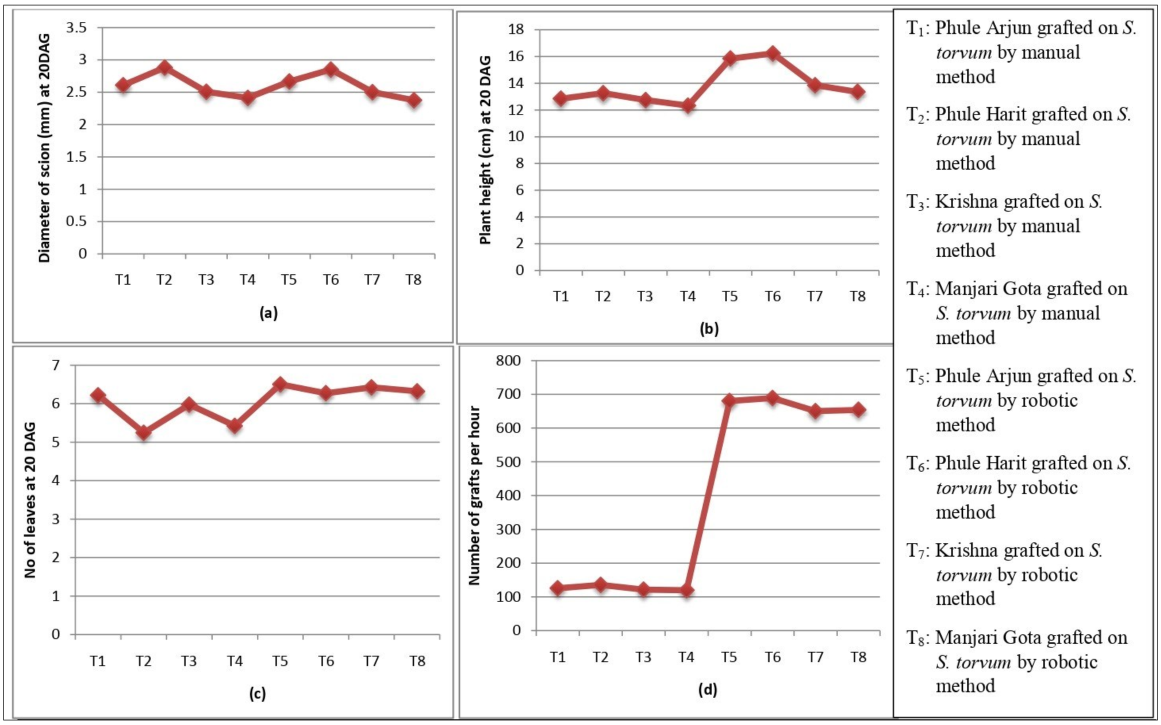

Fig. 5. Effect of manual and robotic grafting methods on diameter of scion (mm) (a), plant height (cm) (b), number of leaves (c) and number of grafts per hour (d) of brinjal varieties grafted on *S. torvum.*

well as season to season. However, temperature and humidity are observed to have a greater impact. Active cell division at the graft junction is important for successful grafting. Cell division allows the vascular tissues of the scion and rootstock to blend, followed by secondary growth that reinforces the graft. The findings are in accordance with previous works (35-38). Grafting success varied significantly on the 20DAG (Table 3 and Fig. 4). This could be because of quicker wound healing, cambium interlocking and quicker growth process at the brinjal joint. Furthermore, creating a mist chamber for a week and then exposing the brinjal grafts to light resulted in good success. The above findings are consistent with those of early results, who identified that graft success varied from 85-87 % (39), possibly for the reason that of the promising conditions on condition that in the graft chamber and who exposed that graft survival surpassed 92 % in all eighteen well know rootstocks of tomato and five scion varieties (40), with an average of 97 %. Through using cleft grafting between the graft combinations, the amount of graft success was sophisticated through *Solanum torvum* than with other rootstocks. In tomato, cleft grafting is the most effective method (41, 42). Furthermore, in eggplant (85 %), the efficacy of grafting, curative circumstance, rootstock and scion physiological and biochemical characters show a significant role (8).

Significantly, the more diameter of rootstock at 20 DAG was noted in Phule Harit jointed on *Solanum torvum* through physical technique (2.898 mm). It was statistically at par with Phule Harit attached to *Solanum torvum* through robotic technique (2.893 mm) and followed by Phule Arjun jointed on *Solanum torvum* by robotic grafting technique (2.715 mm) and Phule Arjun joined on *Solanum torvum* by manual technique (2.623 mm). However, the minimum diameter of rootstock was noted in Manjari Gota joined on *Solanum torvum* through robotic method (2.408 mm) followed through Manjari Gota attached on *Solanum torvum* through manual technique (2.415 mm) (Table 3 and Fig. 4). There was clear rise in the rootstock diameter after grafting with different scions through both the methods, but the degree of expansion indicated the ease of compatibility among scion and rootstock.

Significantly, the highest diameter of scion at 20 DAG was noted in Phule Harit joined on *Solanum torvum* through physical technique (2.880 mm). It was statistically at par with Phule Harit joined on *Solanum torvum* through robotic technique (2.850 mm) and followed by Phule Arjun joined on *Solanum torvum* by robotic technique (2.665 mm) and Phule Arjun joined on *Solanum torvum* through manual technique (2.608 mm). While the minimum diameter of scion was found in Manjari Gota attached on *Solanum torvum* by robotic technique (2.375 mm) followed by Manjari Gota attached on *Solanum torvum* through manual technique (2.413 mm) (Table 4 and Fig. 5). The more graft compatibility more was the diameter of the scion in different grafts prepared through manual as well as robotic methods. Significant results even at 20 days after grafting made it easy in judging best compatible pair of scion and rootstock.

Data regarding scion to stock ratio at 20 DAG was not significantly influenced by different grafting methods revealed significantly, the maximum plant height at 20 DAG was observed in Phule Harit (16.225 cm) followed by Phule Arjun (15.845 cm) and Krishna (13.845 cm) joined on *Solanum torvum* through robotic technique. While the minimum height of plant was recorded in Manjari Gota (12.323 cm) followed by Krishna (12.735 cm) attached on *Solanum torvum* through manual technique (Table 4 and Fig. 5). Progress in the height of the plant in grafts is comparatively less at early stage; even though there was clear evidence of significant difference between scions as well as grafting methods. These differences, reveals the compatibility relationship of scion and rootstock that establish quick and grow further.

Significantly, the highest number of leaves per plant at 20 DAG was noted in Phule Arjun (6.503) after that Krishna (6.425) and Manjari Gota (6.320) joined *Solanum torvum* by robotic technique. While the minimum number of leaves per plant were recorded in Phule Harit (5.245) and Manjari Gota (5.423) joined on *Solanum torvum* by manual technique. Upon grafting seedlings usually pause the process of regular organogenesis up to completion of the process of healing and there by re-establishment of vascular bounding between rootstock and scion (43). Probably it was the reason for lower number of leaves even after 20 days of grafting.

Significantly, the greater number of grafts per hour was got in Phule Harit (689.50) tailed by Phule Arjun (680.75) and Manjari Gota (654.50) attached on *Solanum torvum* by robotic technique. While the least number of grafts per hour was logged in Manjari Gota (120.00) followed by Krishna (121.75) joined on *Solanum torvum* through manual technique (Table 4 and Fig. 5). There was a lot of difference in the speed of grafting with respect to manual and robotic was noticed, it was because of precise control of robotic machine with respective to making cut and joining the scion and stock in a fixed interval. The work also supported the results obtained in this study (44-46).

Conclusion

Based on the findings, it can be inferred that grafting technology had a positive effect when *Solanum torvum* Sw. was used as rootstock. This experiment gives a novel method to enhance the efficiency of brinjal grafting. The quality of semi-automatic robotic grafting was superior to the manual grafting with respect to days for healing, sprouting, grafting success and efficiency, height of plant, leaves number and grafts per hour. Adoption of automated grafting robots (semi or fully) aids in the resolution of large-scale production issues and improves uniformity of high-quality mass production of grafted seedlings.

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Authors' contributions

MJ carried out all the field trials and research work and writing, GUS contributed to all manuscript revisions and provided guidance in the writing process. TBT gave guidance throughout the research, from the initial setup to data collection, analysis and organization. All authors read and approved the final manuscript.

Compliance with ethical standards

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