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Grafting of Tomato (*Solanum Lycopersicum* L.) onto Potato (*Solanum tuberosum* L.): Harvesting Double Crops from a Single Plant

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ABSTRACT

Rapid Urbanization and industrialization have been overtaking land for food production at the global level. Further, climate change has necessitated the modification of the existing food production system to adapt the changing environmental situations. Grafting is a rapid and economical solution to improving the yield in Solanaceous vegetables. In this study, the effects of grafting tomato (cv. Garv) on potato (cv. Desiree) rootstock were evaluated for yield of tomato and potato in comparison to non-grafted tomato and non-grafted potato plants. The results showed that the yield of tomato was significantly higher in non-grafted tomato (11.05 t/ha) and tomato grafted on potato with decapitation of potato shoots (4.07 t/ha) compared to that of tomato grafted on potato without decapitation of potato shoots (0.94 t/ha). On the other hand, the yields of non-grafted potato (1.44 t/ha) and tomato grafted on potato without decapitation of potato shoots (1.00 t/ha) were statistically higher than that of tomato grafted on potato with the decapitation of potato shoots. There were no statistical differences between the treatments for dry matter content and Total Soluble Solutes (TSS) of tomato and potato. The yield of tomato of the grafted pomato was negatively correlated to the yield of potato rootstock, but it was not statistically different. The data from this study suggest grafting of tomato on potato with decapitation of potato shoots is recommended for obtaining higher yield of grafted tomato and without decapitation of potato shoots for higher yield of potato from grafted plants.

Keywords; *Pomato; Grafting; Tomato; Potato; Double Crop*

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1 Introduction

Globally, land for food production has been facing intense competition from urbanization and industrialization activities. Further, climate change has necessitated the modification of an existing food production system in order to adapt to changing environmental situations. Given the limited potential for horizontal expansion of agricultural land in Bhutan, the adoption of various forms of multiple cropping is considered a highly viable strategy for crop intensification (Katwal, 2013). Grafting is a promising technique, regarded as a rapid and economical solution to improving the yield in vegetable (Kumar & Sanket, 2017). The vegetable grafting began in Japan and Korea in the late 1920s by using resistant rootstock to control soil-borne diseases in cucurbits caused by *Fusarium oxysporum* and has since expanded to include vegetables such as eggplant, tomato, chili and several other solanaceous crops (Genova, Schreinemachers, & Afari-Sefa, 2013). The use of vegetable grafting was adopted by the World Vegetable Centre (AVRDC) and is now widespread across Asia, parts of Europe and the Middle East (Genova et al., 2013). Several studies have reported that vegetable grafting can increase resistance to abiotic stresses such as drought, salinity, heat and low soil temperatures and improve water use efficiency (Genova et al., 2013; Kumar & Sanket, 2017; Parthasarathi, Ephrath, & Lazarovitch, 2021).

In a vegetable graft, the above ground part (scion) is used to produce high nutritious yield while the below ground part (rootstock) is used to tolerate soil-borne stresses. Tomato and potato hetero-grafting combines two different species of vegetables for harvesting tomato fruits and potato tubers from scion and rootstock respectively avoiding many biotic stresses. This technique is an optimal agricultural production system for increasing crop yield and utilizing natural resources effectively (Parthasarathi et al., 2021). According to Mohammed, Humidan, Boras, & Abdalla (2009), tomato production improved significantly by 21%, and fruit total soluble solids content was also increased by grafting. The present study aimed to evaluate the effects of grafting tomato on potato rootstock, fruit characteristics, days to fruit maturity of tomato, tuber characteristics in potato, yield and post-harvest quality in both the crops.

2 Materials and Methods

2.1 Treatment and Experimental design

The study was conducted under a sub-tropical agroecological region at the Agriculture Research and Development Centre (ARDC) Samtenling (26^{o} 54' 17" N, 90^{o} 25' 51" E) located at 372 meters above mean sea level during the winter-spring cropping season (November-May) 2022-2023. The experiment was conducted using Randomized Complete Block Design (RCBD) with three replications and four treatments. The treatments consisted of potato and tomato grown normally without grafting and graft combination of tomato and potato with and without decapitating the potato shoots grown from the rootstock as detailed below:

1. Treatment 1: Tomato grafted on single potato shoot (rootstock) followed by decapitation of other shoots periodically after successful graft union.
2. Treatment 2: Tomato grafted on single potato shoot (rootstock) but all other shoots from rootstock were kept without decapitation.
3. Treatment 3: Non-grafted "Garv" tomato with single shoot.
4. Treatment 4: Non-grafted potato without decapitation of any shoots arising from the rootstock.

For this experiment, F1 hybrid tomato variety "Garv" (from Seminis Seeds, India) and potato variety "Desiree" were used for graft combination of pomato. The plot size of 2 m x1.2 m was used for each replication. Ten plants were grown with the recommended spacing of 40 x 60 cm in two rows per plot and total of 30 plants were grown for each treatment in three replications.

2.2 Planting materials

The seed tubers of potatoes having individual tuber weights of 30-40 gm were planted on 12th November 2022 in a well-prepared field. Farmyard manure (FYM) at the recommended rate of 5 t/ha was applied to all the plots uniformly during field preparation. The recommended dose of fertilizer NPK (70:40:30) kg/ha was applied as per the recommendation of the National Soil Service Centre (NSSC, 2009). The tomato seeds were sown in plug trays for nursery raising inside polyhouse using well-prepared soil medium one week after the date of planting potatoes.

2.3 Grafting of tomato over potato

One-month-old tomato seedlings were grafted using the cleft grafting method on the potato rootstock in the field on 12th December 2022 as per the method described by Kumar et al.,

(2016). The grafted tomato plants were maintained without flowers up to 45 days after grafting (DAG) since these can represent a competing nutrient sink for the potato tubers. After grafting, the pomato plants were covered with fifty percent shed nets for about a week to avoid desiccation of the grafted plants. The grafting success was recorded 3 weeks after grafting by counting the number of successful graft union formations in the field.

All the plants were stalked using bamboo stalks immediately after the grafting operation. All the plots were mulched using paddy straw and irrigated at weekly intervals. The earthing up of potatoes was carried out 2 months after the planting of potatoes and all other intercultural operations were carried out as required.

2.4 Soil characteristics of the experimental field

Composite soil samples at the depth of 0-20 cm were collected from the experimental site before and after conducting the experiment and were analyzed for the soil parameters namely pH, N, P, K & Mg, and soil texture was also examined. The NPK content of the soil was tested using the Reflectoquant Nitrate Test kits (3-90 mg/l NO_3-), Potassium test kit (Kalium test, 0.25-1.2 g/l k) & P- phosphate test kit (5-120 mg/lPO_4^{3-}, P- phosphate test).

2.5 Data collection

Data were collected from all the 10 plants from each plot. The observations recorded were average number of fruits per plant, average fruit weight (g), average fruit diameter (mm), plant height (cm), yield (t/ac), dry matter content (%) and Total Soluble Solids (TSS Brix◦) of tomato and tuber growth attributes including number of tubers per plant, single tuber weight (g), width of tuber (mm), number of shoots, dry matter content (%) and TSS (Brix◦). The tomato fruits were harvested at colour breaking stage while the potato tubers were harvested later after the haulm senescence and assessed for number of tubers per clump, tuber size, weight of tuber and the yield to analyze the correlation between the tomato and potato yield in pomato. To determine the dry matter content and the TSS of tomato and potato, three fruit or tuber samples per plot were randomly selected (second harvest in tomato). TSS and dry matter content were determined using a hand-held reflectometer (Vee Gee Scientific BTX-1) and oven (Memmert Universal Oven U) respectively following the guidelines developed by the Organization for Economic Co-operation and Development (OECD, 2005; DoA, 2018).

2.6 Organoleptic test

To determine the consumers' acceptability of potato tubers, the organoleptic test was carried out by 15 randomly selected panels. Potato tubers from each treatment were randomly selected immediately after harvesting and cooked without peeling. Each panelist was provided with 2-3 potato tubers of each sample. Potato tubers were assessed for their taste, aroma, texture, peeling easiness and softness using the nine-point Hedonic scale ranging from 1 = Dislike extremely and 9 = Like extremely (Singh-Ackbarali & Maharaj, 2014). The percentage of overall acceptability was calculated using the formula mentioned below (Jayasena & Cameron, 2008).

Equation 1:

$$Percentage\ of\ overall\ acceptibility = \frac{Number\ of\ Panelist\ rated > 5}{Total\ number\ of\ panelist} * 100$$

2.7 Data analysis

The collected data were firstly entered and processed in Microsoft Excel 2007 spreadsheet. Then it was analyzed using IBM SPSS Statistics Version 22.0.0. Both descriptive and inferential statistical analyses were done using the IBM SPSS Statistics software. One-way Analysis of Variance (ANOVA), and Tukey HSD post-hoc test was performed for pair-wise comparison and the Pearson correlation coefficient test was performed to analyze the correlation between different parameters at the significance level of p=0.05.

3 Result and Discussion

3.1 Growth characteristics & tomato fruit yield of Pomato plant

The results of this study clearly indicated that the pomato plant can be successfully developed by grafting tomato scion over potato rootstock. The grafting success between the tomato and potato was recorded at 95%. The first harvest of tomato was done on 09/03/2023 (81 DAT of tomato and 117 DAS of potato) and total of seven harvests were made at the interval of 7-10 days. No significant differences were observed in the yield of tomato from the grafted pomato plant with remaining potato shoots decapitated (4.07 t/ha) and the non-grafted tomato plant (11.05 t/ha) but the tomato yield of pomato plant with non-decapitated potato shoots from the rootstock (0.94 t/ha) was significantly lower (p=0.03) as compared to the two other treatments (T1 & T3) as shown in Table 1. The average number of fruits per plant was found to be significantly higher (p=0.01) in the non-grafted tomato plant (65.40) as compared to the two other grafted pomatoes (T1 & T2). The tomato fruit diameter was found to be significantly

higher in non-decapitated grafted pomato (T2=39.25) as compared to the non-grafted tomato (T3=27.04) but there were no significant differences in fruit diameter between the two grafted pomatoes. No significant differences were observed for average fruit weight, tomato plant height, dry matter content and TSS among the treatments.

Table 1. Growth and yield characteristics of grafted and non-grafted tomato plants

Treatment	No. of fruits per plant	Average fruit wt.(g)	Average fruit diameter (mm)	Ave plant height (cm)	Yield (t/ha)	Dry matter content (%)	TSS (Brix ◦)
T1: Tomato grafted on Potato (potato shoots decapitated).	23.23 *b*	42.27	36.68 *ab*	56.77 *b*	4.07 *ab*	5.72	6.46
T2: Tomato grafted on Potato (Potato Shoots Non decapitated).	6.13 *b*	35.58	39.25 *a*	21.43 *c*	0.94 *b*	4.83	5.40
T3: Non grafted Tomato (Garv)	65.40 *a*	38.20	27.04 *b*	79.57 *a*	11.05 *a*	6.45	5.77
p-Value =0.05	0.012	0.190	0.006	<0.001	0.030	0.506	0.181
CV (%)	95.23	11.57	17.94	48.56	100.91	27.61	12.01

3.2 Growth characteristics and fruit yield of potato plant

The potato was harvested on 28/03/2023 (136 DAS) after the haulm senescence. There was a significant effect of decapitating the remaining potato shoots after grafting on the potato tuber yield. The yield of potato was significantly lower (p=0.01) in grafted pomato with remaining potato shoots decapitated (T1: 0.74 t/ha) as compared to the non-grafted potato grown (T3=1.44 t/ha) as control (Table 2). However, the potato yield of non-decapitated grafted pomato (T2=1.00 t/ha) did not have any significant differences with the two other treatments.

Table 2. Plant growth characteristics and fruit yield of potato plant in grafted potato and non-grafted potato

Treatment	No. of potato tubers/ plant	Ave. wt. of potato tuber (g)	Potato yield (t/ha)	No of potato shoots/ clump	Width of potato (mm)	Potato dry matter content (%)	TSS (Brix ◦)
T1: Tomato grafted on potato (potato shoots decapitated).	4.97	39.87	0.74 *b*	1.00 *b*	47.16	14.33	5.43
T2: Tomato grafted on potato (potato shoots Non decapitated).	4.7	48.87	1.00 *ab*	1.33 *b*	48.91	21.90	5.19
T3: Non grafted Potato (Desiree)	8.13	50.74	1.44 *a*	2.37 *a*	50.92	19.76	5.52
p-Value =0.05	0.073	0.601	0.010	0.001	0.780	0.267	0.375
CV (%)	36.56	27.41	33.02	41.66	11.79	30.38	5.31

3.3 Correlation on growth and yield of tomato and potatoes in the grafted Pomato plant

Pearson correlation coefficient was conducted among quantitative parameters (Table 3). It was observed that there was a highly significant positive correlation (r=0.950, P=0.004) between the tomato plant height and number of tomato fruits per plant. This revealed that the number of fruits increased with the increase in plant height. The yield of tomato of the grafted pomato was negatively correlated (r= -468) to the yield of potato rootstock but statistically not significant (p=0.349).

Table 3. Correlation on growth and yield of tomato and potatoes in the grafted pomato plant

Characteristics	No of tomato fruit	Tomato fruit wt. (g)	Tomato yield (kg/ac)	Tomato fruit diameter (mm)	Tomato plant height (cm)	Tomato dry matter content (%)	Tomato TSS (Brix◦)	No of potato tubers/ clump	Ave wt. of potato tuber (g)	Potato yield (kg/ac)	No of potato shoots/ clump	Width of potato (mm)	Potato dry matter content (%)	Potato TSS (Brix◦)
No of Tomato fruit	1	.931**	.994**	-.175	.950**	.535	.474	.386	-.789	-.496	-.790	-.436	-.422	.376
Tomato fruit wt (gm)	.931**	1	.934**	.106	.853*	.469	.304	.140	-.913*	-.673	-.769	-.576	-.632	.432
Tomato yield (Kg/ac)	.994**	.934**	1	-.093	.910*	.552	.386	.401	-.801	-.468	-.744	-.448	-.379	.358
Tomato fruit diameter (mm)	-.175	.106	-.093	1	-.418	-.179	-.862*	-.305	-.338	-.183	.423	-.481	-.088	-.144
Tomato Plant Height (cm)	.950**	.853*	.910*	-.418	1	.497	.711	.344	-.671	-.503	-.877*	-.319	-.509	.436
Tomato Dry matter content (%)	.535	.469	.552	-.179	.497	1	.435	.644	-.104	.269	-.417	.379	-.330	.859*
Tomato TSS (Brix◦)	.474	.304	.386	-.862*	.711	.435	1	.290	-.015	-.104	-.714	.288	-.409	.527
No of potato tubers/ clump	.386	.140	.401	-.305	.344	.644	.290	1	.072	.557	.041	.250	.166	.360
Ave Wt. of potato tuber (gm)	-.789	-.913*	-.801	-.338	-.671	-.104	-.015	.072	1	.820*	.570	.855*	.529	-.096
Potato yield (Kg/ac)	-.496	-.673	-.468	-.183	-.503	.269	-.104	.557	.820*	1	.617	.784	.574	.083
No of potato shoots/clump	-.790	-.769	-.744	.423	-.877*	-.417	-.714	.041	.570	.617	1	.173	.558	-.438
Width of potato (mm)	-.436	-.576	-.448	-.481	-.319	.379	.288	.250	.855*	.784	.173	1	.289	.335
Potato Dry matter content (%)	-.422	-.632	-.379	-.088	-.509	-.330	-.409	.166	.529	.574	.558	.289	1	-.697
Potato TSS (Brix◦)	.376	.432	.358	-.144	.436	.859*	.527	.360	-.096	.083	-.438	.335	-.697	1

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

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

3.4 Sensory evaluation of Potato tuber

The sensory evaluation test results indicated that the average overall acceptability of all three different treatments ranged from 84% to 91% which indicated higher consumer acceptance (Table 3). Comparatively, Panelist preferred T1 (tomato grafted on potato with shoots decapitated) (Average overall acceptability=91%) over T3 (average overall acceptability= 85%) and T2 (average overall acceptability= 84%). The preference of consumers against each parameter is shown in Fig. 3. The overall consumer preferences of each parameters shows that T3 is more preferred for taste/flavor, T1 for aroma/smell, T1& T2 for texture/color, T1 for softness while there are no differences in preference with regards to peeling easiness.

Table 3. Sensory evaluation of Potato tubers from three different treatments

Test Parameters	Overall acceptability percentage		
	T1: Tomato grafted on Potato (Potato shoots Decapitated)	T2: Tomato grafted on Potato (Potato shoots non-Decapitated)	T3: Non grafted Potato
Taste/Flavour	73%	67%	80%
Aroma/Smell	93%	73%	73%
Texture/Colour	87%	87%	80%
Peeling Easiness	100%	100%	100%
Softness	100%	93%	93%
Average	91%	84%	85%

3.5 Soil characteristics and macro nutrient analysis

The soil texture of the experimental site was sandy clay loam both before and after the trial. However, soil pH was 5.17 before the experiment but became slightly alkaline after the experiment (pH=6.38). The value of all macronutrients content of the soil was lower after the experiment except that of Mg as shown in Table 5.

Table 5. Soil test results indicating the level of macronutrients, and other soil characteristics of the experimental site before and after the experiment

	Soil fertility parameters					
Soil sample	pH	Avail. N (%)	Avail. P (mg/l)	Avail. K (g/L)	Mg (mg/L)	Texture
Pre-trial	5.17	0.06	42.24	6.47	0.16	Sandy clay loam
Post-trial	6.38	0.0003	<5	<0.25	<0.5	Sandy clay loam

In this study both non grafted tomato and potato produced higher yield compared to the grafted ones. The Pearson correlation coefficient analysis showed that the yield of tomato of the grafted pomato was negatively correlated to the yield of potato rootstock though not significantly different statistically. This finding contradicts with the results of (Arefin et al., 2019; Singh et al., 2020) who reported that the grafted plants produced higher fruits due to the increase in plant height of the plants, leaf number, and branch number. Plant hormones play essential roles in fruit and tuber development (Aksenova et al., 2012). Specifically, the Gibberellins (GA) and Cytokinin (CK) are the key plant hormones playing pivotal roles in controlling different aspects of plant growth and development, influencing fruit set induction in tomatoes and tuber formation in potatoes (Wang et al., 2009; Matsuo et al., 2012). A high concentration of CK is a prerequisite for healthy tuber formation as well as cell division during tomato fruit development. Therefore, the pomato plant might have a big challenge in regulating Cytokinin for inducing fruiting and tuberization simultaneously (Fleishon et al., 2011). Understanding and manipulating the antagonistic relationship between Cytokinin and Gibberellin in grafted tomato plants can offer opportunities to optimize plant growth, enhance resistance to environmental stress, and improve overall yield and quality. (Fleishon et al., 2011; Schwarz et al., 2010).

From an agronomic point of view, grafting is important because it can combine the surface characteristics (fruit size) of scion plant with the underground characteristics (root system) of rootstock (Giosanu, Uleanu, Trãneci, & Vulpe, 2020). Due to the use of vigorous rootstock of potato, the root system of tomato becomes strong and the absorption of water and minerals increases compared to grafted tomato (Zeist et al., 2017). A good rootstock/scion combination usually guarantees a robust root system and the maintenance of good vegetative vigor and resistance to deal with abiotic and biotic stresses until the end of the farming cycle (Tomassoli, Ilardi, Barba, & Kaniewski, 1999). The low yield of the grafted tomato on potato with non-decapitation of shoots could be due to the partitioning of minerals and nutrients to different sinks namely underground potato tuber and above ground tomato fruits (Zhang & Guo, 2019). Although, this study did not look at the economic analysis of grafting tomato on potato rootstocks for commercial production of double crops on single plant, but grafting of tomato on potato rootstock indisputably reduces labor required for field preparations and enables the production of two different vegetables on a single plant thereby optimizing the utilization of limited land resources (Spanò, Ferrara, Gallitelli, & Mascia, 2020).

4 Conclusions

Grafting is an established technique to improve plant adaptation to various abiotic and biotic factors to increase plant yield and quality. This study showed that the tomato and potato plants belonging to the same Solanaceae family can be grafted successfully to produce double crops from a single plant. Decapitation and non-decapitation of remaining potato shoots was found to significantly affect the yield of tomato and potato as compared to the yield of non-grafted tomato and potato planted as checks. Decapitation of remaining potato shoots after grafting resulted in significantly lower potato yield as compared to the non-grafted potato. Similarly, the yield of tomato was significantly lower in non-decapitated pomato as compared to the non-grafted check tomato plants. Decapitated pomato plants produced higher tomato yields but lower potato yields. In non-decapitated pomato plants, the yield of tomato was recorded lower with higher yield of potato. However, there were no significant differences in yield of both tomato and potato between the decapitated and non-decapitated pomato plants. Hence, grafting of tomato on potato with decapitation of potato shoots is recommended for obtaining higher yield of grafted tomato and without decapitation of potato shoots for higher yield of potato from grafted plants. Although the hetero-grafting technology of pomato can increase food crop productivity for available limited land, it involves intense labor and requires practical grafting skills. Therefore, further economic analysis needs to be conducted to analyze the cost & benefit of the technology and study its potential utilization in enhancing the plant growth and performance under environmental stress. The future study may investigate the effect of potato rootstock on lycopene content of tomato and effect of tomato scion on carbohydrate content of potato. The research on potato rootstock for control of bacterial wilt of tomato is also suggested.

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