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Evaluation of Compatibility, Growth Characteristics, and Yield of Tomato Grafted on Potato ('Pomato')

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Abstract: The aim of this study was to evaluate the grafting compatibility of different varieties of tomato (*Solanum lycopersicum* L.) scions on potato (*Solanum tuberosum* L.) rootstocks to develop a 'pomato' plant. In this study three potato varieties; Diamant (P1), Cardinal (P2) and Asterix (P3), and two tomato varieties; Bangladesh Agricultural Research Institute (BARI) tomato-2 (T1) and BARI tomato-11 (T2) were used to make the grafted combinations T1P1, T1P2, T1P3, T2P1, T2P2 and T2P3, designated G1, G2, G3, G4, G5, and G6, respectively. Tomato seedlings aged 25 (S1) and 35 days (S2) were selected as scions. Graft compatibility was analyzed based on the growth and yield of the pomato plants. The results revealed that varieties and scion age had a significant effect on the pomato fruit and tuber yield. The initiation of flowering was not affected by the various graft combinations; however, plant height, leaf number, branch number, number of clusters per plant, number of fruit per cluster, number of fruit per plant, fruit length, fruit diameter, single fruit weight and total fruit yield per plant were higher in G5S1 among the combinations. On the other hand, the number of tubers per plant, single tuber weight, and tuber yield per plant were highest for a few combinations. Overall, it was concluded that Cardinal (P2) and Asterix (P3) potato were the most compatible for grafting with BARI tomato-11 (T2) at the scion age of 25 days (S1), based on vegetative growth and fruit and tuber yield of pomato plants.

Keywords: tomato; potato; grafting; pomato; growth; fruit; tuber

1. Introduction

The 'pomato' is a chimeric plant produced by grafting a tomato (*Solanum lycopersicum* L.) scion on a potato (*Solanum tuberosum* L.) rootstock, with tomatoes growing on the vine while potato tubers grow under in the soil of the same plant. Both species belong to the Solanaceae family, share a common primary chromosome number, and have natural graft compatibility [1]. Grafting is an established technique to improve plant adaptation to various abiotic and biotic factors in order to increase plant yield and quality. Grafting performance depends on compatibility between the scion and rootstock. Vascular tissue of the scion and rootstock should contact each other in order to make a successful graft. Incompatibility of rootstock and scions causes a decline in productivity and quality. Previously, a hetero-grafting technique was successfully conducted with grafting tomato scions on tobacco (*Nicotiana tabacum* L.) (Tomacco) [2,3], cucumber (*Cucumis sativum* L.) on pumpkin (*Cucurbita pepo* L.) [4], sunflower (*Helianthus annuus* L.) on Jerusalem artichoke (*Helianthus tuberosum* L.) [5], eggplant (*Solanum melongena* L.) on tomato [6], and tobacco on potato [7]. In addition, an effective transition and transport of florigen and tuber inducing signal via a RNA translocation system across the intergeneric grafting junction of pomato was demonstrated [8]. The idea of the pomato plant was conceptualized by Oscar Soderholm in 1930 and later this plant was initially developed by the Max Planck Institute, Germany, in 1977 [9]. Grafted pomato plants were then commercially launched in the United Kingdom in 2013. Recently, the pomato has been produced by the Bangladesh Agricultural Research Institute (BARI) and Bangladesh Agricultural Development Corporation (BADC) [10].

According to Jude [11], tomato seedlings were used for scions and then grafted on the emerging shoot from a potato tuber to produce the dual purpose plant. The hetero-grafting technology of potato and tomato is a new method to increase food crop productivity for available limited land. Therefore, this crop could have significant impacts on food production systems where farmers can save space and time without affecting food crop quality. The pomato plant cannot be crossbred; therefore, grafting is the only way to produce a pomato plant. In addition, grafting can improve resistance to bacteria, viruses and fungi, attract a more diverse group of pollinators and provide a strong trunk [12]. However, the grafting of a pomato is a complex process and affected by different factors, including hormonal regulation of fruit and tuber formation and development.

Through the grafting process, the tissues of the two plants are combined, so they can grow together and produce the unique plant. However, fruiting and tuberization need a great deal from the plant's source-sink relationships and hormonal exchange. Plant hormones play essential roles in fruit and tuber development [13,14]. Gibberellins (GA) and cytokinins (CK) are key regulators of various aspects of plant growth and development, fruit set induction in tomato [15] and tuber formation in potato [16]. Ribak et al. [17] stated that a CK activating enzyme induces de novo homeotic tubers in tomato. Meanwhile, Fleishon et al. [18] discovered a negative reciprocal interaction between GA and CK effects on various developmental and molecular processes during tomato plant growth. GA inhibited CK responses, including the induction of the CK primary response genes. CK also inhibited a subset of GA responses.

In addition, the phytochromes mediated leaf driving signaling on tubarization of a pomato plant is an important factor. Phytochromes are involved in the photoperiodic responses of flowering as well as shade avoidance syndrome, of the photosynthetic apparatus and other biochemical processes [19]. It is well documented that phytochromes (PHY), especially photoreceptors PHYA and PHYB1 biosynthesis in tomato leaf and transfer signaling to the fruit setting [20].

So, a pomato plant would likely have challenges to yield in many tomato and potato combinations as they have two different hormonally-regulated development signals [21]. It is hypothesized that pomato plants might minimize the hormonal antagonistic interaction (GA, CK) through diversion of the hormonal signal to either fruit setting or tuber formation. Therefore, selection of an appropriate biocompatible grafting union is vital to minimizing possible inhibitory hormonal effects and leaf-derived signaling to fruit and tuber formation of pomato plants. Meanwhile, hetero-grafting biocompatibility and transmissible signals for plant growth and development have already been defined and established [2–7]. A novel promising cultivation technique for the improvement of tomato fruit and potato tuber by grafting tomato on a potato rootstock would be a new strategy to increase food crop productivity in a land-limited country like Bangladesh. The purpose of this study was to investigate the possible effects of different graft combinations on fruit and tuber yield and growth attributes of pomato plants, and to determine the best compatible union among different varieties of potato rootstocks and tomato scions.

2. Materials and Methods

2.1. Soil Characteristics

The experiment was conducted at Sher-E-Bangla agricultural university, Dhaka, Bangladesh. The experimental area was under a sub-tropical climate that is characterized by less rainfall associated with plenty of sunshine and moderate temperatures. The farm has sandy loam soil composed of sand 40%, silt 40%, clay 20%, and the soil pH ranged from 6.0–6.6. The chemical composition of the experimental soil is shown in Table 1. The sample was collected at 0–15 cm depth of the soil horizon. The sample was tested by the soil resource development institute (SRDI), Dhaka, Bangladesh.

Table 1. The chemical composition of the soil of the experimental site as observed prior to experimentation (0–15 cm depth).

Soil Characters	Value
Organic matter	1.44%
Potassium	0.15 meq/100 g soil
Calcium	3.60 meq/100 g soil
Magnesium	1.00 meq/100 g soil
Total nitrogen	0.072
Phosphorus	22.08 µg/g soil
Sulphur	25.98 µg/g soil
Boron	0.48 µg/g soil
Copper	3.54 µg/g soil
Iron	262.6 µg/g soil
Manganese	164 µg/g soil
Zinc	3.32 µg/g soil

Source: Soil Resources Development Institute (SRDI), Khamarbari, Dhaka.

2.2. Plant Materials

Three varieties of potato, Diamant, Cardinal, and Asterix, and two varieties of tomato, BARI Tomato 2 and BARI Tomato 11, were used to make grafted combinations of pomato. The potato varieties were collected with the courtesy of the Bangladesh Agricultural Development Corporation (BADC), Dhaka, and the tomato varieties were obtained from Plant Genetic Resource Centre (PGRC) at Bangladesh Agricultural Research Institute (BARI). The graft combinations of pomato are shown in Table 2.

Table 2. Graft combinations of pomato plants. The potato varieties were Diamant (P1), Cardinal (P2) and Asterix (P3), and the tomato varieties were BARI tomato-2 (T1) and BARI tomato-11 (T2). The graft combinations were T1P1 (G1), T1P2 (G2), T1P3 (G3), T2P1 (G4), T2P2 (G5) and T2P3 (G6). Tomato seedlings aged 25 (S1) and 35 days (S2) were selected as scions.

Pomato Combinations	Combination Designation	Scion Age	Final Combinations
T1P1	G1	S1/S2	G1S1/G1S2
T1P2	G2	S1/S2	G2S1/G2S2
T1P3	G3	S1/S2	G3S1/G3S2
T2P1	G4	S1/S2	G4S1/G4S2
T2P2	G5	S1/S2	G5S1/G5S2
T2P3	G6	S1/S2	G6S1/G6S2

2.3. Production of Potato and Tomato Seedlings

Tubers of the three potato varieties were hand cut and an incision was made at two thirds of the longest axis of the seed tubers having at least two eyes. Seed tubers were then stored for a period of 7 days at 18 °C in darkness and very high humidity (80%) to allow wound healing and sprouting. After 7 days, the seed tubers had produced sprouts and were transferred to a polybag filled with a commercial soil mixture (BM2, Berger Group Ltd, St-Modeste, QC, Canada). Fifteen days after transplanting to a polybag, the potato seedlings were used for grafting as a rootstock.

Seeds of tomato varieties (BARI tomato 2 and BARI tomato 11) were treated with Bavistin and sown in 128-cell plug trays containing commercial soil mixture (BM2, Berger Group Ltd, St-Modeste, QC, Canada) in a plastic-covered house. After 7 days, seedlings were transferred to a polybag filled with the same commercial soil mixture. Tomato seedlings of 15 (S1) and 25 (S2) days of age were selected as scions for grafting in order to evaluate the effect of age on graft compatibility.

2.4. Grafting of Potato and Tomato Seedlings

Tomato seedlings S1 and S2 were cleft grafted to the potato rootstock in the polybags. Five to seven leaves of the potato seedlings were removed to a 10–12 cm height from the seedling base. The remaining shoot was removed by a cut with an angle of 35° using a sharp razor. The potato stem (2.5 mm in diameter) was bisected in the middle longitudinally approximately 4 mm deep using a sharp blade. The same diameter of tomato scion stem was removed from a seedling and the largest leaves were trimmed to minimize water loss. The lower edge of the scion stem was carefully sliced by two diagonal cuts to form a blunt wedge approximately 5 mm long. The wedge end of the scion was inserted into the bisected potato root stock. After placing the scion on the potato rootstock, grafting tapes were used to fix the grafted position tightly together. Rootstocks and scion with similar stem diameters were chosen to increase the grafting success. After grafting, the pomato plants were placed in healing chambers for 3–4 days. Healing chambers were equipped with an auto control air conditioning system (temperature at 22 °C and relative humidity at 80–90%) for recovery of the grafted plants. The grafted seedlings were watered regularly to ensure a firm connection between the scion—rootstock and the soil.

2.5. Pomato Plant Transplanting

The experimental plots were ploughed, well-prepared, brought into a good tilth and a raised bed was created. Plant-to-plant spacing was 40 cm and each plot size was 0.85 m × 1.6 m. The experiment was laid out and evaluated under field conditions in a randomized complete block design (RCBD) with 10 replicate plants of each graft combination. Fertilizer was applied as urea at 300 kg/ha, triple superphosphate (TSP) at 200 kg/ha, muriate of potash (MoP) at 220 kg/ha, gypsum at 100 kg/ha and cowdung at 10,000 kg/ha in a three installment sequence. Weeds and other stubbles were removed carefully from the experimental plot and leveled. Pomato seedlings were planted in the experimental plot 4 days after grafting at the end of December. Mechanical support was provided to the growing plants by bamboo sticks to keep them erect. During the early stages of growth, pruning was done by removing some of the lateral branches to allow the plants to get more sunlight and to reduce self-shading. Staking, irrigation and after-care were also done as per requirements.

2.6. Pomato Harvesting

All of the tomato varieties used in this experiment were indeterminate types. So, harvesting continued for about one and a half months because fruits of different lines matured progressively at different dates and over a long time period. The potatoes were harvested after several successful harvestings of tomato. Harvest started on 7th March and ended on 15th April.

2.7. Data Collection

Ten plants were selected from each block of the RCBD for the data collection of pomato plant growth characteristics including: days to first flowering, days to 50% flowering, plant height, leaf number, number of branches, and number of clusters per plant; and tomato fruit growth attributes including: number of fruits per cluster, number of fruit per plant, fruit length, fruit diameter, and single fruit weight; and tuber growth attributes including: number of tubers per plant, single tuber weight, and tuber yield per plant.

2.8. Statistical Analysis

The collected data were statistically analyzed by the MSTAT-C computer program (Michigan State University, East Lansing, 6.0). Duncan's Multiple Range Test (DMRT) was performed for all the characteristics to test the differences between the means of the grafted combinations. Mean, range and coefficient of variation (CV %) were also estimated using MSTAT-C.

3. Results

3.1. Growth and Flowering Characteristics

It was clearly observed from the study that a pomato plant can be successfully developed through grafting a tomato scion to a potato rootstock (Figure 1). Grafting compatibility was evaluated by the analysis of fruit setting and tuber production of the pomato plant.

Figure 1. Pomato plant.

Different grafting combinations showed an influence on growth characteristics of the pomato plant (Table 3). A significantly greater plant height and a number of leaves per plant were observed for G5S1 in comparison to the other combinations. Similarly, a significantly greater branch number per plant was also observed for G5S1 though not from G5S2 and G6S1. However, there were no significant differences days to first and 50% flowering among the different graft combinations (Figure 2).

Table 3. Effect of different graft combinations on growth characteristics of pomato plants.

Treatment (Grafting Combination)	Plant Height (cm)	Leaf Number/Plant	Branch Number/Plant
G1S1	94.53 c	26.89 b	4.22 b
G1S2	93.35 c	23.89 c	4.33 b
G2S1	94.41 c	22.56 c	3.44 c
G2S2	95.67 c	25.89 c	4.59 b
G3S1	93.31 c	23.35 c	3.55 c
G3S2	96.21 c	26.56 b	4.36 b
G4S1	110.3 b	27.33 b	4.37 b
G4S2	112.7 b	24.47 c	4.22 b
G5S1	115.13 a	33.67 a	6.66 a

Table 3. Cont.

Treatment (Grafting Combination)	Plant Height (cm)	Leaf Number/Plant	Branch Number/Plant
G5S2	111.23 b	26.33 b	5.11 ab
G6S1	112.3 b	27.86 b	5.22 ab
G6S2	111.3 b	28.44 b	4.22 b

Mean values with different letters in a column are significantly different by Duncan's Multiple Range Test at $P < 5\%$ (n = 10).

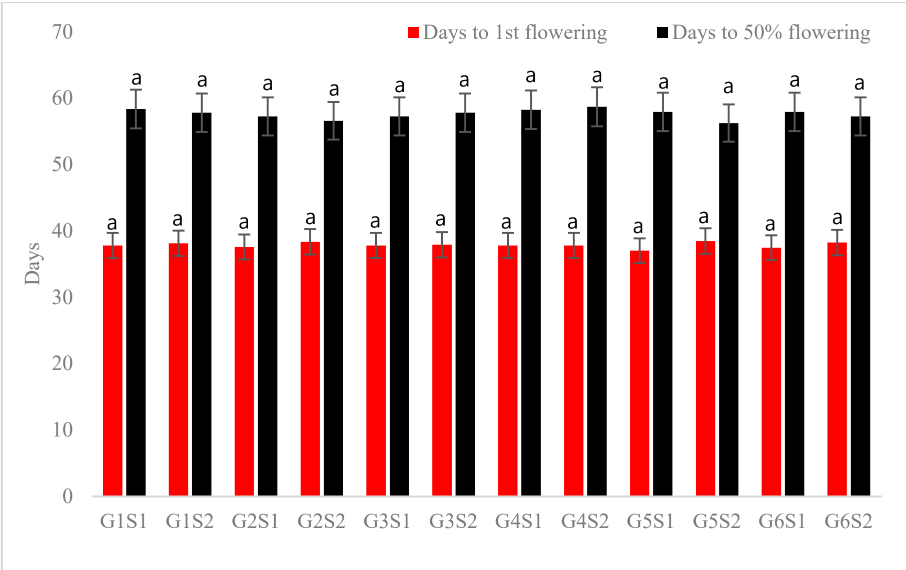

Figure 2. Effect of different graft combinations on initiation of tomato flowering of pomato plants. Mean values with different letters in a category are significantly different by Duncan's Multiple Range Test (DMRT) at $P < 5\%$ (n = 10).

3.2. *Tomato Fruit Yield of Pomato Plants*

There was an impact of different grafting combinations on tomato fruit yield of pomato plants (Table 4). Among the combinations, a significantly increased number of clusters per plant, number of fruit per cluster, number of fruit per plant, and total fruit yield per plant (2.25 kg) were observed for G5S1. Similarly, significantly higher fruit length, fruit diameter, and single fruit weight were observed for G5S1 compared to other combinations.

Table 4. Effect of different graft combinations on tomato fruit yield of pomato plants.

Graft Combination	Number of Clusters per Plant	Number of Fruit per Cluster	Number of Fruit per Plant	Fruit Length (cm)	Fruit Diameter (cm)	Single Fruit Weight (g)	Tomato Yield per Plant (kg)
G1S1	15.22 c	14.00 b	215.78 c	3.54 c	2.52 b	5.11 c	1.34 b
G1S2	14.88 c	13.00 c	215.56 c	3.53 c	2.62 b	5.33 c	1.36 b
G2S1	15.11 c	14.33 b	216.78 c	3.06 c	2.92 b	6.78 b	1.53 b
G2S2	15.22 c	13.66 c	216.78 c	2.01 d	2.07 b	5.00 c	1.55 b
G3S1	14.88 c	14.66 b	219.33 c	2.18 d	2.00 b	5.78 c	1.76 b
G3S2	15.11 c	14.33 b	216.89 c	2.86 cd	2.51 b	5.11 c	1.53 b
G4S1	16.56 b	15.11 b	249.90 b	4.35 b	3.18 b	5.11 c	1.27 b
G4S2	15.89 b	13.56 c	215.70 c	4.31 b	3.00 b	5.77 c	1.24 b
G5S1	18.00 a	17.00 a	272.00 a	5.18a	3.94 a	7.66 a	2.25 a
G5S2	15.00 b	14.44 c	217.30 c	4.60 b	3.14 a	6.11 b	1.90 b
G6S1	15.33 b	14.67 b	225.10 c	3.14 c	2.99 b	6.33 b	1.58 b
G6S2	16.22 b	14.22 b	230.90 c	4.37 b	2.12 b	6.44 b	1.24 b

Mean values with different letters in a column are significantly different by Duncan's Multiple Range Test at $P < 5\%$ (n = 10).

3.3. *Potato Tuber Yield of Pomato Plants*

There was a significant effect of different graft combinations on potato tuber yield of pomato plants (Table 5.). The number of tubers/plant, single tuber weight, and tuber yield/plant varied among the combinations with significant differences between some the highest and lowest mean values.

Table 5. Effect of different grafting combinations on potato tuber yield of pomato plants.

Graft Combination	Number of Tubers/Plant	Single Tuber Weight (g)	Tuber Yield/Plant (kg)
G1S1	3.11 c	64.00 b	0.23 c
G1S2	4.22 ab	62.67 c	0.30 b
G2S1	4.00 ab	60.89 c	0.28 b
G2S2	4.44 b	60.89 c	0.31 a
G3S1	4.11 ab	64.17 b	0.27 b
G3S2	4.11 ab	63.78 b	0.26 bc
G4S1	3.66 c	72.89 a	0.27 b
G4S2	4.44 ab	72.67 a	0.32 a
G5S1	4.22 ab	68.44 a	0.28 b
G5S2	4.87 a	70.00 a	0.33 a
G6S1	5.00 a	78.50 a	0.36 a
G6S2	4.22 ab	62.83 c	0.27 bc

Mean values with different letters in a column are significantly different by Duncan's Multiple Range Test at $P < 5\%$ (n = 10).

4. Discussion

Grafting compatibility and wound healing of the tomato-potato graft union is a complicated process since it requires the establishment of vascular connections between potato rootstock and a tomato scion. Graft incompatibility can lead to decreased water and nutrient flow through the graft union of the pomato plant. However, from the current study, it was observed that tomato can be successfully grafted on different varieties of potato rootstock. The graft combination affects tomato fruit setting and potato tuberization of the pomato plant (Tables 4 and 5). In this study, increased tomato yield was observed for the G5S1 combination whereas, increased potato yield was obtained with the G2S2, G4S2, G5S2, and G6S1 combinations. Regarding the graft combinations, tomato seedling age had a significant effect in promoting fruiting and tuberization. A 25 day old tomato seedling scion was the best compatible attributes regarding the fruit and tuber yield of pomato. The previous study has proved that a younger scion has a higher regenerating ability likely due to higher meristematic cell activity resulting in faster callus formation and quick healing of the graft union [22]. The highest success of a graft union is associated with intimate contact of the cambial regions both rootstock and scion [23]. A rapid formation of callus tissues allowed the translocation of vital metabolites within the plant [24]. The higher yield of pomato plants with younger tomato scions (S1) might be due to improved signal transfer from leaf to root zone.

Possible mechanisms for increased yield were likely the result of increased transmission of photosynthates produced by leaves. In this case BARI tomato 11 (G4, G5 and G6) scions more successfully diverted photoassimilates for tuber development. This effect could best be observed by the correlation between higher tuber yield and higher growth rate indicating positive plant source-sink relationship [21]. A previous study proved that the growth characteristics of the aboveground part have a direct effect on tuber formation of potato [25], more specifically, Van den et al. [26] reported that the rate of potato tuber formation was correlated with the strength of the inductive signal.

In addition, it has also been noted that GA and CK have a primary role in tuber and fruit development [27] while having an antagonistic relationship. The tomato plant is rich in CKs, and the relationship between GA, CK metabolism and tomato fruit development has been established [16]. Potato plants having increased endogenous levels of CKs have a higher capacity for tuber development [28]. It is hypothesized that the antagonistic activity of these two hormones is minimized in pomato plants by the contribution of the hormones to tuber and fruit development. A high concentration of CK is a prerequisite for healthy tuber formation [29] as well as cell division during tomato fruit development [16]. Therefore, the pomato plant might have a big challenge in regulating CK for inducing fruiting and tuberization simultaneously.

The stem and leaves of tomato are more erect and thicker, therefore have the capability of harvesting more light compared to potato leaves. The phytochrome signal occurs in the leaf and then is transmitted to the underground parts across the graft union of pomato plants through the phloem both acropetally and basipetally [30]. Phytochrome A and B are actively involved in the photoperiodic control of flowering, and it is very likely that they are involved in inducing tubers [30]. Previously, Chailakhyan et al. [7] reported that, in tomacco (tobacco scion on potato rootstock), the signal produced in tobacco leaves that induced flowering was the same signal that induced tuberization in potato plants. Similar results have been obtained with induced sunflower leaves which induced tuberization in Jerusalem artichoke rootstocks. Therefore, it is assumed that these phenomena can be applied to pomato plants, where tomato signals would be transferred to the potato tuber. In our study, the highest fruit and tuber production may be due to better hormonal balance and signal transduction.

5. Conclusions

In summary, we have shown that different varieties of tomato scions can be successfully grafted on potato rootstocks, and the specific combinations affect tuberization and fruit set in pomato plants. Development of the pomato plant with interspecific grafts between potato and tomato is an innovative idea to improve food crop production in the same plant. There is a balance of hormonal signaling between tuber formation, fruit development and growth attributes of a pomato plant. In this study, all possible graft combinations showed excellent grafting ability; however, the potato varieties Cardinal and Asterix, and the tomato variety BARI tomato 11 showed the best performance for growth and yield attributes. Finally, tomato—potato grafting appears to be a promising method for pomato production. Therefore, in countries like Bangladesh, where potato and tomato cultivation is carried out by traditional methods, the grafting method described in this study could potentially increase pomato yield and provide higher profit to the farmers. Further studies are needed to improve pomato plant growth attributes, including primary and secondary metabolite content, and to assess fruit and tuber yield in multiple sites and across years.

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