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Insight to the conventional and biotechnological approaches in tomato on potato grafting (Pomato): A review

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Abstract: Pomato is the result of a combination of a tomato scion and a potato
rootstock. This grafted combination is also acknowledged as a horticultural
magic plant, a recombinant double harvest plant, or a chimeric double harvest
plant. This type of plant could meet the need for proper vertical resource usage
in the future, as urbanization is increasing rapidly and agricultural land is now
becoming rare and expensive. Moreover, even though changes in the
environment are the most substantial real limitation in vegetable production,
this category of graft could be employed as an alternative strategy. Few reports
on using somatic interbreeding to establish tomato-potato fusion hybrids have
been available since the early 1900s. This strategy can be used again in the
future to save time and convenience during labor-intensive procedures, as this
plant can indeed be established through any other technique, instead of trying
to make grafting and somatic combination the only reasonable alternatives.
The grafted union of tomato and potato has indeed positively influenced
output, reliability, hormone levels, signaling pathways, and mechanisms. This
paper has been reviewed to gather all information available on the tomato
plant to date, since there has been some experimentation over the past few
decades.

1. Introduction

Vegetable grafting has turned out to be a promising technique to
boost the productivity of vegetable crops, particularly those belonging to
the Solanaceae and Cucurbitaceae families. This technique is most
commonly associated with sustaining the effects of intensive crop
cultivation in several countries (Lee *et al.*, 2010; Thakur *et al.*, 2024).
Beginning publicly in the early 1960s, tomato grafting became an

indispensable technique for tomato cultivation worldwide (Lee and Oda, 2003). The primary rationale for tomato grafting was to use this approach instead of methyl bromide to control soil-borne pathogen incidence under protected conditions (Rivard *et al.*, 2010; McAvoy *et al.*, 2012; Rana *et al.*, 2024). Grafting is currently being used on a large scale to combat abiotic stresses, alike low and high temperature stresses, heavy metals, salinity and water stress, as well as to improve quality and yield (Venema *et al.*, 1999; Abdelmageed and Gruda, 2009; Flores *et al.*, 2010; Turhan *et al.*, 2011; Colla *et al.*, 2013; Bhatt *et al.*, 2015; Kumar *et al.*, 2015; Wudu and Kassaw, 2022). Because of this, the major purpose of adopting grafting techniques in tomatoes is to boost output while preserving nutritional value and minimizing the harmful effects of environmental conditions. The success rate of the grafted plant is determined by a variety of factors, but genomic considerations may be found to be the most important among all others because they confirm the interoperability percentage between the scion and rootstock (Thakur *et al.*, 2022). Various studies have verified that grafting can have either positive or negative effects in terms of performance and yield (Huh *et al.*, 2003; Yetisir *et al.*, 2003; Davis *et al.*, 2008 a). Furthermore, conflicting changes in the transplanted union may occur as a result of a sensitive transplanted union, physical incompatibility, grafted seedling collapse, and toxic compound accumulation (Davis *et al.*, 2008 b; Villyáni *et al.*, 2024). However, graft compatibility is more likely if the scion and rootstock are taxonomically close to each other (Wang, 2011; Farooque *et al.*, 2024). Numerous reports have predicted that grafting can be performed intraspecifically and interspecifically among crops in solanaceous crops (Petran and Hoover, 2014; Chaudhari *et al.*, 2016). Tube and cleft grafting are the furthestmost common techniques used in tomato grafting (Lee and Oda, 2003; Thakur *et al.*, 2024), but amongst these two, tube grafting is found to be the most utilized technique by accelerated farmers worldwide (Hanna, 2012; Vu *et al.*, 2015). Tube grafting is known to produce strong, raised grafts because it confirms a robust vascular attachment amid the union of scion and rootstock (Bausher, 2013; Rana *et al.*, 2024). Successful adaptation, which is the process of rehabilitation and densification of transplanted seedlings before polytunnel or field seeding, is another factor that guarantees successful graft establishment (Lee and

Oda, 2003). Some of the countries, such as China, South Korea, Japan, Spain, Italy, France, Canada, Turkey, the USA, Mexico, India, and other countries (Israel, Netherlands, Egypt, and Brazil) are the major contributors in the vegetable grafting market (Nawaz *et al.*, 2017).

Oscar Soderholm presented the basic concept of conceptualizing the tomato onto a potato, i.e., Tomapotato, in 1930. The Max Planck Institute for Developmental Biology in Tübingen, Germany, initially conceived this grafted pairing in 1977; nevertheless, the resulting grafts failed to produce fruit and tubers. Moreover, the Institute of Plant Biotechnology Research in Koln, Germany, made a successful attempt at tomato/potato grafts in 1977, which produced fruits and tubers on the plant mixture (Reinhard, 2008; Bahadur *et al.*, 2020; Thakur *et al.*, 2022, Thakur *et al.*, 2024). Peres *et al.* (2005) studied the combination by grafting tomato on top of a potato plant: A method for studying leaf-derived signaling on tuberization. The study revealed that tomato and potato seedlings were crossbred when they were 20 days old to maintain nursery stability and yield. Tomato and potato crossbreds can yield up to 5 kg of tomato and 0.5 kg of potato, which is comparable to the yield of the control plant. Kiambu Prison made another attempt, according to another piece of literature cited by Lubbock Online News in 2002. In 2013, a UK-based horticultural mail company, Thompson and Morgan, sold grafts of the “TomTato” plant. The next year, New Zealand’s Incredible Edible Nursery announced a grafted plant called Double UP Potato Tom (Gillies, 2013; Kumar *et al.*, 2015). BARI and BADC are currently producing pomato plants for production purposes (Nusrat, 2014). In India, CSK, HPKV Palampur began research on the tomato plant in 2015 under protected conditions, while ICAR-IIVR Varanasi made a successful attempt in open field conditions for the first time in 2013 (Kumar *et al.*, 2015; Bahadur *et al.*, 2020). Several successful reports have been documented by various researchers until 2021 that claim the Pomato plant’s success story is not only one of comparable yield production but also matches the required quality attributes. Besides this, it can also help in combating biotic and abiotic stresses.

Pomato is a chimeric plant and the result of hetero-grafting, in which a tomato scion is grafted onto a potato rootstock from two different species. As a result, a plant combination is developed that may produce potato tubers below ground and

tomato fruits on stems on the same plant (Albacete *et al.*, 2015). Because crossbreeding cannot be used to develop pomato grafts, grafting is the only viable and possible method (Arefin *et al.*, 2019). Pomato plant yields, tomato fruits per plant about 2.72 kg, while potato tuber yield per plant was 211 g, with the number of fruits and tubers obtained from a double harvest plant estimated to be 35 fruits and 4 to 5 tubers (Islam *et al.*, 2019). Based on the dry matter and mineral distribution process of tomato and potato plant products, nitrogen and phosphorus are distributed along with, but to a lesser extent than, dry matter. Meanwhile, potassium distribution was found to be more liberal than dry matter, whereas magnesium and calcium showed a different pattern than N, P, K, and dry matter content (Bünemann and Grassia, 1973). The combination of the tomato hybrid Sweet Million F1 and red potato variety Memphis had a significantly lower response for the degree of fruit binding than the control in a behavioral study of the tomato plant (Giosanu *et al.*, 2020). Conferring to the report of Negi *et al.* (2016), the combination of GS-600 grafted on Kufri Himalini using the cleft grafting technique resulted in the highest survival rate and grafting success rate. The production of tomato fruits and potato tubers from the pomato plant can also be affected by the scion age; the scion was 25 days old (Arefin *et al.*, 2019). When compared to individual tomato and potato crop returns of 1:1.93 and 1:0.26, respectively, the pomato plant ensures higher returns of about 1:2.12 (Negi *et al.*, 2017). Because tomato is a double-harvest crop, the demand for fertilizer can also double. There is no standard fertilizer application recommendation for the tomato plant. To know the fertilizer's application doses, experimentation was conducted on the tomato plant by Kumar *et al.* (2021). They suggested using the necessary amount of fertilizer as well as fertigation twice a week to meet the grafted plant's nutrient demand. The recommended dose was 75% RDF with fertigation (19:19:19) 4.56 g m² and 100% RDF with fertigation (19:19:19) 4.56 g/m² (19:19:19); 6.84 g/m² (Kumar *et al.*, 2021; Thakur *et al.*, 2024). Furthermore, the plastids of tomato and potato belong to the same family and contain a single species of DNA, the size and density of which (156 kbp and 1.697 g/cm³) are comparable to those of higher plants' mtDNA. So, from the standpoint of utilizing vertical space, the primary need for developing this type of dual-crop potato plant is one of the most feasible ways to

utilize the balcony and backyard space. As the population grows, the effects of urbanization, industrialization, and industrialization on agricultural lands will exacerbate, making agricultural lands more scarce. So, to fulfill the need for food availability, these kinds of combinations can benefit more and more in the future. In another case study conducted by Villyáni *et al.* (2024) studied the influence of tomato grafted onto potato tubers on skin colour and the metabolome of the produce. The outcome of the study confirmed the significant variation in the studied quality traits, skin colour, and metabolome of the harvested produce. Meanwhile, out of the one hundred twelve identified metabolites of the tubers, all three cultivars showed a consistent trend in the amounts of twelve chemicals. Each cultivar showed a rise in tuber starch content relative to the self-grafted control, except 'White Lady' and 'Hópehely,' where protein levels were found to be unchanged. The formerly oval tubers become more circular. There was a correlation between the enhanced anthocyanin content of 'Hópehely' and 'Désirée' tuber skins and the elevation of *StAN1* expression, which was caused by the tomato scion. This research shows that tomato scion significantly affects potato tuber quality measures.

2. Developmental procedure of pomato plants using the vegetable grafting method

Grafting tomato scion onto potato rootstock resulted in pomato plants. Firstly, for the preparation of scion tomato seeds were grown in prostrays filled with a commercial mixture under protected cultivation. Potato tubers were cut into two pieces and stored for at least 7 days at 18°C with 80% RH before developing scion seedlings. Grafting was done when the potato plant reached a graftable size of 15-20 cm (Thakur *et al.*, 2022). For successful graft union establishment, the polyhouse should be kept at the optimal temperature and humidity. Grafting vegetables is a cost-effective method for developing viable tomato grafts. For a strong union between the scion and rootstocks, there is a need for skilled workers and optimum climate conditions (Rana *et al.*, 2024). The detailed procedure for graft development is shown in figures 1 and 2. Detailed instructions for the development of grafts were provided by Kumar *et al.* (2015), Negi *et al.* (2016), Arefin *et al.* (2019), Islam *et al.* (2019) and Kumar *et al.* (2021). Pomato

grafting, which unites a tomato plant (aerial portion) with a potato plant (subterranean portion), often employs a grafting clip or silicone tube to tightly bind the grafted stems throughout the healing phase (Thakur *et al.*, 2024). An acute grafting knife is important for executing precise, congruent incisions on both the scion (tomato) and rootstock (potato) stems, often using a “splice” or “cleft” grafting method. Complementary equipment, such as grafting tape or a film, could be employed to secure and safeguard the graft union, hence reducing

transpiration and infection. A humidity structure or grafting chamber maintains optimal humidity and temperature, facilitating graft union development. These instruments facilitate alignment, sterility, and healing, which are essential for the effective cultivation of pomato plants (Thakur *et al.*, 2024). Farooque *et al.* (2024) successfully grafted two different varieties of tomato, Red cherry tomato and BARI Tomato-15, onto potato rootstock, namely Diment. the results confirmed that the success rate of grafted plants was 94 percent, and also improved

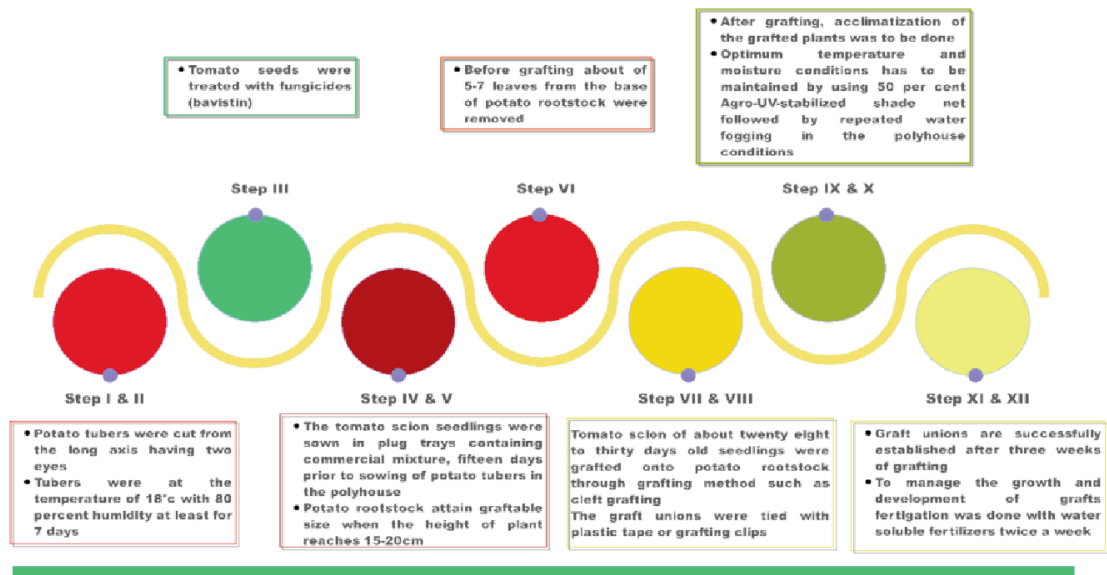


Fig. 1 - Sequential procedure for the successful pomato graft development.



Fig. 2 - Pomato development a) Selection of scion; b) Scion preparation; c) Grafting; d,e,f) Clipping; g) Sucession of graft; h) Yielding (Source: Personal communication).

the growth and yield attributes of harvested produce, i.e., tomato and potato. Meanwhile, another researcher had confirmed that the grafting success rate among the tomato variety “Mersa” grafted onto the potato rootstock variety “Belete” was 64 percent (Wudu and Kassaw, 2022).

3. Differential responses of tomato/potato grafting on fruiting, quality, and abiotic stress

Yield improvement

The pomato plant's proliferation and production characteristics were significantly improved. (Singh *et al.*, 2020). The application of GS-600 to Kufri Himalini improved tuber yield (rootstock) and fruit yield (Scion) per grafted plant (Negi *et al.*, 2016). There is a significant improvement in growth and yield attributes in grafted tomato plants between BARI tomato-11 (scion) and two potato rootstocks, namely Asterix and Cardinal (Arefin *et al.*, 2019) (Table 1). Moreover, among grafting techniques in pomato plants, cleft and tongue grafting showed better results in terms of yield-related aspects such as tuber weight, tubers per plant, tuber yield/plant and meter square, and in tomato for least days to first flowering and harvest, longest harvest duration, fruit length, width, and plant height (Kumar *et al.*, 2016). In some graftings, due to excessive uptake of nitrogen in grafted plants, there was accelerated vegetative growth, resulting in delayed maturity, tuberization, and a reduction in potato tuber quality (Zebarth and Rosen, 2007). Also, it is observed that key qualities to growth and yield are affected by fertigation treatments and fertilizer effects. Treatments affected the no. of shoots per plant, length of the harvest, the time it took to reach graftable shoots, the time it took for the plant to flower, and yield attributes (Kumar *et al.*, 2021). From the above-discussed finding, it has been concluded that the tuber and fruit yield obtained from tomato and potato grafted plants produced a comparable yield as solely grown potato and tomato yield per plant, which could assure a fair means of production and be economically beneficial (Table 2). Meanwhile, in the year 2024, one of the researchers confirmed that the pomato plant can produce more yield than of individual plant of tomato and potato. Apart from this, a single graft union of pomato, from the aerial part of tomato, had the 103.87 g of average fruit

weight, and fruit yield per plant, i.e., 4.11 kg (Thakur *et al.*, 2022). From the same plant, potato had the average tuber weight of 175.83 g, where the tuber yield per plant was 908.11 g (Thakur *et al.*, 2024). Takeuchi *et al.* (2022) made a reverse combination of potato onto tomato to breed potato cultivars through the conventional method. This combination has been made to resolve the flower initiation and seed setting issue in potatoes because the tuber and flowering will occur simultaneously. The outcomes of the results suggested that the fruit formation rate of potatoes was increased by up to 19% in potato/tomato grafts than of non-grafted potato plants with 1.1% success. So, this procedure can ease in development of null sergeant progenies by crossing the mutant lines of potatoes.

Quality focuses on nutritional content

Numerous contradictory reports have been published concerning the quality of fruits (Rouphael *et al.*, 2010). Limited research work has been done on tomato/potato plant quality analysis because the material is scarce for this aspect. A tomato cultivar grafted on four different potato cultivars showed an increase in vitamin C, TSS, and soluble sugars in tomato fruits, while in potatoes, only the reduced sugar content had been leveled up (Zhang and Guo, 2018). Among the various grafting techniques, tongue grafting was found to be significantly beneficial in tomato grafts for aspects of potato starch content, pericarp thickness, TSS, and tomato ascorbic acid content. Maximum TSS was observed in potatoes during cleft grafting (Kumar *et al.*, 2016). However, a different grafted-splice method combination of Yuvraj scion onto K. Jyoti and K. Pukhraj had a significant effect on the biochemical compositions of tomato plant products. So, as per the assurance of the results, the pomato plant might be used as an alternative strategy to get the best quality product along with a double harvest (Diwan and Sharma, 2021). Furthermore, the quality aspects related to the fruits and tubers of the pomato plant influenced it in a positive direction (Panahandeh *et al.*, 2020). Table 2 lists a recent achievement in the quality aspects of the tomato harvest. The quality aspects of pomato are questionable among growers and consumers. As discussed above, quality attributes such as TSS, ascorbic acid, total sugars, and soluble sugars of pomato products have been enhanced along with other yield traits. This assures

Table 1 - Recent achievements in terms of yield, quality and tolerance of pomato plant

Origin of scion and rootstock	Targeted traits	References
GS-600 onto Kufri Himalini	Tuber yield/plant and marketable fruit yield/plant	Negi <i>et al.</i> , 2016
ZY988 onto LS6, QS9, HZ88 and DTS1	Tomato: vitamin C, TSS, soluble sugars, fruit number and size; Potato: tuber sprouting, reducing sugar	Zhang and Guo, 2018
BARI tomato-11 onto Asterix and Cardinal	Morphological traits: Plant height, branches, leaves, and clusters Yielding: Fruits per plant, size of tuber, fruit weight, and yield per plant;	Arefin <i>et al.</i> , 2019
Avinash-2 onto Kufri Jyoti	Fruiting attributes and tuber yield/plant	Islam <i>et al.</i> , 2019
Moneymaker × San Marzano (F1) onto Agria	Chlorophyll index, total soluble solids, dry weight, and titratable acidity	Panahandeh <i>et al.</i> , 2020
Moneymaker × San Marzano (F1) onto Agria	Foliage fresh, fruit weight, and plant height,	Panahandeh <i>et al.</i> , 2020
Kufri Pukhraj onto Pusa Ruby and Kufri Bahar onto Cherry Tomato	Number of fruits per plant, average fruit weight, days to harvest (tubers), tuber yield per plant	Singh <i>et al.</i> , 2020
Cherry tomato onto potato	Tomato-fruit yield and potato-tuber yield (0.5-0.8 kg per plant)	Bahadur <i>et al.</i> , 2020
Lakshmi, Aviral, Yuvraj onto Kufri Jyoti and K. Pukhraj	Ascorbic acid content, acidity %, total sugar % %, reducing sugar %, and non-reducing sugar %.	Diwan and Sharma, 2021
Palam Tomato Hybrid-1 onto Kufri Himalini	Morphological traits like height, number of tubers per plant, tuber yield, tuber weight, marketable fruits, and fruit yield per plant, and tomato fruit weight	Kumar <i>et al.</i> , 2021
Ikram to Charlotte (CV)	Salinity tolerance	Parthasarathi <i>et al.</i> , 2021
Marsa (Tomato scion) grafted onto Belete (potato rootstock)	Improved number of fruits per plant (18), average fruit weight (53 g), fruit yield per plant (954 g), number of tubers per plant (4-5), tuber yield per plant (219.27 g)	Wudu and Kassaw, 2022
Avtar on Kufri Pukhraj	Highest fruit yield per plant	Thakur <i>et al.</i> , 2022
Avtar onto Kufri Jyoti	Minimum days to first flowering, days to first harvest	Thakur <i>et al.</i> , 2022
Avtar (F1 hybrid) onto Kufri Pukhraj	Maximum average fruit weight, fruit yield per square meter, and fruit yield quintal per hectare, tuber yield per plant and quintal per hectare, tuber equivalent yield, B: C ratio,	Thakur <i>et al.</i> , 2024
Red cherry tomato and BARI Tomato-15 grafted onto Diamant	Maximum plant growth, tomato and potato yield per plant	Farooque <i>et al.</i> , 2024
Potato scion Qingshu No. 9 grafted onto tomato rootstock Zhongyan 988	Improved pollen viability up to 15-20 percent, identified 13 DEGs (differentially expressed genes associated with gametophyte, pollen development, protein processing, and carbohydrate metabolism.	Zhang <i>et al.</i> 2024

Table 2 - Germination performance parameters of shallot seeds under different boron concentrations

S. No.	Aim	Methodology	Characterization of materials	Results obtained	References
1	Rejuvenation and genomic count determination in potato and tomato somatic hybrids by iso-electric focusing of RuBPCase subunits	Protoplast Fusion	Incubation of protoplasts in the existence of Polyethylene glycol containing a high concentration of Ca ²⁺ ions	RuBPCase can be utilized to show that the plants are hybrids due to the change in chromosomal number from 48 to 50 in three hybrids and near to 70 in the fourth hybrid.	Melchers and Sacristan, 1978
2	Chilling resistance	Protoplast Fusion	An Aminco DW-2a dual-wavelength spectrophotometer monitored callus transfer and cytochrome reduction.	All four tomato-potato hybrids had intermediate chilling resistance between tomato and potato.	Smillie <i>et al.</i> , 1979
3	Ribulose biphosphate carboxylase small subunit somatic hybrid peptide mapping	Protoplast Fusion	Ribulose biphosphate carboxylase isoelectric focusing pattern as a nuclear and protoplast genome phenotypic marker.	Four somatic hybrids had ribulose biphosphate carboxylase oligomers with tomato and potato genomes. Potato-tomato somatic hybrids have functioning tomato DNA and tyrosine-containing	Poulsen <i>et al.</i> , 1980
4	Restriction endonuclease analysis of fused hybrid plastids DNA, potato, and tomato	Callus Fusion	12 somatic inter-generic hybrid progenies of dihaploid potato and tomato	Each species carries ptDNA of tomato and potato at a 0.1 to 3 % level of detection	Schiller <i>et al.</i> , 1982
5	Steroidal Glyco-alkaloids analysis in tomato and potato somatic hybrids	Protoplast Fusion (pomato with the plastid of potato and topato with the plastid of tomato)	Protoplasts from dihaploid potato liquid cultures and tomato mesophyll fusion	Somatic hybrids had 98 percent potato alkaloid, while tubers had 60–70% tomatine.	Roddick and Melchers, 1985
6	Somatic hybrid identification by pollen, anther protein of somatic hybrids of potato and tomato plants	Protoplast fusion	Extraction of proteins from pollen and anthers of somatic hybrids. Pollen Viability Test by Fluoro-chromatic reaction. Protein estimation by the Lowry method Protein extraction by Isoelectric focusing in polyacrylamide gel	For hybrid identification by pollen and anther proteins	Chen and Ninnemann, 1990
7	Chloroplast and mitochondrial DNA triploid and tetraploid tomato-potato somatic hybrids	Protoplast fusion	Southern Blotting technique with four mtDNA-specific probes	DNA reduction. The 18S + 5S rRNA genes in tomato and potato mt DNAs may be connected to coxII genes.	Wolters <i>et al.</i> , 1991
9	GUS activity, total genomic DNA content, and chloroplast type, shoot regeneration potential, expression of potato iso-enzymes, and relative genomic composition	Asymmetric somatic hybridization protoplast fusion	Fluorometric β -glucuronidase assay, Flow cytometric analysis, DNA isolation, DNA probes, Southern blot, and dot blot analysis	No viable plants were obtained; calli were highly polyploid, and hybrids expressed GUS activity	Schoenmakers <i>et al.</i> , 1994
10	Mitotic and meiotic irregularities in somatic hybrids	Protoplast fusion, Root tip meristems culture	Genomic in situ hybridization, cytological analyses for chromosome counts, and karyotype analysis	Exclusively sterile pollens	Wolters <i>et al.</i> , 1994
11	Regeneration, alien chromosome identification through RFLP, and GISH	Protoplast fusion	Cytological technique for meiosis study, fertility, crossability, and embryo rescue technique, starch composition determination	All fusion hybrids were sterile, the hexaploids produced stainable pollen and berries with badly developed seeds	Jacobsen <i>et al.</i> , 1992

that the quality of pomato products can be improved through grafting; satisfactory results were documented, which match the needs of growers and consumers.

Salinity tolerance

According to various case studies, the potato genome is vital for improving the yield and quality of tubers by the tomato/potato graft (Sue *et al.*, 2010; Arefin *et al.*, 2019). However, the graft of transmissible Ribonucleic acid from the inverse combination of potato onto tomato articulated the phenotype of the scion (Kudo and Harada, 2007). Salinity tolerance was tested in the tomato scion cv. Ikram on the potato cv. Charlotte plant. The results showed that using potato rootstock as a substitute approach to assure irrigation water salinity tolerance and boost the quality and quantity of fruits and tubers harvested from the grafted plant may be useful. The improved characteristics include higher total dry mass, varied root characteristics, equal mineral distribution across the entire plant, and higher water productivity than non-grafted plants (Parthasarathi *et al.*, 2021). Table 2 gives an illustration of salinity tolerance. Only a few attempts have been made recently by researchers to manage abiotic stress, namely using a graft combination of tomato and potato plants. With the studies mentioned above, it is evident that abiotic stresses like salinity, temperature, and mineral stresses can be managed by utilizing tolerant and resistant rootstocks.

4. Developmental procedure of hybrid fusion through somatic hybridization

For the isolation of plant protoplasts, 50 ml of a three- to four-day-old suspension culture was centrifuged at 600 rpm for five minutes. The pellets were then resuspended in 30 ml of AM media. After centrifuging the filtrate suspension, the protoplast pellets were re-suspended in BM media and centrifuged at 600 rpm for five minutes. The centrifuged protoplast pellets were resuspended again in BM media. Using a nylon filter and a centrifuge set at 1000 rpm for 10 minutes, the protoplasts were separated from cell debris. The protoplast was rinsed in AS media (1 fold), excluding enzymes, and in BS media (2 folds). Before electro-fusion, a protoplast mixture (1:1) was made, and 0.4

millilitre of the combination was added to a fusion chamber before electrodes were affixed to a glass petri dish. An alternating current field was useful to the allied protoplasts, followed by a reduction in the AC field to zero. The protoplasts were cultured in TM2G media at a density of 2.5×10^5 protoplasts per ml. The details of the procedure were explained by Roddick and Melchers (1985), Schoenmakers *et al.* (1994), and Wolters *et al.* (1995).

Effect of somatic hybridization on various traits of Pomato fusion hybrid

A few scientists initiated the research work for developing the tomato plant via protoplast fusion. In 1955, a potato + tomato fusion hybrid was developed by researchers through protoplast fusion (Jacobsen *et al.*, 1992). A first attempt had been made to develop a fusion hybrid plant by Melchers and Sacristan in 1978. Roddick and Melchers (1985) carried out the research on the creation of somatic fusion hybrids of tomato and potato, with tomato having tomato plastids and pomato comprising potato plastids. Smillie *et al.* (1979) investigated chilling resistance in various somatic fusions of tomato and potato and discovered that the chilling resilience of tomato-potato somatic hybrids was intermediate between that of tomato and potato. These somatic fusions may be beneficial for relocating genes for chilling resistance to cultivated tomatoes, to know the potential and confines of asymmetric somatic hybridization among tomato and potato plants. The two mutation products of the nitrate reductase-deficient mutant of tomato are isolated and assessed, and they might be used as selectable markers in potato somatic hybrid fusion assessment. The outcome showed that several hybrid fusion plants were developed, but plant regeneration did not take place, as mentioned by Schoenmakers (1993). Wolters *et al.* (1995) demonstrated that mtDNA segregation occurs independently in somatic fusions from chloroplast DNA (cpDNA). It is concluded that the mtDNA of both tomato and potato may contain the *coxII* gene, which is closely associated with the 18S and 5S rRNA genes. A protein of pollen and other sources is used for inter-specific assessment, while Chen and Ninnemann (1990) confirmed the presence of an intermediate protein band pattern in somatic hybrids of tomato and potato. Besides this, a report by Schoenmakers *et al.* (1994) mentioned that an excessive variation had been seen among all the

fusion hybrids for all studied traits, while the expression of GUS activity was also reported in somatic fusion. In another case study, the chromosome count had been analyzed at the mitotic and meiotic stages of division in 107 somatic hybrids of tomato + potato. Although about 79% of fusion combinations are found to be aneuploid with the absence of one or two chromosomes, among the five studied hybrids, 46 chromosomes were found in hybrid K2H2-IC, with the highest percentage. Even though all the microspores degenerated with immediate effect after the tetrad stage, this resulted in pollen sterility (Poulsen *et al.*, 1980; Wolters *et al.*, 1991; Wolters *et al.*, 1994). Table 1 summarises attempts made in the early 1900s to develop fusion hybrid lines through somatic hybridization. To reduce labor and maintenance costs, there is an urgent need to focus on developing the tomato onto potato plants via somatic hybridization. Tissue culture is the only method through which these grafts can be developed. Because seeds can't be obtained from a pomato plant due to a lack of skilled labor and knowledge about the procedure of grafting, growers cannot perform this at the field level. Somatic hybrids can resolve this issue of plant material availability at the market level.

5. Signaling mechanism involved in Pomato

Potato tuberization can be affected by photomorphogenesis and hormones, while the tomato scion does not succeed in producing these substances, which leads to converting stolen into tubers in an established strong source-sink relationship. The source-sink relationship is important in potato tuberization because cytokinin affects tuberization and is thought to be a major contributor (Roitsch and Ehneb, 2000). Thus, the involvement of genes can also contribute to altering the tuberization success, as the over-expression of the "*Knox*" gene can diminish the level of gibberellic acid and level up the cytokinin production that ultimately leads to augmented tuberization (Sakamoto *et al.*, 2001; Frugis *et al.*, 1999; Rosin *et al.*, 2003). In recent case studies, results revealed that the "*ipt* gene" exhibits a better ability for potato tuber formation (Galis *et al.*, 1995). As a result, the diverse range of homoerotic tomato mutants can be used as an effective means of targeting the substances involved in the conversion of stolon into

tuber formation, which forms a strong sink. However, the elimination of *PHYB* through a gene, i.e., anti-sense *PHYB*, resulted in tuber formation in short and long-day conditions, while the over-expression of this gene improved the inhibition effect of long days on tuber formation (Aksenova *et al.*, 2002). Kudo and Harda (2007) carried out experiments on hetero-grafting using potato and tomato as scion and rootstock, respectively. The combination had been tested to ensure that the RNA molecule responsible for altering the leaf shape could function transversely in grafted seedlings. The study found no significant changes in the potato scion as a result of RNA molecule transmission in the grafted plant. But this can be utilized in further cultivar development programmes in vegetable crops. However, in another case study, Nielsen and Stitt (2001) confirmed that a sufficient amount of chimeric transcript can be supplied from the rootstock without leaves to modify the leaves of the scion. Even though the PFP enzyme works well in young leaves, it is distributed evenly throughout the plant. Meanwhile, this *PFP* transcript can also actively participate in the root system. So, this methodology has now been used in vegetable production to combat the various biotic and abiotic stresses. Several reports confirm the utility of *PFP* transcripts in the grafted plant by altering the characters of the scion (Ohata, 1991; Taller *et al.*, 1999) and may lead to the transportation of gene transcripts as per the report of Liu (2006). A recent investigation initiated on the tomato plant revealed that potato rootstock expresses merely a negligible phenotypic alteration in tomato scion, but has shown a minute impact on differential expression genes. On the other hand, in the meantime, tomato scion has shown a strong impact on the rootstock of potatoes, leading to the expression of thousands of differential genes, some of which are concerned with hormone pathways and their signaling (Zhang *et al.*, 2019). Due to the presence of two dissimilar hormone-regulated signaling systems, the yield aspect of the pomato plant would be challenged in numerous tomato-potato combinations (Peres *et al.*, 2005). In the meantime, changes in hormone signaling, either for fruit setting or tuberization, may occur in pomato plants, leading to a downplaying of the antagonistic interactions of hormones such as gibberellic acid and cytokinins (Yasinok *et al.*, 2009). Approximately 209 genes related to the synthesis of starch and sucrose were identified as being upregulated in the tomato scion. The tomato scion had less of an effect on the

development of the signaling substance involved in tuberization, but it did initiate the development of stolons and an aerial stem portion during germination. Based on RNA-sequencing, upregulated and downregulated genes were identified based on a count of 1529 and 1329, respectively, amongst *St-SW* and *St-R*. A few of them took part in hormone signaling transduction via *St DELLA* (receptor) and *StGID 1* (protein) (Zhang *et al.*, 2019). The graft union establishment is affected by the signaling mechanisms of the scion and rootstock. Further research is required to improve plant survival rates and to understand the actual mechanism of the available hormonal pathway between the scion and rootstock combination. This type of investigation has the potential to broaden the research area in grafted vegetable plants. This can also ensure the quality aspects that are in dispute.

6. Movement of small RNA molecules in grafted plants

The transfer of genetic information in the form of small RNAs is a critical problem that has received a lot of attention in the literature over the last decade. So, to accomplish this, grafting has been widely utilised in plant physiology and biology to discover mobile molecules that include small RNA, mRNA, and proteins that influence significant facets of plant growth and development. In higher plants, the phloem transports amino acids, carbohydrates, proteins, vital nutrients, and certain RNA molecules (Wu *et al.*, 2006). Grafting has been employed in several experiments to demonstrate that messenger RNA molecules move throughout plants via the phloem (Turnbull and Lopez-Cobollo, 2013). It has been suggested that phloem sap includes real, tiny regulatory RNAs because small RNAs match multiple potential target genes (Yoo *et al.*, 2004). Yoo *et al.* (2004) also found the same in the phloem sap of cucumber, pumpkin, and castor beans, where they found the existence of an endogenous population of small RNA species with 18 to 25 nucleotides. Ruiz-Medrano *et al.* (1999) confirmed the presence of several mRNAs in the cDNA clones obtained from the phloem sap of pumpkin. Recently, it was proposed that FT (flowering locus T) mRNAs, which are synthesised in the leaves and transported by the phloem to the shoot apex, interact with another transcription factor to form the flowering locus T

protein (Biazquez, 2005). As a result, in reaction to particular environmental factors, the long-distance RNA translocation mechanism seems to influence the development of the entire plant. When Me-like potato leaves appeared to have been induced by the transcript transported through the graft junction from the Me tomato rootstock, Kudo and Harda (2007) demonstrated the presence of chimeric transcripts. PFP promoter activity was seen in the lower sections of the plant, notably in the root system, in addition to the identification of PFP transcripts in the sap from the cut surface. Genetic material has recently been reported to be horizontally transmitted between the two grafted partners, either as DNA or plastids, by Stagemann and Bock (2009). Later in 2012, Stagemann and his coworkers verified that *N. benthamiana* had successfully received the chloroplast DNA of *N. tabacum* (a chloroplast transgenic strain) through a grafting junction. Small RNAs, such as phosphorus deficiency-induced miRNAs, have been demonstrated to transfer from shoot to root systems through the use of micrografting studies (Pan *et al.*, 2008). According to Bhogale *et al.* (2014), additional miRNAs like miR156, miR172, and miR395 may transfer from the scion to the rootstock. Since it is thought that sRNAs move through the phloem and plasmodesmata, it has been demonstrated that sRNA mobility within grafted plants is more effective when sRNAs are produced in the scion and move towards the rootstock rather than vice versa (Melnik *et al.*, 2011). Tomato graft unions were developed using non-transgenic scions and transgenic rootstocks (silenced fatty acid desaturase gene). The silencing of the fatty acid desaturase gene (*LeFAD7*) and the presence of siRNA in grafted scions suggest that both were transferred to the scion via genetically engineered rootstock. It is conceivable that siRNAs generated from the rootstock might similarly go in that direction among these compounds and highlight the considerable phenotypic alterations seen in the scion. In addition, it has been demonstrated that the tomato scion receives viral resistance from the rootstock. The findings of an experiment conducted by Spano *et al.* (2015) demonstrated that when resistant tomato rootstock varieties with higher RNA interference were grafted onto resistant tomato scion varieties that accumulate less viral RNA, the grafted plants displayed the expression of crucial RNAi mechanism genes. The roots of resistant grafted plants showed upregulation of genes such as

Agronaute (AGO) and RDR. It has also been proven that self-grafted plants showed stronger RNAi silencing, and even grafting itself can provoke the activation of resistance mechanisms.

7. Future prospects

Vegetable grafting provides a new perspective to broaden the research area, increase yield, and improve quality attributes associated with vegetable crops. This can be used as a backup method to ensure food availability. Because variety development takes eight to ten years, grafting can compensate for production losses and aid in the resistance to biotic and abiotic stresses during this time. However, the basic requirement for grafting is the development of resistant or tolerant rootstock material on the ground level. This is a farmer-friendly technique because it is environmentally friendly. The pomato, also known as the “horticultural wonder plant,” is the best example of vegetable grafting. Two products can be obtained from a single plant, namely tomato fruit and potato tubers. More research on pomato plants is required because only a few reports have been documented to date. The quality aspects of this plant product are always in doubt, which could be a major hurdle that must be overcome so that farmers can also grow these profitable plants with high-quality produce. Aside from the manual grafting of tomato plants, researchers should concentrate on using biotechnological techniques to create tomato/potato fusion hybrids, such as somatic hybridization. So, because the major downside of developing a pomato plant is that it cannot be grown from seeds, the only way to develop these grafts is through vegetable grafting. To modernize the development process and ensure the availability of grafts on the market, these grafts must be developed using the tissue culture technique.

8. Conclusions

The primary goal of developing pomato plants is to ensure maximum space utilization and combat environmental challenges. A few inconsistent findings on the fixable effects of graft union on horticultural and quality aspects have also been reported. Pomato plants can be grown in two ways: through grafting or somatic hybridization. Several

attempts were made in the 1900s to create hybrid mutants through somatic hybridization. Later, manual grafting was used to develop tomatoes onto potato grafts. Now that only grafting is used on commercial-level tomato plants, there is an urgent need to focus on developing a hybrid tomato/potato graft. To be aware of the utility and benefits of this dual-harvest plant, researchers must focus on the start of additional research work. Many aspects of its biochemical and physiological properties have yet to be studied, particularly to make this grafted plant commercially available to growers. This grafted plant may also be considered an alternative way to produce clean potato seed tubers, especially in hydroponics and aeroponics systems, and in the future, it might be proven to be one of the approaches worth considering. So, there is a need to work on this aspect to get more benefits in terms of quality and quantity. However, several successful reports regarding the tomato/potato plant were documented, so the possible information has been reviewed to learn more about the successful experimentation.

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