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Research article

Rootstock scion interaction studies on various horticultural attributes of pomato grafts under protected structures

Vandana Thakur [a,b], Parveen Sharma [a], Pardeep Kumar [c], Akhilesh Sharma [a], Mamta [d], Abeer Hashem [e], Elsayed Fathi Abd_Allah [f], Sunny Sharma [b,*]

[a] *Department of Vegetable Science and Floriculture, CSK HPKV, Palampur, HP, 176062, India*
[b] *School of Agriculture, Department of Horticulture, Lovely Professional University, Phagwara, Punjab, 144411, India*
[c] *Department of Plant Sciences School of Life Sciences, Central University of Himachal Pradesh, Dharmshala, 176215, India*
[d] *School of Bioengineering and Food Technology, Shoolini University, Solan, Himachal Pradesh, 173229, India*
[e] *Botany and Microbiology Department, College of Science, King Saud University, P.O. Box. 2460, Riyadh, 11451, Saudi Arabia*
[f] *Plant Production Department, College of Food and Agricultural Sciences, King Saud University, P.O. Box. 2460, Riyadh, 11451, Saudi Arabia*

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ABSTRACT

Pomato is a horticultural wonder plant, as tomato and potato can be produced from a single plant. This experiment explored the influence of diverse graft combinations of tomato scions grafted onto potato rootstocks on various growth and yield-attributing traits. The investigation outcomes confirmed the significantly positive influence of scion grafted onto rootstock on various yielding attributes of tomato and potato harvested from pomato grafts. Scion "Rakshita" grafted onto the rootstock of Kufri Himalini had the maximum fruit length. In contrast, the fruits harvested from the graft combination of Avtar grafted onto Kufri Khyati had the maximum number of fruits per cluster and the number of fruits per plant. The highest average fruit weight, fruit yield per meter square, and total fruit yield quintal per hectare were recorded with control "Avtar. The longest harvest duration was noticed with the graft combination of Heemsohna grafted onto Kufri Himalini. Moreover, on, rootstock Kufri Himalini with scion Rakshita resulted in maximum tuber length, and average tuber weight, while Kufri Himalini with Avtar had maximum fruit width. The maximum number of tubers per plant was also noticed with Kufri Pukhraj with Palam Tomato hybrid −1. The potato harvested from the rootstock of Kufri Pukhraj with Avtar had the highest tuber yield per plant, total tuber yield quintal per hectare, and tuber equivalent yield. The highest survival percentage of grafted plants was noted in Heemsohna onto Kufri Jyoti. In context to the cumulative yield of tomato fruits and potato tubers obtained from the pomato graft was found to be incremented in grafts of Avtar grafted onto Kufri Pukhraj followed by Rakshita grafted onto Kufri Rakshita, which also resulted in the maximum benefit-cost ratio with highest net return and gross return. The graft combination of scion Avtar and Rakshita onto Rootstock Kufri Pukhraj resulted in a positive increment in yield attributing traits of the pomato plant than of control of un-grafted tomato and potato.

* Corresponding author.
E-mail addresses: sunny.29533@lpu.co.in, sunnsharma141@gmail.com (S. Sharma).

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1. Introduction

Pomato is a graft combination unambiguously developed employing tomato scion grafted onto vigorous potato rootstock [1]. In other words, this plant is a product of a chimeric combination or hetero-grafting [2]. It is also known as "TomTato" or Future horticultural wonder plant, as this grafted plant owns two products on a single plant [3]. Tomato and potato belong to the Solanaceae family and share a common basic chromosome number, due to which these two crops show natural graft compatibility [4]. This plant does not grow naturally nor through seed/sexual means of propagation. Pomato plant not only endures the properties of two plants in the single grafted unit but correspondingly upsurges the capability of the plant to mitigate harsh environmental conditions, which makes this wonder plant popularized among growers as a space-saving or dual cropping plant [1,3]. In other words, it can be designated as two in a plant combination, where potato tuber grows underground and tomato fruit on the top of the ground level [4]. Oscar Soderholm 1930 conceptualized the ideation of the pomato grafts; later in 1977 pomato plant was primarily developed by the German-based institute "Max Planck Institute for Developmental Biology in Tubingen [1,5]. Earlier in September 2013, the UK-based horticultural mail company of Thompson and Morgan introduced the ketchup and fries, ketchup and chips, or TomTato plant and started selling the grafted plants. In the same month identical concept of PotatoTom was announced by "Incredible Edibles Nursery in New Zealand [1,3]. The development of tomato onto potato grafts is an intricate process, which is affected by several factors such as hormonal regulation that occurs during the fruit and tuber development. Meanwhile, they merely depend on each other for growth and nourishment [4]. On the other hand, two major factors are needed for the fruiting and tuberization process of pomato grafts i.e. hormonal exchange and source-sink relationship among scion and rootstock [6]. In the 2 modern era, the Pomato plant has been seen as a novel emerging technology to increase production and productivity without compromising product quality from limited land sources [7]. For which all available resources are used in the best way to maximize the yield potential per unit area, especially in peri-urban areas of the country. It provides several opportunities to polyhouse growers to utilize the vertical space more proficiently and to maximize the yield capacity and profit margins from a limited area. Growers can save space, time, and labor costs without compromising the quality of obtained fruits and tubers harvested from the pomato plant [1,3]. Besides this, photoperiodic hormonal signaling showed a great influence on tuberization in pomato grafts however, phytochromes affect the flowering and biochemical mechanism of the grafts [8,9]. The yield and quality of pomato produce vary from one another graft combination, as they share two different kinds of hormonal signaling pathways [10]. Several reports suggested that tomato onto potato grafts regulate the hormonal antagonistic interaction such as of gibberellins and cytokinins via redirecting the hormonal signaling to either tuberization or fruit formation [4]. Thus, the selection of suitable scion and rootstock combinations is imperative to minimize the negative effects of leaf-derived signaling and hormonal possessions on the fruiting and tuberization of tomato/potato plants [11,12]. Tomato is a warm-season crop but with the introduction of plastic in agriculture we can grow tomato crops throughout the years. The area of tomatoes in India is 845 thousand hectares with production of 21181 thousand metric tons and 25.07 metric tons per hectare of productivity [13]. Tomato and potato are the two potential crops, which are not only used in bulk quantity but also for the production of various processed products. In addition to that, these two potential crops contain a significant amount of essential minerals and nutrients, which contribute to the dietary intake of human beings. 3 Tomato is one of the most versatile crops among all vegetables and is universally known as a "protective food" as it comprises all types of minerals and vitamins in a fair amount [14]. It is mostly eaten raw in a salad, utilized for culinary purposes, and in processing units for making different products like purees, ketchup, paste, preserves, etc. Nevertheless, the tomato crop has several nutritional and medicinal values, it is a vital source of minerals especially K, organic acids such as citric and maleic acids, vitamins, etc [15]. In addition to this, various major constituents also contribute to augmenting the quality of tomato fruit. These are ascorbic acid, average total sugar content, tomatine, and free sugar of the TSS are generally glucose, fructose with traces of sucrose content, acidity percentage, and steroidal glycoalkaloids [14]. Apart from this, the ripe fruit of tomato contains amino acids namely, tyrosine, tryptophan, aspartic, glutamic acid vice versa. 'Lycopene' is a potent non-nutrient bioactive substance and also a major carotenoid pigment that acts as an antioxidant, which is accountable for the red color of the tomato fruit [16]. On account of this, tomato also contributes towards medicinal values, cures for cancer of the digestive tract, colon, stomach, and prostrate cholesterol, etc., and this valuable effect is expressed due to the presence of various anti-oxidant compounds like Vitamin C, beta carotene, alpha tomatine, and lycopene as mentioned by Refs. [17,18]. On the worldwide platform, India is ranked the 2nd largest producer of potatoes which occupies an area of 21.4 M ha with production of 51.3 MT and 2.4 t ha^{-1} tons per hectare of average yield whereas, around 87 % of input comes from North Indian plains. Potato is a cool-season crop mostly grown in open field conditions throughout the country. The area of the potato in India is 2203 thousand hectares with a production of 56173 (1000 MT) and productivity of 25.49 MT ha^{-1}) [13]. The leaves and blossom appearance of tomato and potato crops resemble each other, which supports the taxonomic grouping of these two crops [19]. Potato is the most important staple food after rice, maize, & wheat, it is also known as wholesome food and contains a fair amount of dietary constituents, 4 essential nutrients such as carbohydrates approximately 20.6 %, protein, major minerals (Ca, P, and Fe), vitamins particularly Vitamin B1, B2 and B3 and essential nutrients like leucine, isoleucine and tryptophan, respectively. Besides this, potatoes are also known for their medicinal values, as they contain a high amount of carbohydrates, which are easy to digest mostly boiled potato tubers are prescribed to weak people, and cure high blood pressure as they contain a small amount of sodium, effective against gum problems, cold, etc. and raw pulp of potato is used as a good natural healer [17]. The present scenario of the potato crop in India proposes its diversified production and utilization in the domestic and international markets. The potato processing industries in India were not in trend up to the '90s but with the openings of indigenous and domestic industries, the potato processing market has expanded manifolds. At present, 68.5 percent of the potato production is being utilized for domestic table consumption and only 7.5 percent of its harvest is utilized for processing purposes. However, in developed countries, 31 percent of potato harvest is utilized for table purposes, and the rest of the 54 percent is used in processing industries. Based on the pattern followed by Indian potato processing industries, it has been concluded that over the next forty years, a rapid increase can be seen to fulfill the demand for potatoes for processing industries. According to the current trends, the demand for processing quality potatoes is predicted to reach 25 million tons by 2050. Limited information is available for the pomato plant, as there is no further detailed investigation has been initiated as long so far, on the horticultural aspect with special emphasis on quality aspects. The mineral and nutrient content of tomato and potato on an individual level has been confirmed by many researchers in their case studies, but there are some contradictions are there regarding the produce quality of the pomato plant among the growers and the consumers [20]. The nutritional distributions among the fruits (aerial) and tuber (underground) are necessary for quality production. So, to get a positive outcome it is necessary to initiate the experimentation for evaluating the scion and rootstock varieties and their combinations [21]. Potato rootstocks can enhance the fruit quality of tomatoes such as ascorbic acid, total soluble solids, and soluble sugar content which vary from variety to variety [14]. Keeping all these aspects in view as discussed above, to ensure the quality stability of the produce and to find the best combination based on growth and yield traits the present investigation was initiated on 'Rootstock and Scion Compatibility Studies in Pomato' with the following objectives i.e. to find out best compatible rootstock and scion combination of pomato on the basis on their various horticultural traits.

2. Materials and methods

2.1. Experimental location

The experimental site is located at 32°6′ N and 76°3′E, latitudinally and longitudinally at an elevation of 1290.80 m from the mean sea level. The experimental area is positioned in the mid-hills of the Kangra district of Himachal Pradesh surrounded by the Northern Himalayas.

2.2. Growing conditions

The investigation was conducted in naturally ventilated poly houses, at the Research farm of the Department of Vegetable Science and Floriculture, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishivavidalaya, Palampur, Himachal Pradesh, India. The experiment was laid out in an RCBD (Randomized Complete Block Design). Pomato graft unions were developed by using four diverse tomato hybrids (scion) viz., Avtar, Rakshita, Heemsohna, and Palam Tomato Hybrid-1, and potato varieties (rootstocks) i.e. Kufri Jyoti, Kufri Khyati, Kufri Himalini, and Kufri Pukhraj, respectively. A total of sixteen graft combinations were developed along with two controls comprising a sole un-grafted plant of tomato and potato each, respectively as mentioned in Table 1. The tomato seeds were sown in soilless media comprised of cocopeat in combination with vermiculite and perlite in the ratio of 3:1:1, fifteen days before the sowing of potatoes, to achieve the graftable size of scion and rootstocks. Big-sized seed potato tubers were cut into small pieces having two to three sprouts per piece with the help of a sterilized knife. The cut tubers were treated with a fungicide solution of Diathane M − 45 @ 2.5 g per liter of water to prevent the attack of the soil-borne pathogens. The seed tubers were sown at the spacing of 70 cm × 30 cm (row to row and plant to plant), along with two controls each of tomato (Avtar) and potato (Rakshita). Besides this, tomato seedlings of the Avtar variety were also transplanted as control. A total of sixteen diverse graft combinations were developed by using a cleft grafting approach. Grafted unions were sprayed with water to avoid the wilting of grafted plants. One-month-old graft unions were sprayed with urea at the concentration of 0.1 % two times a week, to hasten the vegetative growth of the grafts, followed by the continuous application of water-soluble fertilizers (19:19:19) @ 2–3 g per square meter twice a week. Standardized packaging and practices for tomatoes and potatoes were followed for the crops under protected conditions. Tomato plants were trained on two stem systems, while de-suckering was done at regular intervals in potatoes, to ensure the proper growth and development of the grafts.

Table 1
Treatment details of the experiment.

Potato varieties (Rootstock): Kufri Jyoti (R_1); Kufri Khyati (R_2); Kufri Himalini (R_3); Kufri Pukhraj (R_4)	
Tomato hybrid (Scion): Avtar (S_1); Rakshita (S_2); Heemsohna (S_3); Palam Tomato Hybrid-1(S_4)	
R_1S_1	Kufri Jyoti + Avtar
R_1S_2	Kufri Jyoti + Rakshita
R_1S_3	Kufri Jyoti + Heemsohna
R_1S_4	Kufri Jyoti + Palam Tomato Kybrid-1
R_2S_1	Kufri Khyati + Avtar
R_2S_2	Kufri Khyati + Rakshita
R_2S_3	Kufri Khyati + Heemsohna
R_2S_4	Kufri Khyati + Palam Tomato Kybrid-1
R_3S_1	Kufri Himalini + Avtar
R_3S_2	Kufri Himalini + Rakshita
R_3S_3	Kufri Himalini + Heemsohna
R_3S_4	Kufri Himalini + Palam Tomato Kybrid-1
R_4S_1	Kufri Pukhraj + Avtar
R_4S_2	Kufri Pukhraj + Rakshita
R_4S_3	Kufri Pukhraj + Heemsohna
R_4S_4	Kufri Pukhraj + Palam Tomato Kybrid-1
S_{T0}	Avtar
R_{T0}	Kufri Pukhraj

2.3. Pomato yield attributing traits

The data on the various yielding attributing traits were taken from the five randomly selected pomato plants from each treatment along with undrafted controls (tomato and potato).

2.4. Tomato harvested from pomato grafts

The data was collected for various yielding attributes of tomato harvested from pomato grafts namely, fruit length, average fruit weight, fruit width, number of fruits per cluster and plant, fruit yield per square meter, total fruit yield quintal per hectare, and harvest duration. The length and diameter of five randomly chosen samples of tomato fruit were measured with the help of the vernier caliper. Meanwhile, the mean value for average fruit weight was determined from the randomly tagged plants, by using a digital weighing balance. The total number of fruits was totaled from each cluster of tagged plants & the means of five chosen plants were taken for the same. The total number of fruits per plant was counted till the last harvesting of the tomato fruit, & the average was calculated for it. Total yield per plant was determined by combining the weight of all fruits harvested from the selected plants in multiple pickings for a specific treatment, and then calculating the mean value for the same, accordingly. Additionally, to calculate the fruit yield per square meter, fruit yield per plant was multiplied by the total number of plants present in individual treatments. Total fruit yield quintal per hectare for individual treatment was obtained by multiplying the average value of fruit yield per plant with the total number of grafted plants occupied per hectare area.

2.5. Potato harvest from pomato grafts

Tuber length and width were determined by using a vernier caliper, and the mean values were calculated for each treatment. Meanwhile, the tubers harvested from tagged pomato grafts were weighed individually to calculate the mean value for average tuber weight. The total no. of tubers harvested from an individual plant of each treatment was multiplied by the average tuber weight to obtain tuber yield per plant. Meanwhile, the total tuber yield quintal per hectare was determined by multiplying the tuber yield per plant with the total number of plants occupied in per hectare area. Tuber equivalent yield (q ha^{-1}) was calculated by applying the formula as given below:

$$\text{Tuber equivalent yield } \left(\text{q ha}^{-1}\right) : \frac{\text{Yield of tomato} \times \text{Price of tomato}}{\text{Price of potato}}$$

2.6. Pomato

The aggregate yield of fruits (Tomato) and tubers (potato) harvested from the pomato grafts was also calculated for the developed grafts to know the benefits of growing pomato plants than of individual tomato and potato crops. An individual pomato graft produced more yield than an individual un-grafted tomato and potato plants. The total yield per plant of pomato was calculated by the sum of the tomato fruit yield (multiple harvesting) with tuber yield obtained from an individual pomato graft. Meanwhile, the total yield per square meter and quintal per hectare was determined by multiplying the total yield per plant by the total no. of plants occupied per area.

2.7. Economics (pomato grafts)

To get the most profitable treatment combination of suitable pomato graft, the economics of individual treatment/graft was calculated at prevailing and output rates in the market. The total cost of cultivation was determined by the sum of fixed cost and variable cost, where the fixed cost incurred the rental land, machinery, while the variable cost includes seed, fertilizers, chemicals, and labor, etc. The gross return for each treatment was determined by multiplying the total yield (q ha^{-1}) with the market price of the crops (Rs/kg), while to get the net return total cost of cultivation was subtracted from the gross return value. The values for the benefit-to-cost ratio were incurred by dividing the net returns by the total cost of cultivation.

2.8. Statistical analysis

The data collected for various horticultural attributes of pomato plants were subjected to analysis of variance in Randomized Complete block design, to find the critical difference ($\leq$0.05) among the treatments. The data was analyzed using SPSS and WASP 2.0 software to check the significance level between the various treatments as Gomez and Gomez [22] suggested.

3. Results

Most of the studied treatments/graft combinations showed significantly positive influences on the various yielding attributes on the harvested produce of pomato i.e. tomato fruits and potato tubers. However, the resulting outcomes of the investigation also confirm the highest compatibility rate amongst the used varieties/hybrids of tomato (scion) and potato (rootstocks). Meanwhile, these graft combinations can further be used for the efficient utilization of capital and land. Based on the differential economic analysis between

Table 2
Effect of rootstock-scion interaction of tomato onto potato grafts on fruit length, fruit width, number of fruits per cluster, and number of fruits per plant of tomato.

Treatments	FL (cm)			FW (cm)			NFPC			NFPP		
Pomato graft combinations												
	2019–20	2020–21	Pooled	2019–20	2020–21	Pooled	2019–20	2020–21	Pooled	2019–20	2020–21	Pooled
R_1S_1	5.20[a]	5.31[a]	5.25[a]	5.38	5.69	5.53	4.80[a]	5.08	4.94	33.60	32.53	33.07
R_1S_2	5.02[a]	5.18	5.10[a]	5.14	5.60	5.37	7.80[a]	6.15	6.98	30.20	31.33	30.77
R_1S_3	5.00[a]	4.77	4.89	5.12	5.14	5.13	6.40[a]	6.53	6.47	34.20	33.87	34.03
R_1S_4	3.88	4.37	4.12	5.10	5.11	5.10	7.20[a]	6.67	6.93	33.00	32.29	32.64
R_2S_1	5.24[a]	5.36[a]	5.30[a]	5.80	5.77[a]	5.78	6.20[a]	7.07	6.63	32.40	21.80	27.10
R_2S_2	4.78	4.81	4.79	5.52	5.27	5.39	6.60[a]	7.00	6.80	27.80	26.94	27.37
R_2S_3	4.68	4.52	4.60	5.38	5.10	5.24	7.20[a]	7.27	7.23[a]	33.80	26.87	30.33
R_2S_4	4.44	4.49	4.46	5.16	5.11	5.14	8.80[a]	7.60	8.20[a]	47.60[a]	45.74[a]	46.67[a]
R_3S_1	4.26	4.88	4.57	5.54	5.44	5.49	8.60[a]	7.00	7.80[a]	27.20	24.20	25.70
R_3S_2	5.68[a]	5.52[a]	5.60[a]	5.30	5.48	5.39	5.80	6.59	6.19	29.70	27.37	28.53
R_3S_3	4.64	4.65	4.65	5.20	5.23	5.22	5.80	6.08	5.94	33.20	33.53	33.37
R_3S_4	4.34	4.37	4.36	4.78	4.99	4.89	6.80[a]	7.42	7.11[a]	43.60[a]	45.73[a]	44.67[a]
R_4S_1	5.38[a]	5.22[a]	5.30[a]	6.24	6.00[a]	6.12[a]	5.80	7.14	6.47	39.84	39.31	39.57
R_4S_2	5.38[a]	5.24[a]	5.31[a]	5.48	5.56	5.52	6.60[a]	6.31	6.45	36.11	36.40	36.26
R_4S_3	4.70	4.53	4.61	4.76	5.05	4.90	6.20[a]	6.60	6.40	41.60[a]	40.97[a]	41.29[a]
R_4S_4	4.80	4.63	4.71	5.12	5.32	5.22	6.40[a]	7.00	6.70	33.40	34.47	33.93
Control (Ungrafted tomato plant)												
S_{T0}	4.98	5.19	5.08	6.40	5.76	6.08	5.80	8.20	7.00	40.20	40.67	40.43
Range	3.88–5.68	4.37–5.52	4.12–5.60	4.76–6.24	4.99–6.00	4.89–6.12	4.80–8.80	5.08–8.20	4.94–8.20	27.20–47.60	21.80–45.74	25.70–46.67
Mean	4.85	4.88	4.87	5.38	5.39	5.38	6.64	6.81	6.72	35.14	33.77	34.45
SE (±)	0.09	0.15	0.12	0.08	0.16	0.14	0.13	0.15	0.16	0.57	1.81	1.35
C.V.	3.15	5.30	4.36	2.46	5.05	4.38	3.51	3.81	4.24	2.80	9.27	6.77
C.D. at $P \leq 0.05$	0.25	0.43	0.25	0.22	0.45	0.28	0.39	0.43	0.33	1.64	5.20	2.74

Abbreviations: FL: Fruit length; FW: Fruit width; NFPC: Number of fruits per cluster; NFPP: Number of fruits per plant; *superior over control; R_1S_1: Kufri Jyoti + Avtar; R_1S_2: Kufri Jyoti + Rakhsita; R_1S_3: Kufri Jyoti + Heemsohna; R_1S_4: Kufri Jyoti + PTH-1; R_2S_1: Kufri Khyati + Avtar; R_2S_2: Kufri Khyati + Rakhsita; R_2S_3: Kufri Khyati + Heemsohna; R_2S_4: Kufri Khyati + PTH-1; R_3S_1: Kufri Himalini + Avtar; R_3S_2: Kufri Himalini + Rakhsita; R_3S_3: Kufri Himalini + Heemsohna; R_3S_4: Kufri Himalini + PTH-1; R_4S_1: Kufri Pukhraj + Avtar; R_4S_2: Kufri Pukhraj + Rakhsita; R_4S_3: Kufri Pukhraj + Heemsohna; R_4S_4: Kufri Pukhraj + PTH-1; S_{T0}: Avtar.

[a] Significance at $P \leq 0.05$.

Table 3
Effect of rootstock-scion interaction of tomato onto potato grafts on average fruit weight, fruit yield per square meter, total fruit yield, and harvest duration of tomato.

Treatments	AFW(g)			FYPSM(kg)			TFY(qha^{-1})			HD(days)		
Pomato graft combinations												
	2019–20	2020–21	Pooled	2019–20	2020–21	Pooled	2019–20	2020–21	Pooled	2019–20	2020–21	Pooled
R_1S_1	100.40	107.20[a]	103.80	20.24	20.93	20.59	2024.06	2093.12	2058.59	74.54	84.20	79.37
R_1S_2	97.20	99.33	98.27	17.61	18.68	18.15	1761.42	1868.15	1814.79	80.89[a]	90.93[a]	85.91[a]
R_1S_3	70.40	72.73	71.57	14.45	14.78	14.62	1445.42	1478.45	1461.93	82.44[a]	92.27[a]	87.35[a]
R_1S_4	69.20	68.87	69.03	13.70	13.29	13.49	1369.78	1329.20	1349.49	88.68[a]	98.73[a]	93.71[a]
R_2S_1	94.60	96.13	95.37	18.39	12.48	15.43	1839.02	1247.93	1543.47	79.65	89.93	84.79
R_2S_2	75.00	75.60	75.30	12.51	12.22	12.37	1251.48	1222.31	1236.89	79.32	89.20	84.26
R_2S_3	77.60	73.80	75.70	15.74	11.98	13.86	1573.81	1198.40	1386.10	81.55[a]	91.67[a]	86.61[a]
R_2S_4	69.40	66.93	68.17	19.80	18.35	19.08	1979.88	1835.14	1907.51	84.61[a]	94.73[a]	89.67[a]
R_3S_1	86.00	84.33	85.17	14.03	12.27	13.15	1402.58	1227.16	1314.87	80.93[a]	90.73[a]	85.83[a]
R_3S_2	82.00	84.00	83.00	14.61	13.79	14.20	1461.17	1378.60	1419.88	81.49[a]	91.53[a]	86.51[a]
R_3S_3	70.00	70.07	70.03	13.95	14.11	14.03	1394.83	1411.04	1402.94	89.68[a]	99.47[a]	94.57[a]
R_3S_4	62.00	62.73	62.37	16.22	17.21	16.72	1621.91	1721.25	1671.58	85.73[a]	95.93[a]	90.83[a]
R_4S_1	102.60	105.13[a]	103.87	24.53	24.79	24.66	2452.76	2479.05	2465.91	78.93	88.67	83.80
R_4S_2	100.80	100.93	100.87	21.84	22.04	21.94	2183.97	2203.92	2193.95	77.47	87.20	82.34
R_4S_3	78.60	76.47	77.53	19.64	18.80	19.22	1963.56	1880.07	1921.81	82.33[a]	92.10[a]	87.22[a]
R_4S_4	70.00	71.40	70.70	14.02	14.76	14.39	1402.46	1475.99	1439.22	83.20[a]	93.07[a]	88.13[a]
Control (un-grafted tomato plant)												
S_{T0}	107.40	103.40	105.40	25.92	25.19	25.56	2591.77	2519.28	2555.52	79.91	89.93	84.92
Range	62.00–107.40	62.73–107.20	62.37–105.40	12.51–25.92	11.98–25.19	12.37–25.56	1251.48–2591.77	1198.40–2519.28	1236.89–2555.52	74.54–89.68	84.20–99.47	79.37–94.57
Mean	83.13	83.47	83.30	17.48	16.80	17.14	1748.15	1679.95	1714.05	81.84	91.78	86.81
SE(±)	1.19	2.05	1.71	0.40	1.07	0.83	40.06	107.15	82.50	0.92	2.74	2.39
C.V.	2.48	4.26	3.55	3.97	11.04	8.34	3.97	11.04	8.34	1.94	5.18	4.77
C.D. at P ≤ 0.05	3.43	5.92	3.48	1.15	3.09	1.68	115.40	308.67	168.05	2.64	7.91	4.87

Abbreviations: AFW: Average fruit weight; FYPSM: Fruit yield per square meter; TFY: Total fruit yield; HD: Harvest duration; *Superior over control; R_1S_1: Kufri Jyoti + Avtar; R_1S_2: Kufri Jyoti + Rakhsita; R_1S_3: Kufri Jyoti + Heemsohna; R_1S_4: Kufri Jyoti + PTH-1; R_2S_1: Kufri Khyati + Avtar; R_2S_2: Kufri Khyati + Rakhsita; R_2S_3: Kufri Khyati + Heemsohna; R_2S_4: Kufri Khyati + PTH-1; R_3S_1: Kufri Himalini + Avtar; R_3S_2: Kufri Himalini + Rakhsita; R_3S_3: Kufri Himalini + Heemsohna; R_3S_4: Kufri Himalini + PTH-1; R_4S_1: Kufri Pukhraj + Avtar; R_4S_2: Kufri Pukhraj + Rakhsita; R_4S_3: Kufri Pukhraj + Heemsohna; R_4S_4: Kufri Pukhraj + PTH-1; S_{T0}: Avtar.

[a] Significance at $P \leq 0.05$.

non-grafted plants and pomato grafts, the study confirmed that the individual pomato graft can produce more yield than of non-grafted sole plant, and also incremented the benefit-to-cost ratio in terms of profitability.

3.1. Tomato harvested from grafted pomato plant

3.1.1. Yielding attributes

Tomato fruit length was significantly influenced by different graft combinations established between the tomato scions and potato rootstocks (Table 2). In between the comparison of various pomato graft combinations Rakshita grafted onto Kufri Himalini resulted in the highest fruit length in both the respective years and pooled over years. In the first year of experimentation, when the experimental treatment combinations were compared with control Avtar, the seven graft combinations were found to be most superior and had the highest fruit length than of control viz., Rakshita onto Kufri Himalini, Kufri Jyoti and Kufri Pukhraj, Avtar onto Kufri Pukhraj, Kufri Khyati and Kufri Jyoti, Heemsohna onto Kufri Jyoti. Meanwhile, in the second year and pooled over the years of experiment, a total of five pomato grafts showed superiority over the control namely, Rakshita grafted onto Kufri Himalini and Kufri Pukhraj, while Avtar onto Kufri Khyati, Kufri Jyoti and Kufri Pukhraj, respectively. Additionally, Avtar grafted onto Kufri Himalini was found to have a 14.06 %, 6.3 %, and 10.24 % increment in fruit length than of control in both respective and pooled over the year. The presented data in Table 2, illustrated that significant variation was recorded for fruit width amid the treatments. The highest value for fruit width was noted with graft combination of Avtar onto Kufri Pukhraj during both respective years and pooled over years. The fruit width of control Avtar was compared with sixteen pomato graft combinations during both years and pooled over the years. The presented data of the second year elucidated that only two pomato combinations viz., Avtar onto Kufri Pukhraj and Kufri Khyati had showed their superiority over all other graft combinations and control. Meanwhile in pooled over the years one of the graft combinations i.e. Avtar onto Kufri Pukhraj was found better over the control. The non-grafted tomato plant performed 2.5 % better than of studied combinations in 2019–20. But in the second year and pooled over years the best combination expressed their superiority about of 4.16 % and 0.65 % over the control for the studied trait. Meanwhile, a positive increment in the no. of fruits per plant resulted in the produce harvested from the scion Palam Tomato Hybrid-1 grafted onto rootstock Kufri Khyati, during both years and pooled over the years. A non-grafted control "Avtar" produced 40.20, 40.67, and 40.43 lesser fruits per plant, when compared with pomato graft combinations, where three of the graft combinations i.e. Palam Tomato Hybrid-1 grafted onto Kufri Khyati and Kufri Himalini, also Heemsohna onto Kufri Pukhraj were showed their superiority over control during both consecutive years and pooled over years. The combination Palam Tomato Hybrid-1grafted onto Kufri Khyati produced 18.41 %, 12.47 %, and 15.43 % significantly greater no. of fruits per plant than of control. In addition to this, average fruit weight was positively affected by all the treatments used in the study as mentioned in Table 3. The data analyzed in the first year of the study revealed that only a sole graft combination of Avtar grafted onto Kufri Jyoti had the maximum average fruit weight, while in the second year and pooled over the years, among all the studied treatments it resulted in the fruits collected from the non-grafted sole tomato plant of "Avtar". In comparison amongst combinations, Avtar grafted onto Kufri Pukhraj recorded with highest average fruit weight during the first year and pooled over the years. Whereas in the second year, Avtar grafted onto Kufri Jyoti showed the highest value for the studied character which was followed by Avtar onto Kufri Pukhraj. When the pomato graft combinations were compared with control "Avtar", during the year first year only two graft combinations namely, scion Avtar grafted onto the rootstock of Kufri Jyoti and Kufri Pukhraj showed superiority over the control. The control fruits' weight was found 4.46 % and 1.45 % more than the best-performing combination in the first year and pooled over years, 3.67 % more than of control in the second year.

All the sixteen graft interactions were compared with each other and the results revealed that the graft combination Avtar grafted onto Kufri Pukhraj produced maximum fruit yield per square meter, and performed best in both consecutive years and pooled over years. In comparison amongst the control to the graft combinations, none of the graft combinations was found superior over the control during both consecutive years and in pooled mean. To get a clear view of the percentage effect of combination over control, the value stated that combinations had 5.36 %, 1.58 %, and 3.52 % lesser fruit yield than of control during both consecutive years and pooled over years. However, over the environments, a positive increment in the total fruit yield quintal per hectare was observed in control Avtar as mentioned in Table 3. During the comparison between different graft interactions, the data revealed that Avtar grafted onto Kufri Pukhraj produced the highest fruit yield over the environments. Meanwhile the control "Avtar" produced a significantly higher yield than all sixteen combinations during consecutive years and pooled over years, while no other combination showed superiority over the control throughout the investigation. In the comparison of the yield of control "Avtar", the graft combination Avtar onto Kufri Pukhraj resulted in 5.36 %, 1.59 %, and 3.50 % lower yield per hectare during both years and pooled over years.

From the perusal of data demonstrated in Tables 3 and it has been noticed that all the treatments showed a positive outcome on the studied character. In the comparison amongst the graft combinations harvest duration was recorded highest in graft Heemsohna grafted onto Kufri Himalini, during both consecutive years and pooled over the years. After comparing the combination among them, the performance of combinations was compared over the control i.e. sole un-grafted tomato "Avtar, where the result depicted that the eleven different graft combinations except scion of Rakshita grafted onto the rootstock of Kufri Pukhraj and Kufri Khyati, also scion "Avtar" grafted onto the rootstock of Kufri Jyoti, Kufri Pukhraj and Kufri Khyati were performed superior over control during both years and pooled over years. On the other hand, the best-performing combination Avtar onto Kufri Himalini showed that the combination has a longer harvest duration than of control.

3.2. Potato harvested from grafted pomato plant

The survival rate of graft unions depends on various factors, including the kind of variety used, the taxonomic proximity of the scion

Table 4
Effect of rootstock-scion interaction of tomato onto potato grafts on the survival rate of grafted plants, tuber length, tuber width, and number of tubers per plant of potato.

Treatments	SRGP (%)			TL (cm)			TW (cm)			NTPP		
Pomato graft combinations												
	2019–20	2020–21	Pooled	2019–20	2020–21	Pooled	2019–20	2020–21	Pooled	2019–20	2020–21	Pooled
R_1S_1	85.20	88.33	86.77	6.66[a]	6.76[a]	6.71[a]	5.74[a]	6.01[a]	5.87[a]	5.20	5.60	5.40
R_1S_2	83.73	86.67	85.20	4.92	6.49[a]	5.70	5.38[a]	5.53[a]	5.46[a]	4.98	5.45	5.21
R_1S_3	90.10	93.33	91.72	7.08[a]	6.12[a]	6.60[a]	5.40[a]	5.27[a]	5.33[a]	7.20[a]	6.80[a]	7.00[a]
R_1S_4	74.10	70.00	72.05	6.12	6.27[a]	6.20[a]	5.54[a]	5.16[a]	5.35[a]	4.90	4.82	4.86
R_2S_1	80.12	81.67	80.89	6.40[a]	6.36[a]	6.38[a]	5.62[a]	5.47[a]	5.54[a]	5.10	6.40[a]	5.75
R_2S_2	84.60	86.67	85.63	5.30	6.70[a]	6.00	5.88[a]	5.81[a]	5.85[a]	6.30	5.33	5.82
R_2S_3	87.20	90.00	88.60	6.12	6.22[a]	6.17[a]	4.66[a]	5.41[a]	5.03[a]	4.90	4.80	4.85
R_2S_4	73.40	71.67	72.53	5.98	6.35[a]	6.17[a]	4.40[a]	5.08[a]	4.74[a]	4.80	5.31	5.06
R_3S_1	85.40	85.00	85.20	7.72[a]	8.05[a]	7.89[a]	7.66[a]	6.61[a]	7.14[a]	4.30	4.53	4.42
R_3S_2	81.20	86.67	83.93	8.12[a]	8.80[a]	8.46[a]	6.86[a]	7.03[a]	6.95[a]	4.80	4.87	4.83
R_3S_3	75.90	78.33	77.12	7.34[a]	8.75[a]	8.05[a]	7.22[a]	6.81[a]	7.02[a]	4.60	5.67	5.13
R_3S_4	77.10	76.67	76.88	8.00[a]	7.59[a]	7.80[a]	6.50[a]	6.32[a]	6.41[a]	5.10	5.60	5.35
R_4S_1	88.60	90.00	89.30	8.26[a]	8.61[a]	8.43[a]	6.64[a]	6.40[a]	6.52[a]	6.10	5.73	5.92
R_4S_2	80.10	83.33	81.72	8.40[a]	8.38[a]	8.39[a]	6.12[a]	6.61[a]	6.37[a]	5.00	5.20	5.10
R_4S_3	85.99	86.67	86.33	6.26[a]	7.22[a]	6.74[a]	6.18[a]	6.51[a]	6.35[a]	5.10	5.13	5.12
R_4S_4	85.10	91.60	88.35	7.49[a]	6.21[a]	6.85[a]	3.40	4.48	3.94	7.30[a]	8.20[a]	7.75[a]
Control (Un-grafted tomato plant)												
S_{P0}	–	–	–	6.20	6.01	6.11	4.12	4.65	4.38	6.70	6.20	6.45
Range	73.40-											
90.10	70.00-											
93.33	72.05–91.72	4.92–8.40	6.01–8.80	5.70–8.46	3.40–7.66	4.48–7.03	3.94–7.14	4.30–7.30	4.53-			
8.20	4.42–7.75											
Mean	77.52	79.21	78.37	6.85	7.11	6.98	5.72	5.83	5.78	5.43	5.63	5.53
SE(±)	1.07	0.69	0.95	0.14	0.16	0.18	0.08	0.21	0.17	0.14	0.19	0.17
C.V.	2.40	1.51	2.11	3.67	3.81	4.53	2.47	6.27	5.17	4.55	5.92	5.38
C.D. at $P \le 0.05$	3.09	2.00	1.94	0.42	0.45	0.37	0.24	0.61	0.35	0.41	0.55	0.35

Abbreviations: SRGP: Survival rate of grafted plants; TL: Tuber length; TW: Tauber weight; NTPP: number of tubers per plant; *Superior over control; R_1S_1: Kufri Jyoti + Avtar; R_1S_2: Kufri Jyoti + Rakhsita; R_1S_3: Kufri Jyoti + Heemsohna; R_1S_4: Kufri Jyoti + PTH-1; R_2S_1: Kufri Khyati + Avtar; R_2S_2: Kufri Khyati + Rakhsita; R_2S_3: Kufri Khyati + Heemsohna; R_2S_4: Kufri Khyati + PTH-1; R_3S_1: Kufri Himalini + Avtar; R_3S_2: Kufri Himalini + Rakhsita; R_3S_3: Kufri Himalini + Heemsohna; R_3S_4: Kufri Himalini + PTH-1; R_4S_1: Kufri Pukhraj + Avtar; R_4S_2: Kufri Pukhraj + Rakhsita; R_4S_3: Kufri Pukhraj + Heemsohna; R_4S_4: Kufri Pukhraj + PTH-1; S_{T0}: Avtar.

[a] Significance at $P \le 0.05$.

Table 5
Effect of rootstock-scion interaction of tomato onto potato grafts on average tuber weight, tuber yield per plant, total tuber yield, and tuber equivalent yield of potato.

Treatments	ATW(g)			TYPP(g)			TTY(qha^{-1})			TEY(qha^{-1})		
Pomato graft combinations												
	2019–20	2020–21	Pooled	2019–20	2020–21	Pooled	2019–20	2020–21	Pooled	2019–20	2020–21	Pooled
R_1S_1	79.30[a]	87.87[a]	83.58[a]	412.39[a]	491.85[a]	452.12[a]	247.44[a]	295.11[a]	271.27[a]	1619.25	1674.50	1646.87
R_1S_2	102.90[a]	95.47[a]	99.18[a]	512.09[a]	519.98[a]	516.03[a]	307.26[a]	311.99[a]	309.62[a]	1409.14	1494.52	1451.83
R_1S_3	43.80	53.27	48.53	315.46	362.52	338.99	189.28	217.51	203.39	1156.33	1182.76	1169.55
R_1S_4	54.20	47.93	51.07	265.69	229.01	247.35	159.41	137.41	148.41	1095.83	1063.36	1079.60
R_2S_1	85.80[a]	90.33[a]	88.07[a]	437.59[a]	581.09[a]	509.34[a]	262.56[a]	348.66[a]	305.61[a]	1471.21	998.34	1234.78
R_2S_2	135.50[a]	115.33[a]	125.42[a]	853.37[a]	615.39[a]	734.38[a]	512.02	369.23[a]	440.63[a]	1001.18	977.85	989.51
R_2S_3	89.70[a]	71.13[a]	80.42[a]	439.56[a]	341.12	390.34	263.74[a]	204.67	234.20	1259.05	958.72	1108.88
R_2S_4	103.40[a]	87.27[a]	95.33[a]	496.13[a]	463.28[a]	479.71[a]	297.68[a]	277.97[a]	287.82[a]	1583.90	1468.11	1526.01
R_3S_1	127.70[a]	147.47[a]	137.58[a]	549.08[a]	667.83[a]	608.46[a]	329.45[a]	400.70[a]	365.07[a]	1122.07	981.73	1051.90
R_3S_2	179.40[a]	172.27[a]	175.83[a]	860.95[a]	836.28[a]	848.62[a]	516.57[a]	501.77[a]	509.17[a]	1168.94	1102.88	1135.91
R_3S_3	134.40[a]	149.80[a]	142.10[a]	618.31[a]	848.92[a]	733.61[a]	370.98[a]	509.35[a]	440.17[a]	1115.87	1128.83	1122.35
R_3S_4	161.70[a]	155.60[a]	158.65[a]	824.44[a]	871.24[a]	847.84[a]	494.67[a]	522.74[a]	508.70[a]	1297.53	1377.00	1337.26
R_4S_1	154.50[a]	152.60[a]	153.55[a]	942.23[a]	873.99[a]	908.11[a]	565.34[a]	524.39[a]	544.87[a]	1962.21	1983.24	1972.72
R_4S_2	152.40[a]	134.67[a]	143.53[a]	763.06[a]	700.88[a]	731.97[a]	457.84[a]	420.53[a]	439.18[a]	1747.18	1763.13	1755.16
R_4S_3	99.60[a]	139.73[a]	119.67[a]	507.92[a]	717.31[a]	612.61[a]	304.75[a]	430.38[a]	367.57[a]	1570.85	1504.06	1537.45
R_4S_4	64.30[a]	54.73	59.52	469.59[a]	448.29[a]	458.94[a]	281.75[a]	268.98[a]	275.37[a]	1121.97	1180.79	1151.38
Control (Ungrafted tomato plant)												
S_{P0}	61.50	66.00	63.75	412.00	409.08	410.54	247.20	245.45	246.32	–	–	–
Range	43.80–179.40	47.93–172.27	48.53–175.83	265.69–942.23	229.01–873.99	247.35–908.11	159.41-					
565.34	137.41-											
524.39	148.41 –											
544.87	1001.18–1962.21	958.72–1983.24	989.51–1972.72									
Mean	107.65	107.15	107.40	569.41	586.94	578.17	341.64	352.17	346.90	1356.41	1302.49	1329.45
SE(±)	1.86	3.51	2.82	23.61	27.19	25.22	14.16	16.31	15.13	28.39	85.81	64.80
C.V.	3.00	5.68	4.54	7.18	8.02	7.55	7.18	8.02	7.55	3.85	12.12	8.97
C.D. at P ≤ 0.05	5.37	10.12	5.73	68.00	78.32	51.37	40.80	46.99	30.82	81.79	247.20	132.00

Abbreviations: ATW: Average tuber weight; TYPP: Tuber yield per plant; TTY: Total tuber yield; TEY: Tuber equivalent yield *Superior over control; R_1S_1: Kufri Jyoti + Avtar; R_1S_2: Kufri Jyoti + Rakhsita; R_1S_3: Kufri Jyoti + Heemsohna; R_1S_4: Kufri Jyoti + PTH-1; R_2S_1: Kufri Khyati + Avtar; R_2S_2: Kufri Khyati + Rakhsita; R_2S_3: Kufri Khyati + Heemsohna; R_2S_4: Kufri Khyati + PTH-1; R_3S_1: Kufri Himalini + Avtar; R_3S_2: Kufri Himalini + Rakhsita; R_3S_3: Kufri Himalini + Heemsohna; R_3S_4: Kufri Himalini + PTH-1; R_4S_1: Kufri Pukhraj + Avtar; R_4S_2: Kufri Pukhraj + Rakhsita; R_4S_3: Kufri Pukhraj + Heemsohna; R_4S_4: Kufri Pukhraj + PTH-1; S_{T0}: Avtar.

[a] Significance at P ≤ 0.05.

and rootstock, and several other environmental factors [23]. As the tomato and potato belong to the same family, and genera, and share a similar basic chromosome number it, can increase the success rate of established graft unions [24].

From the data given in Table 4, it has been recorded that a significant effect of all studied treatments including sixteen different graft combinations and one check (Potato) used in the study was recorded for the survival rate of grafted plants. Amongst the sixteen diverse graft interactions, the highest level of survival rate of graft interactions was recorded in the graft union of Heemsohna onto Kufri Jyoti, which was found at par with two other combinations namely, Kufri Avtar onto Kufri Pukhraj and Heemsohna onto Kufri Khyati in the first year. Apart from this, the same combination i.e. Heemsohna onto Kufri Jyoti resulted in the highest survival percentage value in the second year followed by Palam Tomato Hybrid-1, while in pooled the over years as well where none of the other graft interactions was noticed at par to best performing graft combination.

Tuber size can also contribute to increasing the tuber yield as the bigger the size of the seed tuber more the yield. The bigger-sized seed tuber has comparatively high food reserves in it that might have a noteworthy influence on the growth and development of plants and subsequently improve the large-sized tuber yield of potatoes. It is summarized from the data elaborated in Table 4, that there was a significant outcome of different graft interactions of potato and tomato were documented for tuber length and width during both respective and pooled over years. Additionally, in comparison amongst the graft combinations the maximum tuber length was reported in the graft union established in between scion Rakshita onto Kufri Pukhraj (2019-20), and Rakshita onto Kufri Himalini (2021-22 and pooled over the years). Apart from this, in the first year of the experiment, eleven different graft combinations showed their superiority over the control excluding Palam Tomato Hybrid-1 grafted onto Kufri Jyoti and Kufri Khyati, Heemsohna onto Kufri Khyati, Rakshita onto Kufri Jyoti and Kufri Khyati. All sixteen graft combinations in the second year and fifteen in pooled over years excluding Rakshita onto Kufri Khyati showed superiority over the potato control (Kufri Pukhraj). The performance of best-performing combinations during both years and pooled over the years demonstrated the percent value of superiority over control at about 35.48 %, 46.42 %, and 38.46 %, respectively. Meanwhile, amongst the graft combinations, the tuber width was found to be higher with a graft union of scion Avtar grafted onto Kufri Himalini (2019-20 & pooled) and Rakshita onto Kufri Himalini (2022-21). On comparison of sixteen diverse graft combinations, as observed earlier, the controls produced a smaller width size of tuber than most of the graft interactions. The collected data was evaluated to know the performance of graft interactions over control, all fifteen diverse graft interactions during both years and pooled over years other than of Palam Tomato Hybrid-1 grafted onto Kufri Pukhraj showed their superiority over control. As per the evaluated data values for the studied character the tuber harvested from graft union of scion "Avtar" onto Kufri Himalini (2019-20 & pooled) and Rakshita onto Kufri Himalini (2020-21) had a maximum tuber width of about 85.92 %, 51.18 %, and 63.01 % than of control.

The number of tuber plants is one of the yield-contributing traits and affects the yielding ability of potato tubers, for that purpose the potato tubers were counted from each replication for all treatments. A critical examination of the data noted in Table 4, depicted that the combination Palam Tomato Hybrid −1 grafted onto Kufri Pukhraj had the highest no. of tubers per plant which was noted at par with Kufri Jyoti + Heemsohna during both respective years and pooled over the years. A non-grafted potato plant of Kufri Pukhraj was also compared to all sixteen different interactions during both years and pooled over years. The results elucidated that two of the graft interactions namely, Palam Tomato Hybrid −1 grafted onto Kufri Pukhraj and Heemsohna onto Kufri Jyoti performed better over control in 2019–20. In the meantime, three and two of the pomato grafts during 2020-21 and pooled over years showed their superiority over control "Kufri Pukhraj" i.e. Palam Tomato Hybrid −1 onto Kufri Pukhraj, Avtar onto Kufri Khyati, Heemsohna onto Kufri Jyoti in 2020-21 and Palam Tomato Hybrid-1 onto Kufri Pukhraj, Heemsohna onto Kufri Jyoti in pooled over years, correspondingly. The combinations produced 8.96 %, 32.26 %, and 20.16 % more tubers than control Kufri Pukhraj.

A significant level of variation was recorded among the studied treatments for average tuber weight (Table 5). In between all sixteen graft interactions, the maximum average tuber weight amongst all the studied treatments was notified with pomato graft of Rakshita onto Kufri Himalini, during both consecutive years and pooled over years. Furthermore, a sole non-grafted potato plant tuber was compared with sixteen different graft combinations, demonstrating that in the first year of study, fourteen different graft interactions were reported their superiority over control except the combinations of scions Heemsohna and Palam Tomato Hybrid-1 grafted onto the rootstock of Kufri Jyoti, individually. Likewise in the second year of study, thirteen graft interactions excluding three i.e. Palam Tomato Hybrid-1 onto Kufri Jyoti, Heemsohna onto Kufri Jyoti, and Palam Tomato Hybrid-1 onto Kufri Pukhraj, while during the pooled analysis of both years, thirteen different pomato grafts except Heemsohna onto Kufri Jyoti and Palam Tomato Hybrid-1 onto Kufri Jyoti was proclaimed their superiority over potato control. The pomato graft of Rakshita onto Kufri Himalini produced 117.9 g (2019-20), 65.12 g (2020-21), and 112.08 g (pooled mean) of more tuber weight than the weight of control Kufri Pukhraj. A positive increment in tuber yield per plant was recorded with interaction of Avtar onto Kufri Pukhraj, over the environments and pooled mean. In the continuation of this, a sole non-grafted potato plant variety Kufri Pukhraj used as a check was also weighed up with all studied pomato graft combinations. In the first year of the experiment, a total of fourteen pomato graft interactions produced higher yield than of control except Palam Tomato Hybrid-1 onto Kufri Jyoti and Heemsohna onto Kufri Jyoti. Likewise in the second year, thirteen other graft interactions also performed better over control excluding Palam Tomato Hybrid-1 onto Kufri Jyoti, Heemsohna onto Kufri Khyati, and Heemsohna onto Kufri Jyoti. Pooled over years of data validated that the twelve different pomato graft unions except Palam Tomato Hybrid-1 onto Kufri Jyoti, Heemsohna onto Kufri Jyoti, and Heemsohna onto Kufri Khyati showed their superiority over control. As per the above-discussed results, it has been demonstrated that graft combinations performed well over control for yield per plant, and produced 128.69 %, 113.65 %, and 121.19 % more yield per plant than of control Kufri Pukhraj during both consecutive and pooled over years.

Total tuber yield quintal per hectare was remarkably affected by all studied treatments during the evaluation trials during 2019–20, and 2020-20 and pooled over years as mentioned in Table 5. From the collected data for sixteen different combinations, it has been concluded that the graft combination namely, Avtar grafted onto Kufri Pukhraj produced the highest tuber yield quintal per hectare

Table 6
Effect of rootstock-scion interaction of tomato onto potato grafts on total yield per plant, total yield per square meter, and total yield of pomato plant.

Treatments	TYPP (kg)			TYPSM (kg)			TY (q/ha)		
Combinations									
	2019–20	2020–21	Pooled	2019–20	2020–21	Pooled	2019–20	2020–21	Pooled
R_1S_1	3.79[a]	3.98[a]	3.88[a]	22.71[a]	23.88[a]	23.30[a]	2271.50[a]	2388.23[a]	2329.86[a]
R_1S_2	3.45[a]	3.63[a]	3.54[a]	20.69[a]	21.80[a]	21.24[a]	2068.68[a]	2180.14[a]	2124.41[a]
R_1S_3	2.72[a]	2.83[a]	2.78[a]	16.35[a]	16.96[a]	16.65[a]	1634.69[a]	1695.96[a]	1665.33[a]
R_1S_4	2.55[a]	2.44[a]	2.50[a]	15.29[a]	14.67[a]	14.98[a]	1529.20[a]	1466.61[a]	1497.90[a]
R_2S_1	3.50[a]	2.66[a]	3.08[a]	21.02[a]	15.97[a]	18.49[a]	2101.57[a]	1596.58[a]	1849.08[a]
R_2S_2	2.94[a]	2.65[a]	2.80[a]	17.63[a]	15.92[a]	16.78[a]	1763.50[a]	1591.54[a]	1677.52[a]
R_2S_3	3.06[a]	2.34[a]	2.70[a]	18.38[a]	14.03[a]	16.20[a]	1837.55[a]	1403.07[a]	1620.31[a]
R_2S_4	3.80[a]	3.52[a]	3.66[a]	22.78[a]	21.13[a]	21.95[a]	2277.56[a]	2113.11[a]	2195.33[a]
R_3S_1	2.89[a]	2.71[a]	2.80[a]	17.32[a]	16.28[a]	16.80[a]	1732.03[a]	1627.86[a]	1679.94[a]
R_3S_2	3.30[a]	3.13[a]	3.22[a]	19.78[a]	18.80[a]	19.29[a]	1977.74[a]	1880.37[a]	1929.06[a]
R_3S_3	2.94[a]	3.20[a]	3.07[a]	17.66[a]	19.20[a]	18.43[a]	1765.82[a]	1920.39[a]	1843.11[a]
R_3S_4	3.53[a]	3.74[a]	3.63[a]	21.17[a]	22.44[a]	21.80[a]	2116.58[a]	2243.99[a]	2180.29[a]
R_4S_1	5.03*T&P	5.01*T&P	5.02*T&P	30.18*T&P	30.03*T&P	30.11*T&P	3018.10*T&P	3003.44*T&P	3010.77*T&P
R_4S_2	4.40*T&P	4.37*T&P	4.39*T&P	26.42*T&P	26.24*T&P	26.33*T&P	2641.81*T&P	2624.45*T&P	2633.13*T&P
R_4S_3	3.78[a]	3.85[a]	3.82[a]	22.68[a]	23.10[a]	22.89[a]	2268.31[a]	2310.45[a]	2289.38[a]
R_4S_4	2.81[a]	2.91[a]	2.86[a]	16.84[a]	17.45[a]	17.15[a]	1684.21[a]	1744.97[a]	1714.59[a]
Control									
S_{T0}	4.32	4.20	4.26	25.92	25.19	25.56	2591.77	2519.28	2555.52
R_{P0}	0.412	0.409	0.411	2.47	2.45	2.46	247.20	245.45	246.32
Range	2.55–5.03	2.44–5.01	2.50–5.02	15.29–30.18	14.67–30.03	14.98–30.11	3018.10–1529.20	1466.61–3003.44	1497.90–3010.77
Mean	3.41	3.31	3.36	20.43	19.87	20.15	2043.05	1986.95	2015.00
SE(±)	0.07	0.18	0.14	0.44	1.08	0.84	43.69	107.95	83.64
C.V.	3.62	9.20	7.03	3.62	9.20	7.03	3.62	9.20	7.03
C.D. at P ≤ 0.05	0.21	0.52	0.28	1.26	3.11	1.70	125.86	310.98	170.38

Abbreviations: TYPP: total yield per plant; TYPSM: total yield per square meter, TY: total yield; *Superior over potato control; *T&P Superior over tomato and potato control; R_1S_1: Kufri Jyoti + Avtar; R_1S_2: Kufri.Jyoti + Rakhsita; R_1S_3: Kufri Jyoti + Heemsohna; R_1S_4: Kufri Jyoti + PTH-1; R_2S_1: Kufri Khyati + Avtar; R_2S_2: Kufri Khyati + Rakhsita; R_2S_3: Kufri Khyati + Heemsohna; R_2S_4: Kufri Khyati + PTH-1; R_3S_1: Kufri Himalini + Avtar; R_3S_2: Kufri Himalini + Rakhsita; R_3S_3: Kufri Himalini + Heemsohna; R_3S_4: Kufri Himalini + PTH-1; R_4S_1: Kufri Pukhraj + Avtar; R_4S_2: Kufri Pukhraj + Rakhsita; R_4S_3: Kufri Pukhraj + Heemsohna; R_4S_4: Kufri Pukhraj + PTH-1; S_{T0}: Avtar; R_{P0}: Kufri Pukhraj.

[a] Significance at $P \leq 0.05$.

over the environments and in pooled mean. Likewise, the graft interactions were also compared with control Kufri Pukhraj over the environments. The outcomes of the results presented those fourteen diverse graft interactions of different potato rootstocks and tomato scions showed their superiority over control except Palam Tomato Hybrid-1 onto Kufri Jyoti and Heemsohna onto Kufri Jyoti (2019-20). However, during 2020-21 and pooled over years thirteen graft combinations other than of Palam Tomato Hybrid-1 onto Kufri Jyoti, Heemsohna onto Kufri Khyati and Heemsohna onto Kufri Jyoti (2020-21) also Palam Tomato Hybrid-1 onto Kufri Jyoti and Heemsohna onto Kufri Jyoti in pooled over years performed better over the control. Furthermore, the best-performing pomato graft interaction resulted in 128.69 % (318.14 q), 113.64 % (278.94 q), and 121.20 % (298.55 q) higher yield than of control. Meanwhile, the total equivalent yield per hectare was also calculated for the studied treatments/grafts. The results obtained from the calculated data depicted that a graft combination of Avtar grafted onto Kufri Pukhraj resulted in a significantly positive increment in the tuber equivalent yield quintal per hectare during both years and pooled over the years.

3.3. Pomato

The cumulative yield of the pomato grafts (tomato fruits and potato tubers) for individual treatment was also analyzed, to know the overall production increments per unit area occupied by the pomato grafts over the control. The resulting data values provide the actual values for profitable treatments, particularly for the cultivation of grafted plants over the un-grafted sole production of tomatoes and potatoes. A significant variation was observed amongst the graft combinations for total yield per plant. In between the comparison of all sixteen combinations as mentioned in Table 6, it has been concluded that the total yield per plant (kg), total yield per square meter, and total yield quintal per hectare of pomato grafts comprising tomato fruits and potato tubers was worked out at highest value with graft combination of Avtar onto Kufri Pukhraj during both years and pooled over years. However, the lowest yield was observed with the graft combination of Palam Tomato Hybrid-1 onto Kufri Jyoti during both years and pooled over years, correspondingly. When the non-grafted control of tomato and potato was compared with grafted combinations for total yield per plant and total yield per square meter, two of the graft interactions namely, Avtar onto Kufri Pukhraj and Rakshita onto Kufri Pukhraj produced more yield and showed their superiority over the tomato control (Avtar) during both years and pooled over years. Meanwhile, in comparison of sixteen graft combinations with potato control (Kufri Pukhraj), all the graft combinations performed better than of control over the environments. In context to total yield quintal per hectare, four other graft combinations namely, Rakshita onto Kufri Pukhraj, Heemsohna onto Kufri Pukhraj, Avtar onto Kufri Jyoti and Palam Tomato Hybrid-1 onto Kufri Khyati was also had comparable yield with best performing one i.e. Avtar onto Kufri Pukhraj. In comparison of graft combinations with tomato (Avtar) and potato (Kufri Pukhraj) control, two of the graft interactions viz., Avtar onto Kufri Pukhraj and Rakshita onto Kufri Pukhraj showed their superiority over the non-grafted tomato control (Avtar), whereas in case of comparison amongst potato control with graft interactions, all the sixteen different pomato grafts showed their superiority over the control (Kufri Pukhraj) during 2019–20, 2020-21 and pooled over years.

Table 7
Influence of different potato rootstock and tomato scion combinations on the economics of tomato fruits and potato tubers harvested from pomato plant pooled over years.

Treatments	TYPP (Kg)	TY/250m^2 (kg)	GR (Rs/250 m^2)	CC (Rs/250 m^2)	NR (Rs/250 m^2)	B: C ratio
Combinations						
R_1S_1	3.88	3492.00	157140.00	37860.40	119279.60	4.15*
R_1S_2	3.54	3186.00	143370.00	37918.00	105452.00	3.78*
R_1S_3	2.78	2502.00	112590.00	38054.00	74536.00	2.96*
R_1S_4	2.50	2250.00	101250.00	37798.00	63452.00	2.68*
R_2S_1	3.08	2772.00	124740.00	37940.40	86799.60	3.29*
R_2S_2	2.80	2520.00	113400.00	37998.00	75402.00	2.98*
R_2S_3	2.70	2430.00	109350.00	38134.00	71216.00	2.87*
R_2S_4	3.66	3294.00	148230.00	37878.00	110352.00	3.91*
R_3S_1	2.8	2520.00	113400.00	37940.40	75459.60	2.99*
R_3S_2	3.22	2898.00	130410.00	37998.00	92412.00	3.43*
R_3S_3	3.07	2763.00	124335.00	38134.00	86201.00	3.26*
R_3S_4	3.63	3267.00	147015.00	37878.00	109137.00	3.88*
R_4S_1	5.02	4518.00	203310.00	37860.40	165449.60	5.37*^{T}
R_4S_2	4.39	3951.00	177795.00	37918.00	139877.00	4.69*
R_4S_3	3.82	3438.00	154710.00	38054.00	116656.00	4.07*
R_4S_4	2.86	2574.00	115830.00	37798.00	78032.00	3.06*
Control						
S_{T0}	4.26	3834.00	172530.00	32482.40	140047.60	5.31
R_{P0}	0.411	369.90	16645.50	7178.00	9467.50	2.32

Abbreviations: TYPP: Total yield per plant; TY: Total yield/250 m^2; GR: Gross return; CC: Cost of cultivation; NT: Net return; B:C: Benefit: cost; *Tomato fruit + potato tuber price: 45/- (Tomato: 20/- and Potato: 25/-); *^{T} Superior over tomato control; *Superior over potato control; R_1S_1: Kufri Jyoti + Avtar; R_1S_2: Kufri Jyoti + Rakhsita; R_1S_3: Kufri Jyoti + Heemsohna; R_1S_4: Kufri Jyoti + PTH-1; R_2S_1: Kufri Khyati + Avtar; R_2S_2: Kufri Khyati + Rakhsita; R_2S_3: Kufri Khyati + Heemsohna; R_2S_4: Kufri Khyati + PTH-1; R_3S_1: Kufri Himalini + Avtar; R_3S_2: Kufri Himalini + Rakhsita; R_3S_3: Kufri Himalini + Heemsohna; R_3S_4: Kufri Himalini + PTH-1; R_4S_1: Kufri Pukhraj + Avtar; R_4S_2: Kufri Pukhraj + Rakhsita; R_4S_3: Kufri Pukhraj + Heemsohna; R_4S_4: Kufri Pukhraj + PTH-1; S_{T0}: Avtar; R_{P0}: Kufri Pukhraj.

3.4. Economics of pomato grafts (benefit: cost ratio)

The economics for pomato grafts has been worked out to know the profit margins obtained from the developed grafts that produced two crops from a single plant grown under a modified naturally ventilated polyhouse in an area of 250 m^2. The total yield of pomato grafts was calculated for 250 m^2 and the gross margin, cost of cultivation, net return, and B: C ratio were calculated for the same. When the economics of the non-grafted tomato plant of "Avtar" was compared with sixteen pomato graft combinations, the calculated results depicted that one of the pomato graft combinations i.e. Avtar onto Kufri Pukhraj incurred the highest B: C ratio accompanied with maximum net return and gross return of Rs. account of yield calculated for the area of 250 m^2. In addition to this, all pomato grafts were also compared with non-grafted potato control "Kufri Pukhraj", and the recorded data for economics showed that all sixteen pomato graft combinations were noticed to had the highest B: C ratio accompanied with maximum net returns and gross returns on account of higher total yield per 250 m^2. In the case of potatoes, out of sixteen the five best-performing graft combinations also registered with higher benefits: cost ratio and net returns. The tabulated data presented in Table 7, resulted in for cost of cultivation of Avtar onto Kufri Pukhraj showing the highest B: C ratio and net return. The best-performing graft combination was followed by four other combinations namely, Rakshita onto Kufri Pukhraj, Avtar onto Kufri Jyoti, Heemsohna onto Kufri Pukhraj, and Palam Tomato Hybrid-1 onto Kufri Khyati on account of yield accompanied with higher net return and benefit: cost ratio. The graft combination Avtar onto Kufri Pukhraj worked out with the highest gross return followed by Rakshita onto Kufri Pukhraj, Avtar onto Kufri Jyoti, Heemsohna onto Kufri Pukhraj, and Palam Tomato Hybrid-1 onto Kufri Khyati. On the other hand, the lowest net return and minimum benefit: cost ratio was worked out with control Kufri Pukhraj (potato).

4. Discussion

The process of establishing vascular association joining the "potato" rootstock and "tomato" scion during the graft union of tomato and potato is a complex process, including grafting compatibility and wound healing. Graft incompatibility may result in reduced nutrient and water transport across the developed grafts of the pomato plant. Meanwhile, from the existing investigation, the results confirmed that tomato scion can be efficaciously grafted onto potato rootstocks. The diverse graft unions significantly affect the growth and yield attributes of the tomato and potato harvested from pomato grafts. The maximum fruit length of tomato was determined in the fruits harvested from the pomato graft combination of Rakshita grafted onto Kufri Himalini, while the fruit width was observed in Avtar onto Kufri Pukhraj. The previous study has proved that Grafting can alter the length and width of the tomato fruits, which might be due to fluctuations in the concentration of plant growth regulators caused by the rootstock. The outcomes are consistent with the earlier results of [25–27]. In addition to this, the scion "Palam Tomato Hybrid −1" grafted onto rootstock "Kufri Khyati" had a significantly positive increment in no. of fruits per cluster and plant. However, the potato harvested from the graft union of Kufri Pukhraj onto Palam Tomato Hybrid-1 had the highest no. of tubers per plant. Grafting boosts marketable and total output while decreasing disparities in marketable and total fruit numbers [28]. Gibberellins and cytokinins are imperative regulators of plant growth and development, including fruit formation in tomatoes [30] and tuber development in potatoes [31]. This has also been shown that gibberellins and cytokinins, while having an antagonistic connection, perform a fundamental role in fruit and tuber growth. The tomato plant is high in cytokinins, and a link has been shown between gibberellins, cytokinins metabolism, and tomato fruit growth [31]. Potato plants with higher endogenous cytokinin levels have a greater capability for tuber growth [4]. It is postulated that the influence of these two hormones on fruit and tuber growth reduces their antagonistic effect in pomato plants. High cytokinin content is required for good fruit formation and cell division throughout tomato fruit development [31]. The association between increased tuber yield and advanced growth rate best exemplifies this impact, suggesting a positive plant source-sink relationship [10]. Previous research demonstrated that the above-ground growth features had a direct influence on potato tuber development [32], and Van den et al. [33] revealed that the pace of potato tuber formation was connected also with the intensity of the inductive signal [4]. The survival rate of grafted plants depends upon the type of scion and rootstock, grafting method and age of seedlings to be grafted. The outcomes of the investigation showed that a graft combination of Scion Heemsohna grafted onto rootstock Kufri Jyoti had the highest survival rate percentage, some of the previous investigations have confirmed that a fledgling scion has a more rejuvenating ability than of older one, as in response of grafting these young seedlings boost the meristematic cell activity that ensuing the faster callus formation and quick healing in graft combinations. The current study's findings demonstrate that both rootstock and scion impact grafting efficiency. Grafting success in vegetable crops is caused by cell division at the graft union site of the scion and rootstock, followed by vascular linkage [34]. The above-discussed results conform with Kumar et al. [35], and Negi et al. [36]. The average fruit weight of the tomato fruit was also recorded as highest in control (Avtar), meanwhile, the graft combination of Kufri Pukhraj + Avtar and Kufri Jyoti + Avtar also yielded comparable fruit yield. A rootstock-scion association alters mineral intake and water connections, which results in an augmented average fruit weight of the grafted plants. The conclusions shown above are corroborated by the assertions made by Dijdonou et al. [37]; Kumar et al. [38]; Zhang et al. [39], Ellenberger et al. [40], Mitsanis et al. [41]. On account of this, the fruits harvested from the control plant of Hybrid "Avtar had maximum fruit yield per meter square and total fruit yield quintal per hectare, meanwhile amongst the combined yield of pomato plant graft combination namely, Avtar onto Kufri Pukhraj followed by Rakshita onto Kufri Pukhraj had the highest yield than of control (Tomato and Potato). The tomato plant has several cytokinins and there's a relationship between gibberellins, cytokinins metabolism, and tomato fruit development [31]. Plants with higher endogenous cytokinin levels are more suited for tuber development [42]. Because of the hormonal function in tuber and fruit growth, the antagonistic action of these two hormones is assumed to be decreased in pomato plants. Throughout tomato fruit development, a large amount of CK is necessary for normal fruit formation and cell division [31,43]. As a result, pomato plants are likely to produce fewer tomatoes than self-rooted plants. Moreover, numerous workers have indicated that rootstocks and scions connect, leading to greater root vigor and better mineral and water uptake, resulting in augmented yield and fruit improvement [44,45]. However, yield in pomato plants is minimized by the partitioning of the assimilates into two i.e. fruit and tuber development. The indirect effect of rootstock on scion for vigor, fruit load, the timing of flowering, ultimately fruit maturation, and yield. Grafting can be considered a high-input production approach in this regard, with a proclivity for increased crop burden Djidonou et al. [37], Moreno et al. [29], Lakra et al. [27], Kumari et al. [28] confirmed the same for fruit yield per hectare. The harvest duration of tomato fruit was recorded as highest in the graft union of Kufri Himalini + Heemsohna. Higher vigor in grafted plants arises from increased water and mineral intake, resulting in strong root and foliar development, which leads to increased and longer metabolic processes even in harsh environmental circumstances. This might explain why grafted plants produce more blooms and maintain a longer season harvest, as well as enhanced resistance to numerous diseases [46]. Comparable results also have been found by Refs. [1,38]. The potato genome affects tuber quality and yield of interspecific (tomato/potato) grafts, according to Kelly and Somers, [47]. The maximum tuber length was examined with graft union of Rakshita onto Kufri Himalini, while the tuber width was in Avtar onto Kufri Himalini. Enhanced transmission of photosynthates generated by the plant's vegetative development was among the probable factors underlying expanded tuber length and breadth. The association between increased tuber yield as well as higher growth rate, suggesting a beneficial plant source-sink relationship, is the greatest way to see this impact [4]. The outcomes of this experiment showed that the aboveground growth features have a direct influence on the development of potato tuber and that the pace of tuber formation was connected with the intensity of the inductive signal. The outcomes of [48], and [49] were by the current investigation. The graft union of Rakshita onto Kufri Himalini resulted in maximum average tuber weight. The inverse graft pairing (potato/tomato) resulted in graft-transmissible RNA, which might modify the scion's phenotype [50]. The development of sink and source organs in higher plants has resulted in and need for allocation of resources among sink and source organs, which would be a crucial element in plant growth and output [51]. Assimilate partitioning including both tomato fruits as well as storage tubers whenever it pertains to pomatoes. The findings were in a pact with the earliest reports of Khan et al. [49], Arefin et al. [4], Kumar et al. [28], and Parthsarathi et al. [52]. Overall, of that, the maximum tuber yield per plant, total tuber yield per hectare, & tuber equivalent yield were recorded as highest in the graft union of Avtar grafted onto Kufri Pukhraj. The link between tuber production and growth rate suggests a positive plant source-sink relationship that ultimately leads to increased tuber yield of potato plants. The above portion of the plant has a direct effect on potato tuber formation because the strength of inductive signaling passed through the above portion of the plant to the root zone was associated with potato tuber formation and increased potato yield. Tomato plant leaves and stems are more erect and thicker; hence tomato plants can harvest more light than potato plants. The phytochrome signals produced during the photosynthesis process occurs in tomato leaves are transferred to below the ground level parts of the pomato plant in graft unions via phloem, which moves in the pomato plant both acropetally and basipetally [4]. The amount of Co_2 under the polyhouse is always higher than under outside conditions, which increases the photosynthetic activity rate, which ultimately benefits the plant in the way of enhanced growth and development of the pomato plant as well as increasing production. Similar results also have been found by Arefin et al. [4], Islam et al. [53], Giosanu et al. [54], Kumar et al. [38], and Parthsarathi et al. [52]. The aboveground growth characteristics have a direct influence on potato tuber development, according to a recent study. The intensity of the inductive signal was linked to the rate of potato tuber formation [32,33]. Moreover, despite their hostile relationship, Palmer and Smith [55] discovered that GA & CK play a critical role in tuber & fruit growth. The tomato plant has a lot of CKs, and there's been a relationship discovered between GA, CK metabolism, and tomato fruit development [31]. Plants with elevated amounts of endogenous CK have a better capacity to produce tubers [42]. Because of their hormonal function in tuber and fruit growth, the antagonistic action among these two hormones is assumed to be diminished in pomato plants. Throughout tomato fruit ripening, a large amount of CK is necessary for normal tuber formation and cell division [31,43]. As a result, pomato plants are likely to produce fewer tomatoes compared to self-rooted plants. Significant differences in yield were also noted by Congera et al. [56], Garai et al. [57], and Mishra et al. [58]. Additionally, a few of the graft combinations also showed their superiority over both the sole controls of potato and tomato. The highest profit margin in terms of Benefit-cost ratio was incurred with the graft combination of Avtar grafted onto Kufri Pukhraj. This might be due to the cost of cultivation being higher than the obtained yield. The results conform with the outcomes of Negi et al. [36].

5. Conclusion

In the current era, cost-effective and alternate production technologies are occupying their position, to cope with the various environmental stresses. These strategies not only focus on combating the stresses but also add on the benefits, such as getting maximum production from limited land or resources, particularly targeting peri-urban areas. Pomato grafts are one of the best innovations, developed via vegetable grafting. The current study also helps to broaden the research scope of pomato cultivation. Based on formal deliberation, the combination of scion Avtar grafted onto rootstock Kufri Pukhraj has provided significant results for various yielding attributes and was found most efficient to cultivate at commercial level production.

6. Data availability statement

The datasets presented in this study will be provided on request.

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CRediT authorship contribution statement

Vandana Thakur: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Parveen Sharma:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Pardeep Kumar:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Akhilesh Sharma:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Mamta:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Abeer Hashem:** Writing – review & editing, Writing – original draft, Visualization, Investigation, Funding acquisition, Formal analysis. **Elsayed Fathi Abd_Allah:** Writing – review & editing, Writing – original draft, Funding acquisition, Formal analysis, Conceptualization. **Sunny Sharma:** Writing – review & editing, Writing – original draft, Resources, Funding acquisition, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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