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Research Article

Enhancing Production Through Input Use Efficiency of Virus-Resistant Pune Selection-3 Papaya Variety

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Abstract

An experiment was carried out using virus-resistant papaya variety Pune Selection-3 to study the effect of different cultivation methods for enhanced production and input use efficiency at Horticultural Research Farm, RAU, Pusa during the year 2016-2019. The outcomes of raised bed cultivation (a), drip irrigation (b), fertigation (c), polyethylene mulching (d) along with micronutrient spray (e) were analyzed using different combinations of these parameters as treatments for growth, yield-related parameters, and fruit quality. Nutrient use efficiency was also assessed by examining various interactive components such as soil nutrient content, nutrient acquisition with nutrient content in the leaves, the efficiency of nutrient utilization informs of the biomass produced, fruit yield, and fruit nutritional quality. The plant height was maximum in T1 (155 cm) which was significantly higher than the plant of control treatment. The flowering time was found to be reduced in all treatments. However, total soluble sugar was higher in T3. Overall, when the B:C ratio was compared, the treatment (T1) showed a higher value along with a 2.38-fold fruit yield/plant and 0.89-fold increase in fruit yield per hectare. The nutritional quality of fruits enhanced in T1 treated plants having a 1.78-fold increment in flavonoid content, and 1.2-fold more lycopene. The phenolic content was also 1.8-fold higher than the control (T5). The result obtained in the present study demonstrates that with the implementation of a suitable fertigation system in papaya cultivation we can obtain papaya growth, fruit yield per plant, and fruit quality by targeting enhancement in cost: benefit ratio.

Abbreviations:

AAE: Ascorbic Acid Equivalents; CE: Catechin Equivalents ; CI: Cavity Index; DTF: Days Taken to Flowering; FW: Fresh Weight; FW: Fruit Weight; FY: Fruit Yield; GAE: Gallic Acid Equivalents; ICAR: Indian Council for Agricultural Research; NF: Number of Fruit/Plants; PG: Plant Girth; PH: Plant Height; PRSV: Papaya *Ringspot Virus*; PS-3: Pune Selection–III; PT: Pulp Thickness; TPTZ: 2,4,6-Tri(2-Pyridyl)-1,3,5-Triazine; TSS: Total Soluble Solids; YP: Yield/Plant (Kg)

Keywords: Papaya; virus-resistant; biochemical changes; nutritional quality; fruit quality parameters.

Introduction

Papaya (*Carica papaya* L.), a laticiferous herbaceous plant of family Caricaceae, is one of the important fruit crops of the tropical and subtropical regions of the world having nutritious as well as medicinal value (Bose and Mitra, 1990). Because of the sweet taste of fruits, vibrant colors along with a variety of health benefits, fruiting ability, and high palatability, production throughout the year, has gained enormous importance. Cultivation of Papaya crop started from South Mexico and Costa Rica and presently its total annual world production is about 6 million tonnes of fruits (Schroeder, 1958; Brown *et al*., 2012). India leads the papaya production with an annual output of about 3 million tonnes production of papaya fruits when compared with other leading producers such as Brazil, Indonesia, China, Mexico, Nigeria, Thailand, Peru, and Philippines (Storey, 1976; Chávez-Pesqueira *et al*., 2014). The characteristics of a fast-growing, short-duration crop with remunerative properties including easy growth, continuous harvest, and nutritional/medicinal values make this crop high in demand (Saran and Choudhary, 2013). The papaya fruit is ranked first in terms of nutritional quality and antioxidant score such as the content of iron, vitamin A, vitamin C, folate, potassium, thiamine, niacin, riboflavin, calcium, (Huerta-Ocampo *et al*., 2012; Maurya *et al*., 2019). Besides fruits, various other parts of the plant such as stems, leaves, and roots of papaya are also useful in a wide range of medical applications due to the presence of papain-like compounds. (Ming *et al*., 2008). Commercial demand for papain for red meat tenderizer, protein digestion, in treatment of skin warts/scars, and brewing of beer is also high (Ming *et al*., 2012). In the Indian system of medicine, Papaya has been used to treat a broad range of ailments such as killing intestinal worms, hypertension, diabetes, dengue fever, wound repair, and as an abortive agent. The papaya raw fruits are also used as a vegetable in India and fresh ripe fruit is used for table purposes, preparation of candy/tooty fruity, papaya juice, jam, and toffee (Chadha, 1992). The benefits of papaya leaves have been also recorded by several workers because of their presence of minerals in significant amounts, it is low in calories, and also has an enzyme that is largely used in tenderization of meat and also for the treatment of indigestion. Despite these characteristics, its leaves have medicinal uses also that have been documented in various old literature for their anti-inflammatory, antitumor, anti-diabetic properties (Krishna *et al*., 2008; Otsuki *et al*., 2009; Maurya *et al*., 2019). Several studies have demonstrated the effects of various natural bioactive compounds/secondary metabolites in the therapeutic world. (Pandey *et al*., 2011; Rai *et al*., 2012; Arora and Pandey-Rai, 2012; Pandey and Pandey-Rai, 2014; Arora *et al*., 2017; Pandey-Rai, *et al*., 2018; Goswami *et al*., 2019, Rai *et al*., 2020a; Rai *et al*., 2020b; Apoorva *et al*., 2021, Rai *et al*., 2021; Rai *et al*., 2022; Pandey-Rai *et al*., 2022). Recently, the beneficial effects of papaya in curing dengue fever along with homeostatic properties have been also reported. The leaves of papaya have many bioactive components such as cystatin, ascorbic acid, papain, chymopapain, cyanogenic glucoside, vitamins most especially B12, minerals, saponins cardiac glycosides, alkaloids, and flavonoids, that improves the total antioxidant power of blood and also known for reducing lipid peroxidation level which demonstrates its important role in curing thrombocytopenia. Inspire of all these beneficial importance of fruit and leaves the commercial cultivation of papaya crop by farmers still unable to achieve its target. This is because of the occurrence of widespread viral diseases that affects the production and quality of fruits crop. The papaya *ringspot virus* (PRSV-P) having rapid spread nature can infect up to 100% of plants in a given area thereby hindering the desired production.

Further, the farmers are also facing serious problems in procuring seeds of improved varieties that can be employed for commercial cultivation. Recently, in India, various research programs have been also carried out that are mainly based on the development of virus-resistant varieties of papaya. One of the papaya variety Pune Selection -III developed by Pune Virology Institute (Indian Council for Agricultural Research, ICAR system) has high potential in virus resistance along with an average fruit yield of 40 tonnes/ hectare even under high disease pressure. Therefore, a need was felt to evaluate the performance of Pune Selection–III (PS-3) variety in the region of Indo-Gangetic planes of Bihar. The present investigation was carried out to study the effect of different cultivation methods for enhanced production with input use efficiency on Pune selection III variety at Horticultural Research Farm (AICRP on Fruits), DRPCAU, PUSA during the year 2016-2019.

Material and Methods

The investigation was carried out at Horticultural Research Farm, Dr. Rajendra Prasad Central Agricultural University (RPCAU), PUSA, Samastipur, Bihar, India (latitude. 25.980 N, longitude. 85.670 E and the mean altitude 52 m above mean sea level). The experimental site is a papaya growing area having a sub-humid climate. The soil of the experimental plot was alkaline pH (7.2), sandy loam with low organic carbon, available nitrogen, zinc, boron, and sulfur, along with medium availability of phosphorus and potash.

Experimental Setup and Treatment Conditions

The experiment was conducted in a randomized block design using a combination of different cultivation techniques (a) raised bed cultivation, (b) drip irrigation, (c) fertigation, (d) polyethylene mulching, and (e) micronutrient spray. The whole experiment was carried out in three replications using 12 papaya plantlets of viral disease-resistant variety, 'Pune Selection III' per replication. To analyze the input use efficiency and papaya production different treatment combinations were studied as listed in Table 1. The treatment combinations are T1: a+b+c+d+e; T2: a+b+c+d; T3: a+b+c+e T4: a+b+e (RDF–Pocket application of fertilizer) and T5 Control (Soil application of RDF, basin irrigation and no mulching).

Table 1: Different treatment combinations used in this experiment for assessment of input use efficiency to gain higher production.

Treatment number	Treatment combinations	Details of combination treatments
T1	a+b+c+d+e	Raised bed cultivation + Drip irrigation (80% ER at all stages) + Fertigation (75% RDF) + Mulching with 100-micron UV stabilized black polyethylene + Micronutrient spray (ZnSO4 (0.5%) + boric acid (0.2%) alternate months from second month. Prepare separately and mix the micronutrient solution
T2	a+b+c+d	Raised Bed cultivation + Drip irrigation (80% ER at all stages) + Fertigation (75% RDF) + Mulching with 100-micron UV stabilized black polyethylene;
T3	a+b+c+e	Raised bed cultivation + Drip irrigation (80% ER at all stages) + Fertigation (75% RDF) + Micronutrient spray {ZnSO4 (0.5%) + boric acid (0.2%)} alternate months from second month;
T4	a+b+e (RDF–Pocket application of fertilizer)	Raised bed cultivation + Drip irrigation (80% ER at all stages) + Micronutrient spray- ZnSO4 (0.5%) + boric acid (0.2%) alternate months from second month;
T5	Control (Soil application of RDF, basin irrigation and no mulching)	Control (Soil application of RDF, basin irrigation and no mulching)

Morphological Observations and Nutrient Analysis

The morphological observation was recorded during the successive experimental period on plant height, plant girth, days taken on flowering, fruit pulp thickness, number of fruits per plant, fruit weight, fruit yield per plant, fruit yield/hectare. Other parameters such as total soluble solids (TSS%), Cavity index, and B:C ratio was also recorded. The total soluble solids (T.S.S.) of fruits were measured using a hand refractometer (Rangana, 2010). Various nutrient content was measured in leaves and soil collected samples of each treatment in the month of October for three consecutive years by the method of Nishina (1991), nitrogen was determined by Kjeldahl method (1983), phosphorous by vanadomolybdate method given by Jackson (1973) and potassium content by a flame photometer (Chapmanand Pratt 1961). Further, the concentrations of zinc, iron, manganese, and copper were determined with the help of atomic absorption spectrophotometry and the content of boron by the Azomethine-H method.

Extraction For Fruit Phenolics, Flavonoids and Antioxidative Capacity

For estimation, 3 g of fruit flesh from the central part were first homogenized using 20 ml of methanol. The homogenates were then centrifuged at 5000 rpm for 20 min. After centrifugation, the supernatant was stored at −20 °C for further analysis. Total phenolic content was determined following the Folin Ciocalteu method and content was expressed in mg gallic acid equivalents (GAE)/100 g fresh weight (FW). The total fruit flavonoid content was assessed by colorimetric analysis. For this one ml of fruit, the extract was mixed with 4 ml of distilled H2O. After 5 minutes 5% $NaNO_2$(0.3 ml) and 10% $AlCl_3$(0.3 ml) were added and mixed by vertexing. After 6 minutes two ml of 1 M NaOH were added and diluted to 10 ml with distilled H_2O and OD was recorded immediately at 725 nm by using a spectrophotometer. The total flavonoid content was calculated in mg catechin equivalents (CE)/100 g FW. For antioxidant activity determination ferric reducing/antioxidant power (FRAP) method was used. The FRAP solution contains 300 mM acetate buffer (25 ml of pH 3.6), 2.5 ml TPTZ solution (10 mM in 40 mM HCl), and 2.5 ml of 20 mM $FeCl_3.6\text{-}H_2O$ solution. The prewarmed solution at 37 °C is used for further analysis. The 2850 µl of warmed FRAP solution, 75µl of flesh extract, and 75 µl methanol were mixed and kept to react at 37 °C for 60 min. Absorbance was then recorded at 593 nm using the spectrophotometer. The Antioxidant activity was expressed as µmol ascorbic acid equivalents (AAE) per g FW. Further, for lycopene and β-carotene, 0.2 g of fruit pulp were homogenized in 20 ml of a solvent having hexane:ethanol:acetone at a ratio of 2:1:112. After adding 3 ml of water in a homogenized mixture the upper hexane phase content was measured to determine the absorbance at 444 and 503 nm using a spectrophotometer. The contents (mg/100 g FW) of both lycopene and β-carotene were calculated according to Cly = (6.95A503 −

1.59A444)(0.55)(537)(V/W)/10, and $C\beta c=(9.38A_{444}-6.70A_{503})(0.55)(537)(V/W)/10$, respectively, where 0.55 (ratio of the final hexane layer volume and volume of mixed solvents), 537 (molecular weights of lycopene and β-carotene ; g/mol), W (weight of papaya tissue in mg), V (mixed solvents in ml), and 10 (conversion to mg/100 g units). For statistical analysis, data were pooled over the three years. All the analysis was conducted using software SPSS.

Result

The sustainable papaya agriculture faces lots of challenges due to the requirement of the current need to ensure higher crop production to meet the demand of the growing population. The modern agricultural practices not only have an environmental impact as well as the cost associated with them can be worsened due to the high incidence of biotic stresses imposed by climate change such as viral infections in papaya. Therefore, in this experiment, a viral resistant variety Pune Selection 3 (PS3) was selected for its performance as well as nutrient use efficiency. The agricultural use of land for enhanced production has largely impacted on continuous extraction of soil nutrients. An adequate nutrient replenishment technique is needed to meet the subsequent decrease of soil nutrient availability and its availability in soils mainly relies on the use of fertilizers and cultivation methods. In this study different combinations of treatments were analyzed for yield-related parameters and fruit quality. Nutrient use efficiency analysis in the present study was typically divided into three interactive components: soil nutrient content, the efficiency of nutrient acquisition in relation to nutrient supply in the leaves, and the efficiency of nutrient utilization inform of the biomass produced i.e., plant growth and yield-related traits.

The effects of different parameters were first analyzed using growth parameter analysis. The plant height was maximum in T1(155 cm), while plant girth was recorded maximum in T3 (35.03 cm) which was higher than the control. The flowering time was significantly reduced in contrast to control in all treatments and minimum in T4 (111.8 days). In terms of fruit yield-related traits, the T1 shows a maximum significant difference with control as well as with other treatments (Table 2). The fruit yield per plant was 62.23 Kg, a number of fruits per plant (30.7), representing maximum fruit yield per hectare (159.37T/ha) in T1 treatment. However total soluble sugar was higher in T3. Overall, when the B:C ratio was compared the T1 shows a higher B:C ratio (2.13).

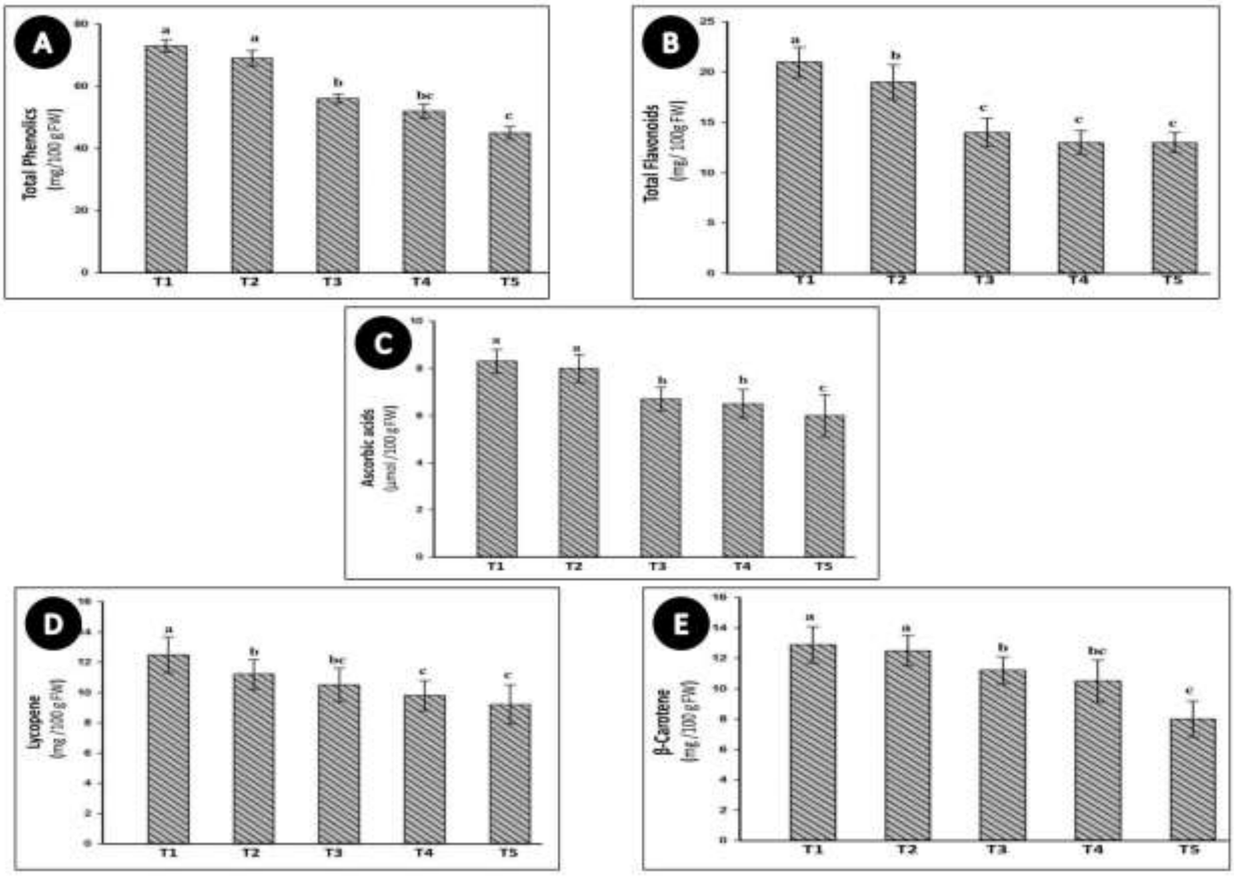

Fig. 1: Nutritional quality parameter of fruits under influence of different treatments (A) total phenolics, (B) total flavonoids, (C) ascorbic acid, (D) lycopene E) β-carotene.

Table 2: Growth parameters and productive variables under the influence of different treatments.

S. N.	Treatments	Plant height (cm)	Pant Girth (cm)	Days taken on flower (Days)	Pulp Thickness (cm)	Number of fruits per plant	Fruit weight	Fruit yield per plant (kg)	Fruit yield/hect (T/Ha)	T.S S %	Cavity index	B:C Ratio
1	T1	155^{a}±1.13	27.93^{b}±0.35	115.7^{b}±1.14	2.73^{a}±0.15	30.7^{a}±0.50	2.0^{a} ±0.14	62.23^{a} ±0.90	159.37^{a} ±1.27	14.1^{a}±0.36	57.3^{a}±0.79	2.13^{a}±0.08
2	T2	140^{a} ±1.21	28.13^{b}±0.42	125.3^{b} ±1.06	2.00^{b}±0.14	28.13^{ab} ±0.47	2.06^{a}±0.23	50.56^{b}±0.84	133.33$^{b`}$±1.01	14.03^{ab}±0.36	55.63^{a}±0.60	1.17^{a}±0.13
3	T3	144^{a}±1.20	35.03^{a}±0.58	119.3^{b}±0.99	1.73^{b}±0.13	25.57^{ab} ±0.79	1.83^{ab}±0.11	35.66^{c}±0.48	89.16^{c}±0.98	14.8^{a}±0.38	47.9^{b} ±0.60	1.43^{a}±0.24
4	T4	142^{a}±1.13	29.83^{b}±0.42	111.8^{b} ±1.00	2.06^{b}±0.18	24.33^{b}±0.37	1.43^{b}±0.13	31.23^{cd} ±0.45	78.8^{cd}±0.67	13.97^{ab}±0.31	57.13^{a} ±0.68	1.47^{a}±0.11
5	T5	135^{a}±1.14	26.57^{b}±0.54	143.7^{a}±0.95	1.933^{b}±0.11	17.867^{c}±0.32	0.93^{c} ±0.13	26.03^{d}±0.47	66.2^{d}±0.52	11.97^{b}±0.30	50.47^{ab} ± 0.55	1.37^{a}±0.16

T1: Raised bed cultivation + Drip irrigation (80% ER at all stages) + Fertigation (75% RDF) + Mulching with 100-micron UV stabilized black polyethylene + Micronutrient spray ($ZnSO_4$ (0.5%) + boric acid (0.2%) alternate months from second month. Prepare separately and mix the micronutrient solution; **T2:** Raised Bed cultivation + Drip irrigation (80% ER at all stages) + Fertigation (75% RDF) + Mulching with 100 micron UV stabilized black polyethylene;**T3:** Raised bed cultivation + Drip irrigation (80% ER at all stages) + Fertigation (75% RDF) + Micronutrient spray {$ZnSO_4$ (0.5%) + boric acid (0.2%)} alternate months from second month **T4:** Raised bed cultivation + Drip irrigation (80% ER at all stages) + Micronutrient spray- $ZnSO_4$ (0.5%) + boric acid (0.2%) alternate months from second month **T5:** Control (Soil application of RDF, basin irrigation and no mulching

Table 3: Effect of different treatments on leaf nutrient accumulation.

S. N.	Treatments	Total leaf nutrients (%)	P_2O_5 % in the leaf concentration	K % in Leaf	Zn in leaf (PPM	Mn in leaf (PPM)	Fe in leaf (PPM)	Boron in leaf (PPM)	Ca in leaf (PPM)	Mg in leaf (PPM)	Cu in leaf (PPM)
1	T1	0.3^{a} ± 0.10	0.48^{a}± 0.06	4.13^{a}± 0.19	13.3^{b}7±0.33	4.77^{bc}±0.18	43.87^{ab}±0.47	15.73^{a} ±0.34	3.03^{a}±0.17	0.41^{a}±0.08	5.23^{a}± 0.17
2	T2	0.33^{a} ± 0.08	0.48^{a}± 0.18	3.93^{a}± 0.19	14.57^{ab}±0.42	4.23^{c}±0.19	46.57^{a}±0.48	12.47^{b} ± 0.41	2.57^{bc}±0.13	0.42^{a}±0.10	4.53^{bc}±0.17
3	T3	0.37^{a}± 0.08	0.51^{a} ± 0.07	5.00^{a}± 0.22	15.53^{a}±0.39	5.2^{b}±0.23	46.10^{a}±0.62	12.67^{b} ±0.34	2.43^{c}±0.13	0.42^{a}±0.09	5.12^{a}±0.18
4	T4	0.27^{a} ± 0.08	0.53^{a}± 0.15	2.93^{a}±0.17	9.90^{c}±0.28	6.13^{a}±0.23	39.60^{bc}±0.61	13.47^{b}±0.32	2.57^{bc}±0.15	0.32^{ab}±0.07	4.23^{c}±0.19
5	T5	0.23^{a}± 0.08	0.37^{a}±0.08	3.2^{a}±0.20	9.35^{c}±0.29	4.27^{c}±0.17	38.3^{c} ± 0.52	14.37^{ab}±0.32	2.83^{ab}±0.13	0.25^{b}±0.07	4.77^{ab}±0.16

T1: Raised bed cultivation + Drip irrigation (80% ER at all stages) + Fertigation (75% RDF) + Mulching with 100-micron UV stabilized black polyethylene + Micronutrient spray ($ZnSO_4$ (0.5%) + boric acid (0.2%) alternate months from second month. Prepare separately and mix the micronutrient solution; **T2:** Raised Bed cultivation + Drip irrigation (80% ER at all stages) + Fertigation (75% RDF) + Mulching with 100 micron UV stabilized black polyethylene;**T3:** Raised bed cultivation + Drip irrigation (80% ER at all stages) + Fertigation (75% RDF) + Micronutrient spray {$ZnSO_4$ (0.5%) + boric acid (0.2%)} alternate months from second month **T4:** Raised bed cultivation + Drip irrigation (80% ER at all stages) + Micronutrient spray- $ZnSO_4$ (0.5%) + boric acid (0.2%) alternate months from second month **T5:** Control (Soil application of RDF, basin irrigation and no mulching

Table 4: Different parameters associated with soil nutrient properties after opting various treatments.

S. No.	Treatments	NPK in Soil (Kg/Ha)	Fe conc. in soil (PPM)	Boron conc. (PPM) in Soil	Zinc conc. (PPM)	P in Soil (Kg/Ha)	K in soil (Kg/Ha)	PH in soil	EC (DS/m) in soil	OC % in soil
1	T1	282.73^{a}±1.32	6.77^{a}±0.20	0.83^{a}±0.08	1.57^{ab} ±0.11	26.27^{a}±0.50	242.07^{a}±1.40	7.53^{a}±0.21	0.23^{a}±0.10	0.32^{a}±0.06
2	T2	280.77^{a}±1.34	6.93^{a}±0.23	0.83^{a}±0.08	1.50^{ab}±0.10	24.93^{a}±0.45	261.47^{a}±1.51	7.87^{a}±0.24	0.24^{a}±0.08	0.33^{a}±0.09
3	T3	256.60^{ab}±1.53	6.60^{a}±0.24	0.7^{a}±E	1.63^{a}±0.11	26.57^{a}±0.44	266.47^{a}±1.22	7.70^{a}±0.26	0.18^{a}±0.10	0.36^{a}±0.04
4	T4	278.07^{a}±1.36	5.60^{b} ± 0.24	0.73^{a}±0.08	1.4^{b} ±0.10	24.83^{a}±0.44	246.5^{a}±1.41	7.30^{a}±0.28	0.25^{a}±0.08	0.34^{a}±0.08
5	T5	242.8^{b} ± 1.41	5.03^{v} ± 0.25	0.76^{a}±0.13	1.43^{ab}±0.11	20.13^{b}±0.42	246.9^{a}±1.40	8.06^{a}±0.21	0.23^{a}±0.08	0.33^{a}±0.11

T1: Raised bed cultivation + Drip irrigation (80% ER at all stages) + Fertigation (75% RDF) + Mulching with 100-micron UV stabilized black polyethylene + Micronutrient spray ($ZnSO_4$ (0.5%) + boric acid (0.2%) alternate months from second month. Prepare separately and mix the micronutrient solution; **T2:** Raised Bed cultivation + Drip irrigation (80% ER at all stages) + Fertigation (75% RDF) + Mulching with 100 micron UV stabilized black polyethylene;**T3:** Raised bed cultivation + Drip irrigation (80% ER at all stages) + Fertigation (75% RDF) + Micronutrient spray {$ZnSO_4$ (0.5%) + boric acid (0.2%)} alternate months from second month **T4:** Raised bed cultivation + Drip irrigation (80% ER at all stages) + Micronutrient spray- $ZnSO_4$ (0.5%) + boric acid (0.2%) alternate months from second month **T5:** Control (Soil application of RDF, basin irrigation and no mulching

The fruit's nutritional quality was also analyzed in all treatments. In the nutritional quality assessment, the various characteristic features such as total phenolics, flavonoids, ascorbic acid, lycopene, β-Carotene were analyzed in all treatments (Fig. 1). The results showed the higher nutritional value of fruits in T1 treatment followed by T2, in contrast, to control (T5). In the fruits of the T1 treatment, the phenolic content, flavonoid content, and β-carotene was found 1.6-fold higher than the control treatment (T5). Ascorbic acid and lycopene in T1 were found also higher (1.84) and 1.30-fold respectively which were significantly higher than T5 (control). Kumar *et al*., 2006 have also shown that the fruit quality of papaya largely depends on the nitrogen, potassium content in the leaf thereby affecting directly higher fruit quality parameters such as soluble solids, pH, fruit yield, and biomass. The results obtained here are in accordance with the several studies reported in papaya (Muller at al., 1979; Saure, 2005; Kumar *et al*., 2006; Vuong *et al*., 2013). Further the leaf nutrient content was also observed in all treatments showing phosphate percentage highest in T4 (0.53), K% in T3 (5%), Zn T3 (15.53ppm), Mg in T2 and T3 (0.42ppm) Fe in T2 (46.57ppm) treatments (Table 3).

To analyze the soil quality after treatments, the nutrient content in soil was also analyzed showing NPK highest in T1(282.73kg/ha), Fe in T2 (6.93ppm), Boron in T1and T2 (0.83 ppm), Zn in T1 1.57 ppm, Phosphorous in T1 and T3 26.0 kg/ha. The PH of the soil was found lower in all treatments (7.3-7.8) in comparison to the control treatment (8.06) (Table 4). The findings of these results are in accordance with the results obtained by Muller *et al*. (1979) with improvement in leaf nutrient content that may be attributed in leaf due to sufficient availability of essential nutrients for growth and development.

The correlation analysis between growth and yield-related traits clearly showed that early flowering characteristics are negatively correlated with plant height and plant girth whereas plant height is positively correlated with fruit weight. On the other hand, the fruit weight is negatively correlated with flowering and has a positive correlation with the number of fruits per plant, however, yield per plant has a negative correlation with the number of fruits per plant (Table 5). Further cavity index positively correlated with pulp thickness and total soluble sugar positively correlated with the number of fruits per plant and plant girth. After analyzing the results of correlation between yield and its components results were further analyzed by path coefficient analysis for yield and yield-related components to correlate the direct and indirect effects among the treatments applied in this study.

The data represented in Table 5 showed the results obtained through path analysis, exploring the correlations between examined variables and their direct and indirect effects on the yield parameters, the values of the coefficients of determination, and the effects of the residual variables. The path coefficient analysis based on genetic correlation showed that the characters, namely plant height (1.00) and days taken to flowering (1.01) exerted a significant positive direct effect on fruit yield per plant (Table 6).

Table 5: Correlation analysis among fifteen yield and yield attributing traits that were analysed in different treatments

	PH	PG	DTF	PT	NFP	FW	Y/P	FY	TSS	CI	BC
Plant height (cm)	1										
Plant girth (cm)	0.36	1									
Days taken to flower	-0.36	-0.27	1								
Pulp thickness (cm)	0.5	-0.28	-0.17	1							
Number of fruit/plants	0.23	0.11	-0.6	0.36	1						
Fruit weight (Kg)	0.53	0.29	-0.56*	0.33	0.70**	1					
Yield/plant (Kg)	0.4	-0.19	-0.24	0.65**	-0.70**	0.70**	1				
Fruit yield (T/ha)	0.32	-0.18	-0.28	-0.68**	0.79**	0.70**	0.94**	1			
Total Soluble sugar (%)	0.3	0.57*	-0.34	0.11	0.52*	0.48	0.35	0.32	1		
Cavity index	0.22	-0.44	-0.25	0.51*	0.29	0.18	0.45	0.45	-0.1	1	
B:C ratio	0.21	0.33	-0.02	0.01	-0.45	0.1	-0.22	-0.29	0.03	-0.22	1

*Significant at 5% level **Significant at 1% 0.01 level. Note: PH: plant height, PG: plant girth, DTF: days taken to flowering, PT: pulp thickness, NF: Number of fruit/plants, FW: Fruit weight (Kg), Y/P: Yield/plant (Kg), FY: Fruit Yield (T/ha): TSS: Total soluble sugar (%), CI: Cavity index, BC: B:C ratio

Table 6: Path coefficient analysis in papaya showing the direct (diagonal) and indirect effects of fruit yield components**.**

	PH	PG	DTF	PT	NFP	FW	Y/P	FY	TSS	CI	Direct effect	Indirect effect
Plant height	**1.00**	-0.27	1.74	-1.12	-0.97	-0.43	-0.92	0.64	0.19	0.50	1.0	-0.64
Pant Girth	-0.27	**-0.45**	0.00	1.00	0.88	0.65	-0.98	-1.45	0.52	0.66	-0.45	1.01
Days taken on flower	1.74	0.00	**1.01**	0.83	0.00	0.00	1.00	0.67	-1.59	-1.48	1.01	1.17
Pulp Thickness	-1.12	1.00	0.83	**0.77**	0.88	0.53	0.00	0.00	0.00	1.00	0.77	3.12
Number of fruits	-0.97	0.88	0.00	0.88	**0.90**	0.81	0.90	0.87	0.00	0.00	0.90	3.34
Fruit weight	-0.43	0.65	0.00	0.53	0.81	**-1.52**	-1.29	-1.39	-1.28	-1.33	-1.52	-3.73
Fruit yield per plant	-0.92	-0.98	1.00	0.00	0.90	-1.29	**-0.27**	-1.51	-1.47	-1.37	-0.27	-5.64
Fruit yield	0.64	-1.45	0.67	0.00	0.87	-1.39	-1.51	**0.01**	1.00	-0.08	0.01	-1.25
T.S S	0.19	0.52	-1.59	0.00	0.00	-1.28	-1.47	1.00	**0.00**	0.00	0.00	-2.36
Cavity index	0.50	0.66	-1.48	1.00	0.00	-1.33	-1.37	-0.08	0.00	**0.01**	0.01	-2.10

Note: PH: plant height, PG: plant girth, DTF: days taken to flowering, PT: pulp thickness, NF: Number of fruit/plants, FW: Fruit weight (Kg), Y/P: Yield/plant (Kg), FY: Fruit Yield (T/ha): TSS: Total soluble sugar (%), CI: Cavity index,

The pulp thickness and number of fruits also exhibit high positive direct effects on fruit yield. The maximum indirect effect was observed on fruit yield per plant. Hence, during the selection process and to assess the treatment effects maximum weightage should be for yield enhancement in papaya. The reduced plant height and early flowering characters during the treatment studies clearly showed that there is the partitioning of the photosynthates towards the sink to enhance the fruit yield but have a negative impact on higher biomass production.

Conclusion

To meet the increasing quality/quantity of papaya fruit produce there is an urgent requirement to focus on smarter cultivation technologies like drip irrigation, fertigation, mulching, biofertilizers, and high-density planting techniques for on-farm/under protected cultivation for quality assured fruit produce on a commercial scale. Fruits of Pune Selection-3 (PS3) variety have medium plant height and pinkish-red pulp color. The average time required for the first flower is 75-100 days (2-2.5 months) under the climatic conditions of Pune. In the Indo-Gangetic planes of Bihar, the variety takes about 145 days to flower but the adoption of suitable fertigation techniques can influence the performance and quality of fruits. The combination of different cultivation methods in T1 (Raised bed cultivation + Drip irrigation (80% ER at all stages) + Fertigation (75% RDF) + Mulching with 100-micron UV stabilized black polyethylene + Micronutrient spray ($ZnSO_4$ (0.5%) + boric acid (0.2%) alternate months from the second month. Prepare separately and mix the micronutrient solution) is significantly effective in terms of fruit yield and quality. The results obtained from this study showed a significant variation in antioxidant properties and fruit qualities under different fertigation conditions. This investigation clearly shows the potential value of selected papaya genotype (PS-3) as new cultivars and their possible cultivation methods for improving fruit quality with high antioxidants

Authors' Contribution

SKR and SKS designed the experimental work. All experiments were conducted by SKR, SKS, and AK. SKR and Apoorva analysed the data and wrote the manuscript. All authors read and approved the manuscript.

Declaration of Competing Interest

Authors declare that there is no conflict of interest.

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