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RESEARCH ARTICLE

Performance of papaya variety 'Surya' under fertigation and foliar nutrition

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ABSTRACT

Effects of fertigation and foliar nutrition with micronutrients on papaya flowering, yield and fruit quality parameters were studied during the period 2018 – 2020 at Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, India. A field experiment consists of 14 treatments replicated thrice was laid out based on randomized block design. A combination of four fertigation doses of 75 %, 100 %, 125 % and 150 % Recommended Dose of Fertilizers (RDF) of N (304.89, 406.52, 508.15 and 609.78 gm urea plant^{-1} year^{-1} respectively based on soil test data in 76 fertigation) and K (426.25, 568.33, 710.42 and 852.50 gm muriate of potash plant^{-1} year^{-1} respectively based on soil test data in 76 fertigation) and three foliar sprays (1.0 % 19:19:19 at bimonthly interval starting from 4 MAP (Month After Planting) to 16 MAP, 0.5% $ZnSO_4$ + 0.3% borax at 4th, 8th, 12th and 16th MAP and water spray at bimonthly interval starting from 4 MAP to 16 MAP) where compared with soil application of recommended dose of NPK (187:170:341 g NPK plant^{-1} year^{-1} based on soil test data) (control 1) and 187:170:341 g NPK plant^{-1} year^{-1} based on soil test data as organic manures as combination of FYM (Farm Yard Manure), poultry manure and vermicompost in the ratio of 2:1:1 (control 2). Application of 100 % recommended dose of N and K through fertigation at weekly interval from one MAP to 20 MAP and foliar sprays of 0.5 % $ZnSO_4$ and 0.3 % borax at 4th, 8th, 12th and 16th MAP (T_5) initiated earliness in flowering (142.67 days) and harvest (275.00 days). However, plants receiving 100 % recommended dose of N and K through fertigation at weekly interval from one MAP to 20 MAP with foliar sprays of 1% 19:19:19 at bimonthly interval starting from 4 MAP to 16 MAP (T_4) significantly improved the fruit weight, number of fruits per plant and total yield per plant in papaya variety 'Surya' and it was on par with T_5. Fruit quality parameters namely TSS (Total Soluble Solids), ascorbic acid and total sugars were found significantly highest in T_5 and lowest titratable acidity was also recorded in T_5. Hence, treatment T_5 which is found superior in initiating early harvest, with higher yield and good quality characters in papaya variety 'Surya' can be recommended to farmers.

Introduction

Papaya (*Carica papaya* L.) is one of the most commonly cultivated tropical fruit crops, which gained popularity due to its nutraceutical properties. India with an area of 139000 hectares and production of 5831000 MT is the leading producer of papaya in the world (1). It is slowly emerging from the status of a homestead crop to that of commercial crop in Kerala. Conventional method of nutrient application (soil application of N, P and K) followed in papaya leads to the loss of nutrients and reduction in nutrient use efficiency, leading to problems of decreased productivity, degradation of soil health and increased environmental pollution apart from the wastage of substantial quantity of costly and scarce inputs. (Nitrogen is the most used nutrient in papaya growth, development and fruit production. Phosphorus absorption by the plant increases uniformly during growth and is most important during initial root development. Among the nutrients, the requirement of potassium is the largest. Papaya takes up potassium continuously throughout the entire plant cycle. It is especially important after the fertilization of the flowers to produce larger, better quality fruit, with elevated levels of sugars and total soluble solids). So there is a pressing need to enhance its productivity by optimal use of fertilizer, water and other inputs. Through fertigation, fertilizers are applied along with irrigation water directly to the region where most of the plant roots develop. It ensures supply of both nutrients and water in controlled and balanced manner resulting in high nutrient use efficiency to an extent of 30-40%. Apart from this, adoption of

fertigation helps in preventing soil degradation, reducing the cost of fertilizer application besides improving the productivity and quality of the produce. Application of 100% recommended dose of N and K_2O through drip fertigation and bimonthly soil application of 50 gm P_2O_5 resulted in the maximum fruit yield in papaya cv. Co.7 (2). Knowledge on correct dose (75%, 100%, 125% or 150% of RDF) of fertilizers to be supplied through fertigation is very important in enhancing the productivity. Despite being a feasible method for application of fertilizers in papaya, not much information is available on the appropriate level of nutrients for fertigation to ensure the highest production of papaya under Kerala conditions (The temperature in Kerala normally ranges from 28°-32° C on the plains but drops to about 20° C in the highlands and with an average annual humidity of 90%). Also, micronutrients are key elements in plant growth and development. Deficiencies of zinc and boron had been increasingly reported in papaya. As papaya is a latex yielding plant, these plants need high metabolic boron. Boron deficiency may lead to latex exudation from fruit skin and tumor like eruptions on fruits (bumpiness) (3). It was reported that zinc deficiency in papaya plants can initiate mild irregular chlorosis of the interveinal areas of middle leaves which later turn necrotic, downward curling of leaf margin and thick and rough leaves (4). Foliar nutrition of micronutrients will be very helpful to overcome this problem. Hence, the present investigation was carried out to study the effect of fertigation and foliar nutrition on flowering parameters and yield of papaya variety 'Surya'.

Materials and Methods

A field experiment was conducted at Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala from June 2018 to February 2020 to elucidate the influence of fertigation and foliar nutrition on flowering and yield of papaya variety 'Surya'. The soil of the experimental site was sandy clay loam which belonged to the order oxisols, Vellayani series having pH 4.50, electrical conductivity (EC) 0.10 d S m^{-1}, organic carbon 1.30 %, medium in available nitrogen (160.00 kg ha^{-1}), available phosphorus (18.50 kg ha^{-1}) and available potassium (207.50 kg ha^{-1}). The weather parameters of experimental site during cropping period are 32^0 C maximum temperature, 24^0 C minimum temperature and 89% relative humidity.

The experiment consists of 14 treatments replicated thrice, which was laid out in Randomised block design. Gross plot size was 24 m^2. Six plants were maintained per plot, thus a total of 252 plants were maintained for the experiment. Fertigation treatments were fixed based on the N and K recommendation as per KAU POP (Kerala Agricultural University, Package of Practices) based on soil test data (187:170:341 gm NPK $plant^{-1}$ $year^{-1}$) for papaya. Three foliar sprays (1.0 % 19:19:19 at bimonthly interval starting from 4 MAP (Month After Planting) to 16 MAP, 0.5% $ZnSO_4$ + 0.3% borax at 4th, 8th, 12th and 16th MAP and water spray at bimonthly interval starting from 4 MAP to 16 MAP) were also used with different levels of fertigation. These where compared with soil application of recommended dose of NPK (187:170:341 gm NPK $plant^{-1}$ $year^{-1}$ based on soil test data) (control 1) and soil application of 187:170:341 gm NPK $plant^{-1}$ $year^{-1}$ based on soil test data as organic manures as combination of FYM, poultry manure and vermicompost in the ratio of 2:1:1 (control 2).

Different treatments were T_1 -75% recommended dose of N and K through fertigation and foliar sprays of 1.0% 19:19:19, T_2 - 75 % recommended dose of N and K through fertigation and foliar sprays of 0.5 % $ZnSO_4$ and 0.3 % borax, T_3 - 75 % recommended dose of N and K through fertigation and water spray, T_4 - 100 % recommended dose of N and K through fertigation and foliar sprays of 1.0% 19:19:19, T_5 - 100 % recommended dose of N and K through fertigation and foliar sprays of 0.5 % $ZnSO_4$ and 0.3 % borax, T_6 - 100 % recommended dose of N and K through fertigation and water spray, T_7 - 125 % recommended dose of N and K through fertigation and foliar sprays of 1.0% 19:19:19, T_8 - 125 % recommended dose of N and K through fertigation and foliar sprays of 0.5 % $ZnSO_4$ and 0.3 % borax, T_9 - 125 % recommended dose of N and K through fertigation and water spray, T_{10} - 150% recommended dose of N and K through fertigation and foliar sprays of 1.0% 19:19:19, T_{11} - 150 % recommended dose of N and K through fertigation and foliar sprays of 0.5 % $ZnSO_4$ and 0.3 % borax, T_{12} - 150 % recommended dose of N and K through fertigation and water spray, T_{13} - control 1 - KAU POP (187:170:341 gm NPK $plant^{-1}$ $year^{-1}$ based on soil test data, soil application of nutrients with conventional land management) and T_{14} - control 2 - organic POP (187:170:341 gm NPK $plant^{-1}$ $year^{-1}$ based on soil test data as organic manures as combination of FYM, poultry manure and vermicompost in the ratio of 2:1:1). In control 2, additional requirement of P and K were met through the application of rock phosphate and potassium sulphate respectively. Organic manure (15 kg FYM $plant^{-1}$) was given uniformly to all treatments as basal. Basal soil application of lime and rock phosphate (500 gm and 850 gm respectively based on soil test data) was applied uniformly for all treatments except controls. To deliver water and fertilizer to the respective plots, four submains were laid out in the field. From each submain, lateral was connected to the respective plots. On the laterals, drippers (pressure compensating) with a discharge rate of 8 l hr^{-1} were connected to deliver water and fertilizer to individual plots. The submains and laterals were provided with flushing devices to remove water and fertilizer after each application. Fertigation was carried out using injector. Urea and Muriate of Potash (MOP) were used as fertilizer sources for fertigation applied weekly from 1 MAP to 20 MAP.

The experiment was conducted using the papaya variety 'Surya' released from Indian Institute of Horticultural Research (IIHR), Bangalore by crossing Sunrise Solo with Pink Flesh Sweet. The variety is gynodioecious in nature with no male plants and this variety address the long felt need of papaya growers to have a small sized fruit with high yield. Healthy seeds of papaya variety 'Surya' were procured from

IIHR, Bangalore. The seeds were treated with 200 ppm GA_3 for 8 hrs for uniform germination and were sown in portrays filled with equal proportions of FYM, soil and sand. Later, 15 days old seedlings were transplanted into polythene bags of 20 cm x 15 cm size. 45 days old seedlings were transplanted into main field.

Effect of fertigation and foliar sprays on flowering, yield and quality was recorded in the experiment. Parameters related to flowering (height at first flowering, days to flowering, sex expression of plant, number of flowers cluster^{-1} and time for first harvest), fruit set percentage and yield (number of fruits per plant and total yield plant^{-1}) was observed from nine observation plants (three from each replication), whereas three fruits each were taken from nine observation plants to assess the fruit quality parameters such as total soluble solids, titratable acidity, ascorbic acid and total sugars.

Height at first flowering

Height at which first flower appeared was recorded in centimeters from the ground level in all observation plants and average were worked out.

Days to flowering

To learn the days taken for flowering, number of days from transplanting to the opening of first female or hermaphrodite flower was recorded in all observation plants and average was worked out.

Sex expression

Sex expression of plant was determined by noting total number of hermaphrodite and female flowers in all observation plants and expressed in % and average was worked out.

Number of flowers cluster^{-1} Number of flowers found in a cluster was counted and recorded in all observation plants and average was worked out.

Fruit set percentage

Total number of hermaphrodite and female flowers and fruits produced were recorded in all observation plants and expressed in per cent and average was worked out to obtain fruit set percentage.

Time for first harvest

Time for first harvest was determined by counting the number of days taken from transplanting to the harvest of first formed fruit in all observation plant and average was worked out.

Fruit weight

Five mature fruits were randomly selected from each observation plants and average fruit weight was worked out and recorded in gms.

Number of fruits per plant

Total number of fruits from each observation plant was counted and average worked out.

Total yield plant^{-1}

Total number of fruits from each plant was multiplied with average fruit weight for getting total yield per plant and expressed in kg plant^{-1}.

Total soluble solids

TSS of the fruit pulp was measured using a hand refractometer (Erma) (range 0-32°Brix) expressed in degree brix (5).

Titratable acidity

Titratable acidity of the fruits was estimated by titrating a known weight of the sample against 0.1 N NaOH solution using phenolphthalein as an indicator. The acidity was calculated and expressed as % citric acid (6).

Ascorbic acid

Ascorbic acid was determined by titrating known weight of sample with 2, 6-dichlorophenol indophenol dye, using oxalic acid as stabilizing agent (7).

Total sugars

Total sugar was determined using Fehling's solution and expressed as gm of glucose per 100 gms of pulp (8).

Statistical Analysis

The data was analysed statistically using WASP (Web Agriculture Statistical Package) software by applying the techniques of analysis of variance (9). Wherever the effects were found to be significant, CD values were calculated by using standard technique.

Results and Discussion

The data pertaining to height at first flowering, days to flowering and sex expression of plant presented in Table 1, clearly depicts that the effect of treatments on these biometric parameters was significant.

Height at first flowering

Application of different levels of fertigation and different foliar sprays registered significant differences on height at first flowering in papaya plants (Table 1). T_4 which received 100 % recommended dose of N and K through fertigation

Table 1. Effect of fertigation and foliar sprays on height at first flowering, days to flowering and sex expression of papaya plants

Treatments	Height at first flowering (cm)	Days to flowering	Sex expression	
			Female plants (%)	Hermaphrodite plants (%)
T_1	108.10	164.00	44.44	55.56
T_2	109.71	162.89	55.56	44.44
T_3	113.53	186.00	38.89	61.11
T_4	74.38	145.78	83.33	16.67
T_5	81.43	142.67	77.78	22.22
T_6	89.35	161.22	66.67	33.33
T_7	100.50	153.33	72.22	27.78
T_8	92.32	150.00	77.78	22.22
T_9	102.04	159.22	66.67	33.33
T_{10}	110.07	170.00	55.56	44.44
T_{11}	104.51	150.44	66.67	33.33
T_{12}	110.88	181.78	38.89	61.11
T_{13}	110.85	174.11	61.11	38.89
T_{14}	104.94	156.55	66.67	33.33
SE (±)	1.93	1.88	5.87	5.87
CD (5%)	5.60	5.46	17.06	17.06

(Number of plants per plot: 6, Observation plants per plot: 3, Replication: 3) (Total number of observation plants: 9)

and foliar sprays of 1.0 % 19:19:19 flowered at shortest height of 74.38 cm. Flowering at maximum height (113.53 cm) was recorded in treatment T_3 (75 % recommended dose of N and K through fertigation with water spray). Flowering at shortest height in T_4 might be probably due to the efficient and timely utilization of optimum dose of nutrients through fertigation in addition to foliar sprays of 19:19:19. Effect on low flowering height upon application of optimum fertilizer dose to the plants has been reported in papaya by many researchers (2, 10, 11).

Days to flowering

The data on days taken to flowering in papaya registered significant difference among treatments (Table 1). Plants receiving 100 % recommended dose of N and K through fertigation and foliar sprays of 0.5 % $ZnSO_4$ and 0.3 % borax (T_5) recorded significantly minimum number of days (142.67 days) for flowering which was found to be on par with treatments receiving 100 % recommended dose of N and K through fertigation and foliar sprays of 1.0 % 19:19:19) (T_4) (145.78 days). However, application of 75 % recommended dose of N and K through fertigation with water spray (T_3) recorded significantly maximum days (186.00 days) for flowering. The possible reason for minimum days to first flowering can be discussed in the light of fact that fertigation activates plant metabolism of metabolically active compounds like amino acids, proteins, nucleic acids, prophytins, nucleotide and co-enzymes which are also responsible for promoting early flowering (12). Enhanced vegetative growth and delayed flower initiation might be due to receival of higher dose of N and K, whereas, application of 100 % RDF might have provided balanced nutrition and brought better growth, development and promoted early flowering. These findings are in conformity with the results of other authors (13, 14).

It is evident from the result that treatments receiving foliar spray of 0.5% $ZnSO_4$ and 0.3% borax (T_2, T_5, T_8 and T_{11}) took minimum number of days for flowering at all the levels of fertigation (75 %, 100 %, 125 % and 150 % recommended dose of N and K) than their respective treatments provided with foliar spray of 1.0% 19:19:19 and water spray. The Hastening of flowering in sweet orange cv. Blood Red was noticed upon application of 0.02% borax and 1.0% zinc as foliar spray (15). Besides the function of stimulation of pollen germination, growth of pollen tube and fertilization process, the micronutrient boron promotes early flower initiation, flower bud formation and production of indigenous and florigenic substances, which might have contributed to the earliness in flowering. Role of boron in regulating translocation of carbohydrates, cell-wall development and RNA synthesis and also increased production of phenolic compounds which regulate polar auxin transport was reported by (16) which might have attributed to the early flowering.

Sex expression of plant

It is evident from the result that highest number of female plant (83.33 %) was found in T_4 which received 100 % recommended dose of N and K through fertigation and foliar sprays of 1.0 % 19:19:19 (Table 1). Optimum quantity of nutrients applied through fertigation and foliar spray of 1 per cent 19:19:19 might have contributed to the production of more female plants. Optimum nitrogen availability to papaya plants increased the femaleness of the plant (17).

Apart from treatments receiving 100 % recommended dose of N and K, in all other fertigation levels (75 %, 125 % and 150 % recommended dose of N and K) foliar application of $ZnSO_4$ (0.5 %) and borax (0.3 %) resulted in more number of female plants. Number of pistilate flowers in litchi was significantly improved by the foliar spray of 1.0 % zinc sulphate (18). Application of $ZnSO_4$ at 0.5 % gave highest number of perfect flowers in cashew cv. BPP- 8, whereas, lowest number of perfect flowers were observed in control (19). It may be due to the diversion of reserve food material from vegetative part to reproductive part due to application of $ZnSO_4$. Physiological changes in the tissues, stimulated by zinc might have influenced the flowering characters, through its role in auxin biosynthesis as auxins play a major role in flowering.

Treatments receiving 100 % recommended dose of N and K through fertigation and foliar sprays of 1.0 % 19:19:19 (T_4) recorded lowest hermaphrodite plants (16.67 %). It was found to be on par with treatments T_5 (100 % recommended dose of N and K through fertigation and foliar sprays of 0.5 % $ZnSO_4$ and 0.3 % borax) and T_8 (125 % recommended dose of N and K through fertigation and foliar sprays of 0.5 % $ZnSO_4$ and 0.3 % borax) with 22.22 % hermaphrodite plants for both. Number of hermaphrodite plants was found to be highest (61.11 %) in treatments T_3 (75 % recommended dose of N and K through fertigation with water spray) and T_{12} (150 per cent of recommended dose of N and K through fertigation with water spray).

Number of flowers cluster^{-1}

The number of flowers per cluster in papaya was significantly influenced by application of different levels of fertigation with different foliar sprays (Table 2). Highest number of flowers per cluster (2.78) was recorded in plants receiving 100 % recommended dose of N and K through fertigation and foliar sprays of 0.5 % $ZnSO_4$ and 0.3 % borax (T_5). It was found to be on par with treatments T_4 (100 % recommended dose of N and K through fertigation and foliar sprays of 1.0 % 19:19:19), T_8 (125 % recommended dose of N and K through fertigation and foliar sprays of 0.5 % $ZnSO_4$ and 0.3 % borax) and T_7 (125 % recommended dose of N and K through fertigation and foliar sprays of 1.0 % 19:19:19) which recorded 2.67, 2.67 and 2.44 flowers per cluster respectively. The adequate availability of nutrient through fertigation and foliar spray might have helped the treatments T_5, T_4, T_8 and T_7 for better flower bud differentiation, primordial development and ultimately increased number of flower production in papaya (2).

Among treatments with different levels of fertigation (75 %, 100 %, 125 % and 150 % recommended dose of N and K), plants which received foliar spray with $ZnSO_4$ (0.5 %) and borax (0.3 %) (T_5, T_8, T_{11} and T_2) registered higher number of

Table 2. Effect of fertigation and foliar sprays on number of flowers per cluster, fruit set (%) and time for first harvest of papaya plants

Treatments	Number of flowers per cluster	Fruit set (%)	Time for first harvest
T_1	2.00	80.57	305.11
T_2	2.11	79.34	306.89
T_3	1.44	64.50	327.56
T_4	2.67	86.27	278.89
T_5	2.78	85.43	275.00
T_6	1.89	75.13	299.56
T_7	2.44	82.12	285.67
T_8	2.67	83.18	280.78
T_9	2.00	77.25	292.67
T_{10}	1.89	70.87	311.78
T_{11}	2.11	81.47	288.67
T_{12}	1.67	66.70	322.89
T_{13}	1.78	70.20	313.67
T_{14}	2.00	80.80	304.00
SE (±)	0.15	0.57	1.29
CD (5%)	0.42	1.67	3.75

(Number of plants per plot: 6, Observation plants per plot: 3, Replication: 3) (Total number of observation plants: 9)

flowers per cluster (2.78, 2.67, 2.11 and 2.11 respectively) among their respective levels of fertigation treatments. Similar result of increment in number of flowers per shoot by foliar application of zinc and boron in pomegranate cv. Ganesh was reported (20). It may also be due to effect of zinc in stimulating the reproductive growth of plants and thereby increasing the number of flower buds. Increased number of flower buds in strawberry by foliar application of zinc was noticed (21).

However, plants receiving 150 % recommended dose of N and K through fertigation and foliar sprays of 1.0 % 19:19:19 (T_{10}) and treatments receiving 150 % recommended dose of N and K through fertigation with water spray (T_{12}) recorded lowest number of flowers per cluster than control 2 (T_{14}) which received 187:170:341 gm NPK plant^{-1} year^{-1} based on soil test data as organic manures. This could be attributed to the supply of high N to papaya plants. Abundant nitrogen supply with ample opportunity for carbohydrate synthesis is known to produce vegetative growth and reduce flowering (22), ie. high nitrogen availability will result in low C: N ratio, which will promotes vegetative growth (23, 24).

Fruit set percentage

Fruit set recorded by different treatments were analysed and the probable causes for variation are discussed below. Among different treatments, highest fruit set (86.27 %) was recorded in plants receiving 100 % recommended dose of N and K through fertigation and foliar sprays of 1.0 % 19:19:19 (T_4), which was on par with T_5 (100 % recommended dose of N and K through fertigation and foliar sprays of 0.5 % $ZnSO_4$ and 0.3 % borax) (85.43 %) (Table 2). However, lowest fruit set of 64.50 % was registered in T_3 (75 % recommended dose of N and K through fertigation with water spray). Amplified synthesis of auxins and gibberellins might have occurred in treatment T_4 as a result of increased uptake of nutrients, which resulted in highest fruit set. As water is applied near to root zone, soil moisture in field capacity range can always be maintained in drip irrigation and no moisture stress is faced during the flowering and fruit development stage and thus fruit drop was minimized. This might have contributed to the higher % of fruit set (25, 26). Role of zinc in auxin biosynthesis, contributed to the early flowering and fruit set. This might have contributed to the increase in fruit set in treatments T_5 (100 % recommended dose of N and K through fertigation and foliar sprays of 0.5 % $ZnSO_4$ and 0.3 % borax) and T_8 (125 % recommended dose of N and K through fertigation and foliar sprays of 0.5 % $ZnSO_4$ and 0.3 % borax). Improved pollen germination, growth of pollen tube that facilitate timely fertilization before the stigma loses its receptivity or the style become nonfunctional and higher metabolites synthesis achieved as a result of combined effect of zinc and boron might have resulted in enhanced fruit set (27). Reduction in nutrient competition among fruitlets and the hormonal balance achieved due to role of zinc and boron, prevented fruit drop and increased their survival. Translocation of hormones, food substances and other factors stimulating fruit formation to the tissue of ovary in greater amount in response to micronutrients application leads to the higher fruit set (28). Also this increase in fruit set could be partly due to a reduction in abscission of buds and flowers as influenced by the micronutrients (29).

Time for first harvest

The results obtained from the current trial revealed that there is a significant impact of application of different levels of fertigation and different foliar sprays on time taken for first harvest in papaya under study (Table 2). The least number of days for first harvest of fruits (275.00 days) was reported in 100 % recommended dose of N and K through fertigation and foliar sprays of 0.5 % $ZnSO_4$ and 0.3 % borax (T_5), whereas plants receiving 75 % recommended dose of N and K through fertigation with water spray took more number of days (327.56 days) for first harvest. In the present study, nitrogen and potassium were applied at weekly intervals through fertigation. Thus, resulting in synthesis and deposition of photoassimilates in papaya plant happened as a result of effective utilization of accurate placement of fertilizers in solution form at the active root zone area. This might have led to induce better growth, fruit bud differentiation and induced precocious flowering and early harvest (30). Minimum days to first harvesting in pomegranate cv. Sindhuri was reported on spraying with zinc sulphate and boric acid (31).

The results of effect of fertigation and foliar sprays on yield parameters of papaya are depicted in the Table 3.

Fruit weight

Significantly highest fruit weight (797.51 gm) was noticed in plants receiving 100 % recommended dose of N and K through fertigation and foliar sprays of 1.0 % 19:19:19 (T_4), which was on par with T_5 (100 % recommended dose of N and K through fertigation and foliar sprays of 0.5 % $ZnSO_4$ and 0.3 % borax) (792.42 gm) (Table 3). Treatments receiving optimum doses of nutrients through fertigation with different

foliar sprays were found to have highest fruit weight. Accelerated photosynthesis in application of 100 % recommended dose of N and K through fertigation, achieved as a result of increased growth and vigour might have first improved the internal nutritive condition of plant leading to accelerated mobility of photosynthates from source to sink as influenced by the growth hormones and finally translocation of assimilates into the fruits (32) thereby increasing the fruit weight. Application of 100 % recommended dose of N and K through fertigation improved the fruit weight in papaya cv. Red Lady (33). Role of boron in hormonal metabolism, increase in cell division and expansion of cell might have contributed to the increased fruit weight with the sprays of borax. Boron also have the capacity to stimulate rapid mobilization of water and sugar in the fruit, which leads to higher fruit weight. Starch production and transportation of carbohydrates in plants is promoted by zinc. More weight of fruits in zinc and boron foliar treated plants might be due to faster loading and mobilization of photo assimilates to fruits and involvement in cell division and cell expansion.

Table 3. Effect of fertigation and foliar sprays on fruit weight, number of fruits per plant and total yield per plant in papaya variety Surya

Treatments	Fruit weight (gm)	Number of fruits per plant	Total yield per plant (kg)
T_1	708.93	41.00	29.06
T_2	703.47	40.11	28.21
T_3	569.84	28.45	16.21
T_4	797.51	48.11	38.30
T_5	792.42	47.45	37.60
T_6	634.60	37.22	23.62
T_7	747.95	44.33	33.16
T_8	754.60	45.00	33.96
T_9	644.11	38.44	24.76
T_{10}	631.38	33.78	21.33
T_{11}	741.49	42.00	31.14
T_{12}	592.45	30.00	17.78
T_{13}	608.71	34.55	21.03
T_{14}	711.31	42.56	30.27
SE	2.80	0.40	0.32
CD (5%)	8.13	1.15	0.93

(Number of plants per plot: 6, Observation plants per plot: 3, Replication: 3) (Total number of observation plants: 9)

Number of fruits per plant

The statistical analysis of number of fruits per plant in papaya revealed a highest number of fruits (48.11) in T_4 which received 100 % recommended dose of N and K through fertigation and foliar sprays of 1.0 % 19:19:19 (Table 3). It was on par with T_5 (100 % recommended dose of N and K through fertigation and foliar sprays of 0.5 % $ZnSO_4$ and 0.3 % borax) with 47.45 fruits. Maximum number of fruits recorded in T_4 and T_5 might be due to the efficient and timely utilization of optimum dose of nutrients through fertigation and foliar sprays of 19:19:19 (1.0 %) and $ZnSO_4$ (0.5 %) + borax (0.3 %). Significantly increased number of fruit per trees in *Citrus reticulata* Blanco cv. Feutrell's Early upon foliar application of zinc and boron was reported earlier (34). Minimal fruit drop might also be contributed to this increase in fruit number. Function of zinc to prevent the formation of abscission layer might also have contributed to the reduction in pre-harvest fruit drop (35). Also zinc has a role in auxin synthesis and the balance of auxin in plant regulates the fruit drop or retention in plants, which altered the control of fruit drop and increased the total number of fruits per tree. Increase in number of fruits in avocado was reported as a result of supplemental foliar sprays of micronutrients during flowering (36).

Total yield plant^{-1}

The results obtained from the present investigation revealed significant difference in total yield per plant among treatments (Table 3). Highest yield (38.30 kg plant^{-1}) was noticed in plants receiving 100 % recommended dose of N and K through fertigation and foliar sprays of 1.0 % 19:19:19 (T_4), which was on par with T_5 (100 % recommended dose of N and K through fertigation and foliar sprays of 0.5 % $ZnSO_4$ and 0.3 % borax) with 37.60 kg plant^{-1}. Higher yield per plant obtained in treatments T_4 and T_5 might be due to application of optimum dose of fertilizers through fertigation (100 % recommended dose of N and K) in addition to foliar spray with 19:19:19 and $ZnSO_4$ + borax, resulting in more preferential influx of photosynthates to the sink contributing to increased fruit weight. Timely application of fertilizers applied in small quantities in the basin of root zone as per need in fertigation, increased the nutrient use efficiency of crop. Apart from this, the technique helped in saving the fertilizer and reducing nutrient losses (37). In strawberry significantly higher yield with fertigation as compared to soil application was reported (38). Foliar application of 19:19:19 at 2, 4 and 6 MAP was effective in enhancing the number of hands in banana cv. Nendran (39). Foliar sprays of zinc sulphate (0.5%) and boric acid (0.1%) at 4th and 8th month after planting increased the yield in papaya cv. CO.5 (40).

The results of impact of fertigation and foliar sprays on fruit quality parameters of papaya are shown in the Table 4.

Total Soluble Solids (TSS)

The data on TSS of fruits showed significant difference among the treatments (Table 4). Highest TSS (15.10°Brix) was noticed in fruits from T_5 (100 % recommended dose of N and K through fertigation and foliar sprays of 0.5 % $ZnSo_4$ and 0.3 % borax), which was on par with T_8 (125 % recommended dose of N and K through fertigation and foliar sprays of 0.5 % $ZnSo_4$ and 0.3 % borax) (14.90°Brix). Lowest TSS (12.50°Brix) was observed in fruits from T_3 (75 % recommended dose of N and K through fertigation and water spray). The results are in accordance with the findings in Kinnow mandarin who reported maximum TSS in treatment provided with 100 % NPK as fertigation (41). Similar results of increment in TSS content due to foliar spray of boron and zinc have also been reported in papaya cv. CO.5 (40). The higher total soluble solids observed in T_5 and T_8 might be due to the efficient translocation of photosynthates to the fruit by regulation of boron.

Boron also facilitates sugar transport within the plant (42).

Titratable acidity

The results obtained from the present investigation revealed significant difference in titratable acidity of fruits (Table 4). Lowest titratable acidity (0.13 %) was noticed in fruits from plants receiving 100 % recommended dose of N and K through fertigation and foliar sprays of 0.5 % $ZnSo_4$ and 0.3 % borax. Highest titratable acidity (0.28 %) was noticed in fruits from plants provided with 75 % recommended dose of N and K through fertigation and water spray (T_3). As reported in a study, zinc has an important role in photosynthesis and enzyme activation, resulting in increasing sugar and decreasing acidity (43).

Table 4. Effect of fertigation and foliar sprays on total soluble solids, titratable acidity, ascorbic acid and total sugars of papaya variety Surya fruits

Treatments	Total soluble solids (°Brix)	Acidity (%)	Ascorbic acid (mg 100 g^{-1})	Total sugars (%)
T_1	13.15	0.26	54.36	7.46
T_2	13.36	0.23	57.78	7.80
T_3	12.50	0.28	43.42	7.15
T_4	14.73	0.16	65.30	9.30
T_5	15.10	0.13	68.38	9.66
T_6	14.01	0.17	62.91	8.73
T_7	14.43	0.16	64.96	9.15
T_8	14.90	0.15	67.69	9.45
T_9	14.11	0.17	63.59	8.92
T_{10}	13.10	0.26	51.28	7.45
T_{11}	14.32	0.17	63.93	9.00
T_{12}	12.89	0.27	49.23	7.16
T_{13}	13.40	0.22	58.12	8.15
T_{14}	13.61	0.18	62.22	8.36
SE (±)	0.07	--	1.64	0.03
CD (5%)	0.22	0.01	4.77	0.10

(Number of plants per plot: 6, Observation plants per plot: 3, Replication: 3) (Total number of observation plants: 9)

Ascorbic acid

Application of different levels of fertigation and different foliar sprays had significant effect on ascorbic acid content of papaya fruits (Table 4). Highest ascorbic acid content of 68.38 mg $100g^{-1}$ was noticed in T_5 (100 % recommended dose of N and K through fertigation and foliar sprays of 0.5 % $ZnSo_4$ and 0.3 % borax) which was on par with T_8 (125 % recommended dose of N and K through fertigation and foliar sprays of 0.5 % $ZnSo_4$ and 0.3 % borax) (67.69 mg $100g^{-1}$). Plants receiving 75 % recommended dose of N and K through fertigation and water spray (T_3) recorded lowest ascorbic acid content (43.42 mg $100g^{-1}$). Higher ascorbic acid content with application of optimum levels of nitrogen might be attributed to increase in synthesis and catalytic activity of several enzymes and co-enzymes which are instrumental in ascorbic acid synthesis (44). Apart from this zinc play an active role in the production of auxin in plant species (45), and the production of auxin increases ascorbic acid content which was reported in Kinnow mandarin (46).

Total sugars

The treatment which received well balanced nutrition inclusive of major and micro nutrients (T_5 - 100 % recommended dose of N and K through fertigation and foliar sprays of 0.5 % $ZnSo_4$ and 0.3 % borax) recorded highest total sugar content (9.66 %), whereas T_3 (75 % recommended dose of N and K through fertigation and water spray) which received lower dose of nutrients performed inferiorly with lowest total sugar content of 7.15 % (Table 4). The increase in sugar content in T_5 and T_8 could be due to enhancement of sugar translocation from leaves to developing fruits by boron. The mechanism of such rapid translocation of sugar under boron application was explained by (47). Also the action of zinc on converting complex substances into simple ones enhances the metabolic activity in fruits, which results in increased total sugar content of fruit. Results are in agreement with the findings of (48) who reported that application of zinc with boron increased the total sugars percentage in Khasi mandarin.

Conclusion

The findings of the study reveal that application of 100 % recommended dose of N and K through fertigation at weekly interval from one MAP to 20 MAP and foliar sprays of 0.5 % $ZnSO_4$ and 0.3 % borax at 4^{th}, 8^{th}, 12^{th} and 16^{th} MAP (T_5) along with basal application of 850 gm rock phosphate and 15 kg FYM initiated earliness in flowering (142.67 days) and harvest (275.00 days), improved the fruit weight, number of fruits per plant and total yield per plant and recorded significantly higher total soluble solids, ascorbic acid content, total sugars and lowest acidity in papaya variety 'Surya'. Hence, treatment T_5 which was found effective in providing early harvest and improving the yield and fruit quality parameters can be recommended for commercial papaya cultivation.

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Authors' contributions

The work was a part of Ph.D thesis work of first author, which was supervised by second and third authors. All authors read and approved the final manuscript.

Conflict of interests

Authors do not have any conflict of interests to declare.

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