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Influence of crop regulation on growth, yield and quality of purple passion fruit (*Passiflora edulis*)

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ABSTRACT

The study was carried out during 2021–22 and 2022–23 at Mizoram University, Aizawl, Mizoram to assess the impact of flower and fruit thinning and growth regulating chemicals on yield attributing characters, yield, and quality of purple passion fruit (*Passiflora edulis* Sims.). The experiment was laid out in randomized block design (RBD) with 14 treatments, viz. T_1, Control; T_2, Flower thinning; T_3, Manual fruit thinning; T_4, GA_3; T_5, ethephon; T_6, Forchlorfenuron (CPPU); T_7, Flower thinning + GA_3; T_8, Flower thinning + ethephon; T_9, Flower thinning + CPPU; T_{10}, Flower thinning + GA_3 + ethephon + CPPU; T_{11}, Manual fruit thinning + GA_3; T_{12}, Manual fruit thinning + ethephon; T_{13}, Manual fruit thinning + CPPU; T_{14}, Manual fruit thinning + GA_3 + ethephon + CPPU. The results indicated that crop regulation with manual fruit thinning + GA_3 + ethephon + CPPU (T_{14}) was the most effective in terms of highest fruit set percentage (58.92%), minimum fruit drop (38.22%), maximum yield/vine (10.52 kg), fruit weight (56.60 g), TSS (15.85°Brix), total reducing and non-reducing sugars (11.53, 8.80, 2.59%), ascorbic acid (35.56 and 36.93 mg/100 g), carotenoid (3.32 mg/100 g), and total phenols (23.16 mg GAE/100 g). This study recommends that treatment involving manual fruit thinning + GA_3 + ethephon + CPPU is considered as best crop regulating technique in commercial passion fruit cultivation to improve yield and fruit quality.

Keywords: Crop regulation, Passion fruit, Yield, Quality

Passion fruit (*Passiflora edulis* Sims.), a native of Brazil and a member of the Passifloraceae family which has popularised as one commercial fruit in north-east India (Chadha 2002). In India, the cultivation is confined to only few districts of Karnataka, Kerala and Tamil Nadu and north-eastern states. However, the national productivity of passion fruit in India is around 5.02 t/ha which is very low as compared to other passion fruit growing countries like Brazil, Australia, Colombia where average productivity is 30–35 tonnes/ha (Joy 2010). Since the soil and climatic condition of north-east India is very much congeniel for growth and development of passion fruit, there may have enormous potential for cultivation of passion fruit to boost the nation's output of passion fruit.

In passion fruit, the vine tends to overbear, and produces smaller and lower-quality fruits, which is one of the important production problem faced by most of the growers of our country. To improve fruit quality, crop regulation through fruit thinning and using plant growth hormones are very essential. In passion fruit, crop regulation as a mean of improving clusters, and fruit quality is one of the most suitable solution for the growers. As far as crop regulation is concerned, it is a way to force a tree for its rest and to produce profuse blossom and fruits during flushes. It aims to regulate into a uniform and good quality fruit and to maximize the production as well as profit to the grower. The management of passion fruit canopy through regulation of pruning and thinning is necessary to control the accumulation of reserves of carbohydrates, which in turn determines the canopy's performance in the following cycle. According to Zheng *et al.* (2017), a correctly pruned canopy increases sunshine exposure, decreases shoot density, and increases photosynthesis. The impacts of flower and fruitlet thinning are among the most significant orchard management techniques that effect crop load and fruit quality.

The quantity of fruits on a tree is closely correlated with the size and weight variation of the fruit and hand thinning is the most popular method to control the size of the fruits (Rahman *et al.* 2017). Several studies have found that thinning of fruit improves fruit quality and size. In order to increase fruit size, GA_3 is widely employed; which led to decrease bunch compactness, whereas, CPPU, is used to stimulate the plant cell division. Similarly, ethephon typically works better for thinning of the fruitlets.

Keeping in view all the above information in mind, the present experiment was planned to see the impact of crop

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regulation on fruit development, yield and quality purple passion fruit.

MATERIALS AND METHODS

The study was carried out during 2021–22 and 2022–23 at Mizoram University, Aizawl, Mizoram. A farmer's field at Mualkawi village, Champhai, Mizoram (latitude 23.4566° N and longitude 93.3282° E) was selected for the study. The vines were spaced at 3 m × 3 m. The soil of the experimental plot was clayey loam, acidic, with *p*H 5.67; the available N, P and K were 278.56 kg/ha, 28.67 kg/ha and 142.56 kg/ha respectively, with 0.78% organic carbon. The experiment was set up in a randomised block design (RBD) with 14 treatments (T_1, Control; T_2, Flower thinning; T_3, Manual fruit thinning; T_4, GA_3; T_5, ethephon; T_6, Forchlorfenuron (CPPU); T_7, Flower thinning + GA_3; T_8, Flower thinning + ethephon; T_9, Flower thinning + CPPU; T_{10}, Flower thinning + GA_3 + ethephon + CPPU; T_{11}, Manual fruit thinning + GA_3; T_{12}, Manual fruit thinning + ethephon; T_{13}, Manual fruit thinning + CPPU; T_{14}, Manual fruit thinning + GA_3 + ethephon + CPPU) and three replications. The spacing was maintained 3 m × 3 m. For flower thinning, flowers were thinned by using scissors at 50% bloom, to cut off the terminal section of the bloom. The manual fruit thinning was done by removing 20% of the fruitlets by hand thinning when the fruitlets reached the pea-size stage. GA_3 at 50 ppm concentration was applied by dipping flower clusters at 50% bloom. Whereas, ethephon was applied at a concentration of 500 ppm immediately after fruit set at pea stage through bunch dipping. Forchlorfenuron (CPPU) was applied at a concentration of 3 ppm at pea stage through bunch dipping. The dosage of the PGRs have been fixed by consulting previous published literatures on impact of PGRs in crop regulations in different fruit crops. The combinations of diverse group of PGRs and pruning treatments were done to see the best possible PGRs and pruning treatments either singly or in combinations and its impact on passion fruit.

The nutrient requirements were managed by applying the recommended dose of fertilizers (RDF) (80 g N, 40 g P_2O_5, and 50 g K_2O/plant/year). Treatments were administered in two divided doses in each of the two years (2021–22 and 2022–23); 2/3rd of the calculated amount was given in the final week of February, when passion fruit started flowering, and the remaining 1/3rd dose was applied in August. Light irrigation was administered right away following the application of fertilisers.

The growth characteristics, viz. length and diameter of the shoot, internodal length, and cane diameter, were evaluated in accordance to standard protocols. By dividing the number of canes that bear fruit by the total number of canes, the percentage of fruitful cane was determined. By calculating total weight of fruit on a single vine, the yield/vine was determined and expressed in kg. Twenty fruits were chosen at random from every replication to assess the physical and quality parameters, and their mean was computed. Fruits' total and reducing sugars were calculated using the AOAC (2016) protocol. Oven-dry method was used to determine the fruits' moisture content as per Rangana (2000). The fruit's total soluble solid (°Brix) was determined using a Milwaukee digital refractometer. The AOAC's (2016) standard techniques were used to assess the titratable acidity. The reducing, total and non-reducing sugars, ascorbic acid was estimated by using by adopting the standard methods of AOAC (2016). The anthocyanin content of the fruits were calculated spectrophotometrically. Using spectrophotometry, fruit's total carotenoid contents were determined and expressed as mg/100 g. Folin-Ciocalteu technique was used to estimate total phenolic content by using gallic acid as standard. The lyophilized sample's GA equivalent (mg/g) was used to express quantity of total phenolics.

PROC GLM of Statistical Analysis System (SAS) software (version 9.3; SAS Inc, Cary, NC) was used for analysis of variance (one-way classified data) for each parameter. Least significant different (LSD) test ($P \leq 0.05$) was used for obtaining mean separation for different treatments and parameters.

RESULTS AND DISCUSSION

Growth, yield attributing characters and yield: Among all the treatments, manual fruit thinning + GA_3 + ethephon + CPPU (T_{14}) recorded the maximum values for the shoot length (129.96, 133.41 and 131.69 cm), shoot diameter (1.86, 1.98 and 1.93 cm), internodal length (10.65, 11.53 and 11.09 cm) and cane diameter (0.78, 0.84 and 0.81 cm) in both the years and pooled data while the lowest was observed in control (T_1) (121.21, 122.76 cm and 122.02 cm), shoot diameter (1.60, 1.71 and 1.66 cm), internodal length (9.06, 9.96 and 9.51 cm) and cane diameter (0.47, 0.52 and 0.50 cm) (Table 1). The maximum values of shoot length and shoot diameter in manual fruit thinning + GA_3 + ethephon + CPPU could be attributed to the stimulatory influence of thinning and PGRs on meristematic tissues' cell division and to lessen unfavourable competition among shoots. Additionally, a decrease in number of flowers/fruits per vine may significantly lessen the significance of fruits as main sink, changing the way resources are partitioned to prioritise the growth of other sinks (vegetative growth). These outcomes are consistent with the findings of Kumawat *et al.* (2012) in guava and Barkule *et al.* (2018) in grape. The increase in internodal length due to manual fruit thinning might be due to the prevention of translocation of carbohydrates to the root system thus making it available for shoot growth. Our results are in the line of conformity with the findings of Lalhriatpuia *et al.* (2021) who suggested that manual fruit thinning and plant growth regulators increases the internodal length of grapevines.

The highest fruitful cane and fruit set percentage (80.42, 87.45 and 83.94% and 58.08, 59.76 and 58.92%, respectively) in 1st year, 2nd year and pooled analysis was observed in T_{14} (manual fruit thinning + GA_3 + ethephon + CPPU) while the lowest was recorded in control (T_1) (64.96, 68.63 and 66.80 % and 41.83, 42.50 and 42.17%, respectively) (Table 1). Fruit thinning provided balance in

Table 1 Effects of crop regulations on growth and yield attributing characters of passion fruit

Treatment	Shoot length (cm)			Shoot diameter (cm)			Internodal length (cm)			Cane diameter (cm)			Fruitful cane (%)			Fruit set (%)			Fruit drop (%)			Yield/vine (kg)		
	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled
T_1	121.27^{j}	122.76^{c}	122.02^{g}	1.60^{e}	1.71^{e}	1.66^{e}	9.06^{i}	9.96^{h}	9.51^{j}	0.47^{h}	0.52^{e}	0.50^{g}	64.96^{f}	68.63^{f}	66.80^{j}	41.83^{g}	42.50^{g}	42.17^{h}	51.62^{a}	50.55^{a}	51.09^{a}	5.81^{h}	6.07^{j}	5.95^{k}
T_2	122.03^{i}	124.61^{bc}	123.33^{fg}	1.68^{de}	1.79^{de}	1.74^{de}	9.52^{i}	10.33^{g}	9.93^{i}	0.59^{g}	0.65^{d}	0.63^{f}	69.69^{e}	77.02^{e}	73.36^{i}	44.59^{f}	45.82^{f}	45.21^{g}	47.73^{b}	46.13^{b}	46.94^{b}	6.88^{g}	7.43^{i}	7.16^{j}
T_3	124.59^{h}	125.40^{bc}	125.00^{ef}	1.71^{cd}	1.82^{cd}	1.77^{cd}	9.59^{hi}	10.46^{g}	10.03^{hi}	0.61^{fg}	0.66^{d}	0.64^{ef}	70.23^{e}	79.20^{de}	74.72^{hi}	46.22^{ef}	46.49^{f}	46.36^{fg}	45.77^{bcd}	43.62^{bcd}	44.70^{bcd}	7.22^{g}	7.63^{i}	7.43^{j}
T_4	127.33^{e}	129.02^{ab}	128.18^{abcd}	1.75^{bcd}	1.86^{bbcd}	1.81^{bcd}	9.88^{fg}	10.81^{ef}	10.35^{fg}	0.64^{defg}	0.70^{cd}	0.67^{def}	73.42^{cd}	82.02^{bbcde}	77.72^{efgh}	48.28^{de}	49.12^{e}	48.71^{ef}	44.81^{bcde}	43.74^{bcd}	44.28^{cde}	8.65^{f}	9.01^{gh}	8.31^{hi}
T_5	125.46^{g}	127.56^{abc}	126.51^{de}	1.74^{bcd}	1.85^{bcd}	1.80^{bcd}	9.76^{ghi}	10.71^{f}	10.24^{gh}	0.61^{efg}	0.67^{d}	0.65^{ef}	71.57^{de}	80.84^{cde}	76.21^{ghi}	46.89^{ef}	47.03^{f}	46.97^{fg}	47.03^{bc}	45.02^{bc}	46.03^{bc}	7.89^{f}	8.22^{h}	8.06^{i}
T_6	125.98^{f}	128.47^{abc}	127.23^{cde}	1.79^{abc}	1.91^{abc}	1.85^{abc}	9.84^{cfgh}	10.77^{ef}	10.31^{g}	0.67^{cdefg}	0.71^{cd}	0.70^{cdef}	76.89^{b}	83.82^{abcd}	80.36^{bcde}	49.66^{cd}	50.50^{d}	50.08^{de}	44.03^{cde}	42.96^{bcde}	43.50^{cdef}	8.01^{de}	8.60^{efg}	8.84^{fg}
T_7	127.78^{de}	129.76^{ab}	128.77^{abcd}	1.80^{abc}	1.90^{abc}	1.86^{abc}	10.32^{bcd}	11.20^{bc}	10.77^{bcd}	0.69^{bcdef}	0.75^{bc}	0.72^{bcde}	73.79^{cd}	84.06^{abcd}	78.93^{defg}	51.06^{c}	51.53^{d}	51.30^{d}	44.04^{cde}	40.61^{def}	42.33^{defg}	9.12^{de}	9.48^{def}	8.97^{ef}
T_8	125.85^{fg}	127.91^{abc}	126.88^{cde}	1.77^{abcd}	1.88^{abcd}	1.83^{abcd}	10.01^{efg}	10.89^{def}	10.46^{efg}	0.66^{cdefg}	0.72^{bcd}	0.70^{cdef}	71.59^{de}	80.86^{cde}	76.23^{ghi}	50.32^{cd}	50.59^{de}	50.46^{de}	44.77^{bcde}	41.83^{cdef}	43.31^{def}	8.32^{ef}	8.86^{fg}	8.59^{gh}
T_9	126.14^{f}	128.07^{abc}	127.11^{cde}	1.81^{abc}	1.91^{abc}	1.87^{abc}	10.17^{cde}	11.12^{bcd}	10.65^{cde}	0.74^{abc}	0.80^{ab}	0.77^{abc}	77.78^{b}	84.58^{abc}	81.18^{abcd}	53.86^{b}	54.93^{c}	54.40^{c}	42.77^{def}	40.03^{efg}	41.40^{fg}	8.73^{cd}	9.21^{cde}	9.30^{de}
T_{10}	128.39^{c}	132.08^{a}	130.24^{ab}	1.83^{ab}	1.96^{ab}	1.90^{ab}	10.52^{ab}	11.26^{bc}	10.89^{abc}	0.76^{ab}	0.83^{a}	0.80^{ab}	79.23^{ab}	86.17^{ab}	82.70^{ab}	55.87^{ab}	56.11^{bc}	55.99^{bc}	40.82^{fg}	38.89^{fg}	39.86^{gh}	9.59^{bc}	9.97^{bc}	9.79^{bc}
T_{11}	127.87^{d}	130.13^{ab}	129.01^{abcd}	1.82^{ab}	1.92^{abc}	1.87^{abc}	10.56^{ab}	11.36^{ab}	10.97^{ab}	0.70^{abcd}	0.77^{abc}	0.74^{abcd}	74.40^{c}	84.74^{abc}	79.57^{cdef}	55.05^{b}	55.92^{bc}	55.49^{bc}	43.28^{def}	40.07^{efg}	41.68^{efg}	9.65^{cd}	10.18^{bcd}	9.45^{cd}
T_{12}	127.67^{de}	128.12^{abc}	127.90^{bcd}	1.80^{abc}	1.91^{abc}	1.86^{abc}	10.09^{def}	11.02^{cde}	10.56^{def}	0.70^{bcde}	0.76^{abc}	0.73^{abcd}	72.20^{cde}	81.07^{bcde}	76.64^{fgh}	53.83^{b}	54.40^{c}	54.12^{c}	42.90^{def}	40.96^{def}	41.94^{efg}	8.78^{de}	9.42^{cdef}	9.10^{def}
T_{13}	129.19^{b}	129.86^{ab}	129.53^{abc}	1.85^{ab}	1.94^{ab}	1.90^{ab}	10.39^{abc}	11.18^{bc}	10.79^{bcd}	0.77^{ab}	0.83^{a}	0.80^{ab}	78.08^{ab}	86.01^{abc}	82.05^{abc}	56.43^{ab}	57.56^{b}	57.00^{ab}	42.02^{efg}	39.78^{efg}	40.90^{fg}	9.15^{b}	9.75^{ab}	9.92^{b}
T_{14}	129.96^{a}	133.41^{a}	131.69^{a}	1.86^{a}	1.98^{a}	1.93^{a}	10.65^{a}	11.53^{a}	11.09^{a}	0.78^{a}	0.84^{a}	0.81^{a}	80.42^{a}	87.45^{a}	83.94^{a}	58.08^{a}	59.76^{a}	58.92^{a}	39.25^{g}	37.18^{g}	38.22^{h}	10.34^{a}	10.70^{a}	10.52^{a}
SEM (±)	0.16	1.76	0.88	0.03	0.03	0.03	0.08	0.07	0.08	0.02	0.02	0.02	0.85	1.63	0.99	0.85	0.96	0.82	0.93	1.04	0.86	0.16	0.18	0.12
CD (P=0.05)	0.47	5.16	2.57	0.09	0.09	0.10	0.25	0.22	0.23	0.07	0.07	0.07	2.49	4.77	2.87	2.49	2.83	2.38	2.70	3.04	2.51	0.48	0.54	0.36

Treatment details are given under Materials and Methods.

highly fruitful vines between vegetative growth and fruit biomass. Among the PGR treatments, ethephon showed considerably lower fruit set (%) as compared to GA_3 and CPPU which is similar to the findings of Sabir *et al.* (2021) in sweet cherry and Sharma *et al.* (2018) in pear.

Table 1 showed minimum fruit drop (%) (39.25, 37.18 and 38.22%) under combined interaction of treatments in T_{14} (manual fruit thinning + GA_3 + ethephon + CPPU) while the maximum was recorded in control (T_1) (51.62, 50.55 and 51.09 %) for both the years and pooled data. By altering the balance of endogenous hormones and boosting the availability of carbohydrates, CPPU treatment may decrease fruit drop. Additionally, Sadia *et al.* (2017) concluded that reduced abscission layer due to GA_3 enhancement prevents premature flowering and fruit drop. Gattass *et al.* (2018) in mango and Ennab (2019) in plum also reported similar findings.

With regards to yield per vine, maximum yield (10.34, 10.70 and 10.52 kg) showed in T_{14} (manual fruit thinning + GA_3 + ethephon + CPPU) with minimum in control (T_1) (5.81, 6.07 and 5.95 kg) for 1st year, 2nd year and pooled analysis (Table 1). These findings could be explained by the interaction of many fruit physical properties, such as increased fruit set and average fruit weight, which are enhanced by GA_3 and CPPU's effects on cell division and elongation. The outcomes are comparable to those of Elmenofy *et al.* (2021) in Washington navel orange and Barkule *et al.* (2018) in sapota.

Fruit physical parameters: Manual fruit thinning + GA_3 + ethephon + CPPU (T_{14}) revealed maximum fruit weight (56.09, 57.11 and 56.60 g), fruit longitudinal and transversal diameter (5.59, 5.72 and 5.66 cm and 5.11, 5.22 and 5.17 cm), and fruit volume (58.98, 61.42 and 60.20 cc), while the minimum values for these parameters were recorded in control (T_1) (40.28, 40.77 and 40.50 g; 4.40, 4.79 and 4.60 cm; 4.22, 4.27 and 4.25 cm and 43.73, 45.07 and 44.40 cm, respectively) (Table 2). Fruit weight was improved through thinning, which decreased fruit compactness and promoted fruit cell division with adequate photosynthetic availability for fruit development and less nutritional competition among the developing fruits on the plant. GA_3 and CPPU treatment enhance cell division and elongation, which maximises the storage of food materials in the developing fruits. It might be due to the fact that GA_3 showed indirect effect through auxin stimulation on the cell elongation by the enlargement of vacuoles and loosening of cell wall after increasing its plasticity, which lead to increase in fruit weight. The modulation of semi-permeability of the cell wall by GA_3, which allowed water to be mobilised and extended into the fruit, may be the cause of increasing fruit volume. Increase in fruit size with manual fruit thinning and growth regulators might be pertained to the fact that gibberellins indirectly affected the level of auxin that ultimately caused cell elongation by enlargement of vacuoles and loosening of cell wall after increasing its palatability. Fruit treated with PGRs appeared to have a substantially thicker cuticular membrane than control; this difference was explained by an increase in cell size. This finding agrees with the results of Rahman *et al.* (2017) in guava and Salama *et al.* (2022) in pomegranate.

Concerning the seeds characters, Table 2 revealed minimum seed thickness (3.60, 3.82 and 3.71 mm) length (0.538, 0.522 and 0.530 cm), seed width (0.449, 0.432 and 0.441 cm), and seed weight (0.035, 0.025 and 0.030 g) was recorded in T_{14} (manual fruit thinning + GA_3 + ethephon + CPPU), whereas it was maximum in control (T_1) (3.02, 3.10 and 3.06 mm; 0.572, 0.563 and 0.568 cm; 0.487, 0.473 and 0.480 cm and 0.068, 0.061 and 0.065 g, respectively) in 1st year, 2nd year and pooled analysis respectively. Similar outcomes were published by Wani *et al.* (2017) and Susila *et al.* (2013) in watermelon.

Fruit quality parameters: The minimum moisture content (73.00, 69.96 and 71.48%) for 1st year, 2nd year and pooled analysis was found in T_{11} (manual fruit thinning + GA_3) while maximum (78.61, 77.18 and 77.89%) was recorded for T_1 (control) (Table 3). The manually thinned fruits had substantially decreased moisture content, which may have been caused by the fruits' hydrolysis of reserved metabolites from insoluble into soluble form. Our study is in the line of conformity with the studies of Lalhriatpuia *et al.* (2021) who reported a similar outcome.

The maximum total soluble solids (TSS) (15.55, 16.15 and 15.85°Brix) was observed in manual fruit thinning + GA_3 + ethephon + CPPU (T_{14}) while the minimum (12.60, 12.93 and 12.76°Brix) was in T_1 (control) (Table 3). Increased TSS in manual thinning could be the result of a higher leaf to fruit ratio caused by a lower fruit set rate or crop load. The mobilisation of carbohydrates from source to sink may be accelerated by GA_3 and CPPU. The outcomes closely align with findings of Saleem *et al.* (2008) in sweet orange and Rahman *et al.* (2017) in guava.

Table 3 revealed that in 1st year, 2nd year and pooled analysis, the lowest titratable acidity (2.42, 2.51 and 2.46%) was observed in T_{14} (manual fruit thinning + GA_3 + ethephon + CPPU) while the maximum (3.30, 3.39 and 3.34%) was observed in control. The less acidity in the particular treatment might be due to converting the organic acids into sugars or their utilisation in respiration. Our study is in close conformity with the findings of Barkule *et al.* (2018) in sapota and Patel *et al.* (2014) in peaches.

The highest total, reducing and non-reducing sugars (11.13, 11.93 and 11.53%; 8.44, 9.16 and 8.80% and 2.69, 2.77 and 2.73%, respectively) in manual fruit thinning + GA_3 + ethephon + CPPU i.e. T_{14} while the minimum (9.11, 9.39 and 9.25%; 7.27, 7.48 and 7.38% and 1.83, 1.91 and 1.87) was in control (T_1) (Table 3). This may be caused by decrease in crop load as a result of fruitlets being thinned; which increased sugar synthesis, accumulation, and transport in the surviving fruits. CPPU may have helped to manufacture more metabolites by increasing the number of leaves and their chlorophyll content. These results are consistent with those of Patel *et al.* (2014) and Barkule *et al.* (2018).

It is revealed from the data presented in Supplementary

Table 2 Effect of crop regulation on fruit physical parameters of passion fruit

Treatment	Individual fruit weight (g)			Fruit longitudinal diameter (cm)			Fruit transversal diameter (cm)			Fruit volume (cc)			Skin thickness (mm)			Seed weight (g)			Seed length (cm)			Seed width (cm)		
	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled
T_1	40.28^{g}	40.77^{g}	40.53^{h}	4.40^{f}	4.79^{d}	4.60^{e}	4.22^{e}	4.27^{d}	4.25^{e}	43.73^{g}	45.07^{f}	44.40^{f}	3.02^{a}	3.10^{b}	3.06^{a}	0.068^{a}	0.061^{a}	0.065^{a}	0.572^{a}	0.563^{a}	0.568^{a}	0.487^{a}	0.473^{bc}	0.480^{a}
T_2	44.43^{f}	46.22^{f}	45.33^{g}	4.76^{e}	4.81^{d}	4.79^{de}	4.49^{de}	4.56^{cd}	4.53^{de}	48.12^{f}	50.96^{e}	49.55^{e}	3.13^{a}	3.27^{ab}	3.20^{a}	0.058^{b}	0.047^{b}	0.053^{b}	0.566^{ab}	0.552^{ab}	0.559^{ab}	0.475^{ab}	0.458^{bc}	0.466^{ab}
T_3	46.03^{ef}	46.97^{ef}	46.51^{fg}	4.85^{de}	4.89^{cd}	4.88^{cde}	4.52^{cde}	4.70^{bc}	4.61^{cd}	48.69^{ef}	51.37^{e}	50.03^{e}	3.18^{a}	3.31^{ab}	3.25^{a}	0.057^{b}	0.045^{bc}	0.051^{b}	0.563^{ab}	0.548^{ab}	0.556^{ab}	0.472^{ab}	0.456^{bc}	0.464^{ab}
`T_4	50.64^{bcd}	51.49^{bcd}	51.07^{cd}	5.13^{bcde}	5.21^{abcd}	5.17^{bcd}	4.79^{abcd}	4.84^{abc}	4.82^{abcd}	51.46^{cdef}	53.94^{de}	52.70^{de}	3.36^{a}	3.49^{ab}	3.43^{a}	0.046^{def}	0.034^{efg}	0.040^{ef}	0.551^{ab}	0.535^{ab}	0.543^{ab}	0.461^{ab}	0.444^{ab}	0.453^{ab}
T_5	47.87^{de}	48.76^{def}	48.32^{ef}	5.01^{cde}	5.07^{bcd}	5.05^{bcd}	4.75^{abcd}	4.78^{bc}	4.77^{bcd}	49.97^{def}	53.09^{de}	51.53^{de}	3.08^{a}	3.17^{ab}	3.13^{a}	0.052^{c}	0.044^{bcd}	0.048^{bc}	0.561^{ab}	0.548^{ab}	0.555^{ab}	0.469^{ab}	0.454^{abc}	0.461^{abc}
T_6	47.94^{de}	49.87^{cdef}	48.91^{de}	5.08^{bcde}	5.16^{abcd}	5.12^{bcd}	4.75^{abcd}	4.82^{abc}	4.79^{bcd}	50.35^{def}	53.89^{de}	52.13^{de}	3.24^{a}	3.41^{ab}	3.33^{a}	0.049^{cde}	0.040^{bcde}	0.045^{cde}	0.556^{ab}	0.541^{ab}	0.549^{ab}	0.466^{ab}	0.449^{ab}	0.457^{abc}
T_7	52.48^{bc}	52.99^{abcd}	52.74^{bc}	5.30^{abc}	5.41^{abc}	5.36^{ab}	4.95^{ab}	5.00^{ab}	4.98^{abc}	53.04^{bcde}	55.75^{bcd}	54.40^{bcd}	3.40^{a}	3.60^{ab}	3.50^{a}	0.044^{fg}	0.031^{fgh}	0.037^{fg}	0.549^{ab}	0.535^{ab}	0.542^{ab}	0.457^{ab}	0.441^{ab}	0.449^{ab}
T_8	49.47^{cd}	50.97^{bcde}	50.23^{cde}	5.09^{bcde}	5.21^{abcd}	5.15^{bcd}	4.73^{bcd}	4.87^{abc}	4.80^{abcd}	51.05^{def}	55.18^{cd}	53.12^{cde}	3.20^{a}	3.30^{ab}	3.25^{a}	0.050^{cd}	0.041^{bcde}	0.045^{cd}	0.556^{ab}	0.542^{ab}	0.549^{ab}	0.464^{ab}	0.449^{ab}	0.457^{abc}
T_9	50.99^{bcd}	52.08^{bcd}	51.54^{cd}	5.15^{bcd}	5.28^{abcd}	5.22^{abcd}	4.86^{abc}	4.88^{abc}	4.88^{abcd}	55.98^{ab}	58.73^{ab}	57.36^{ab}	3.28^{a}	3.49^{ab}	3.39^{a}	0.047^{def}	0.037^{defg}	0.042^{def}	0.552^{ab}	0.538^{ab}	0.545^{ab}	0.461^{ab}	0.445^{ab}	0.453^{ab}
T_{10}	53.83^{ab}	54.86^{ab}	54.35^{ab}	5.41^{ab}	5.50^{ab}	5.46^{ab}	4.99^{ab}	5.03^{ab}	5.02^{ab}	56.67^{ab}	59.21^{ab}	57.94^{ab}	3.51^{a}	3.72^{ab}	3.62^{a}	0.041^{gh}	0.029^{gh}	0.035^{g}	0.544^{ab}	0.529^{a}	0.537^{b}	0.453^{b}	0.437^{ab}	0.445^{ab}
T_{11}	53.90^{ab}	55.07^{fg}	54.49^{ab}	5.42^{ab}	5.55^{ab}	5.49^{ab}	4.99^{ab}	5.09^{ab}	5.04^{ab}	56.93^{ab}	59.10^{ab}	58.02^{ab}	3.48^{a}	3.71^{ab}	3.60^{a}	0.039^{h}	0.030^{gh}	0.035^{g}	0.545^{ab}	0.530^{a}	0.538^{b}	0.455^{ab}	0.440^{ab}	0.448^{ab}
T_{12}	50.62^{abcd}	52.82^{defg}	51.72^{bc}	5.20^{bcd}	5.40^{abc}	5.31^{abc}	4.81^{abcd}	4.88^{abc}	4.85^{abcd}	53.88^{bcd}	56.02^{bcd}	54.95^{bcd}	3.27^{a}	3.43^{ab}	3.35^{a}	0.04^{ef}	0.038^{cdef}	0.042^{def}	0.554^{ab}	0.540^{ab}	0.547^{ab}	0.461^{ab}	0.446^{ab}	0.453^{ab}
T_{13}	52.08^{abc}	53.62^{efg}	52.85^{bc}	5.27^{abc}	5.39^{abc}	5.34^{ab}	4.79^{abcd}	4.91^{abc}	4.85^{abcd}	55.44^{abc}	57.82^{bc}	56.63^{abc}	3.36^{a}	3.56^{ab}	3.46^{a}	0.042^{gh}	0.034^{efg}	0.038^{fg}	0.549^{ab}	0.534^{ab}	0.541^{ab}	0.458^{ab}	0.443^{ab}	0.451^{ab}
T_{14}	56.09^{g}	57.11^{g}	56.60^{a}	5.59^{a}	5.72^{a}	5.66^{a}	5.11^{a}	5.22^{a}	5.17^{a}	58.98^{a}	61.42^{a}	60.20^{a}	3.60^{a}	3.82^{a}	3.71^{a}	0.035^{i}	0.025^{h}	0.030^{h}	0.538^{b}	0.522^{a}	0.530^{b}	0.449^{b}	0.432^{a}	0.441^{a}
SEM (±)	1.10	1.36	0.87	0.10	0.12	0.11	0.09	0.08	0.09	1.36	1.09	1.21	0.21	0.20	0.21	0.001	0.002	0.001	0.009	0.009	0.01	0.009	0.006	0.01
CD (P=0.05)	3.21	3.98	2.53	0.31	0.36	0.31	0.28	0.25	0.25	3.99	3.21	3.51	0.61	0.60	0.061	0.004	0.007	0.004	0.026	0.026	0.03	0.026	0.017	0.02

Treatment details are given under Materials and Methods.

Table 3 Effect of crop regulation of fruit qualities of passion fruit

Treatment	Moisture content (%)			TSS (°Brix)			Titratable acidity (%)			Ascorbic acid (mg/100 g)			Total sugars (%)			Reducing sugar (%)			Non-reducing sugars (%)		
	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled
T_1	78.61^{a}	77.18^{a}	77.89^{a}	12.60^{g}	12.93^{h}	12.76^{h}	3.30^{a}	3.39^{a}	3.34^{a}	32.11^{g}	33.26^{g}	32.68^{h}	9.11^{g}	9.39^{i}	9.25^{h}	7.27^{g}	7.48^{g}	7.38^{h}	1.83^{b}	1.91^{c}	1.87^{c}
T_2	76.86^{b}	74.56^{b}	75.71^{b}	14.22^{f}	14.88^{g}	14.55^{g}	3.11^{ab}	3.17^{ab}	3.14^{ab}	33.85^{f}	36.46^{f}	35.16^{g}	9.67^{f}	10.25^{h}	9.96^{g}	7.60^{f}	8.17^{f}	7.88^{g}	2.07^{ba}	2.09^{bc}	2.08^{bc}
T_3	75.87^{bcd}	73.65^{bcd}	74.76^{bcd}	14.47^{ef}	14.97^{fg}	14.72^{fg}	3.01^{abc}	3.09^{abc}	3.05^{dabc}	34.03^{f}	36.85^{def}	35.44^{fg}	9.78^{ef}	10.49^{gh}	10.14^{fg}	7.69^{ef}	8.29^{ef}	7.99^{fg}	2.10^{ba}	2.20^{abc}	2.15^{abc}
T_4	74.90^{cde}	73.22^{bcde}	74.06^{cde}	14.95^{bcde}	15.31^{defg}	15.13^{def}	2.77^{bcdef}	2.84^{bcdef}	2.80^{bcdef}	34.72^{cd}	37.40^{bcde}	36.06^{de}	10.16^{cdef}	10.67^{fgh}	10.42^{efg}	7.87^{cd}	8.35^{def}	8.11^{def}	2.30^{ba}	2.32^{abc}	2.31^{abc}
T_5	76.40^{bc}	74.10^{bc}	75.25^{bc}	14.70^{de}	15.14^{efg}	14.92^{efg}	2.95^{bcd}	2.99^{bcd}	2.97^{bcd}	34.26^{ef}	36.81^{ef}	35.54^{fg}	9.90^{ef}	10.58^{fgh}	10.24^{fg}	7.75^{def}	8.33^{ef}	8.04^{ef}	2.16^{ba}	2.25^{abc}	2.20^{abc}
T_6	76.62^{b}	74.09^{bc}	75.36^{bc}	15.11^{abcd}	15.48^{cde}	15.30^{cde}	2.73^{cdef}	2.78^{cdef}	2.76^{cdef}	34.96^{bcd}	37.57^{bc}	36.27^{bcde}	10.35^{bcde}	10.84^{defg}	10.59^{def}	7.99^{c}	8.44^{cde}	8.21^{d}	2.36^{ba}	2.40^{abc}	2.38^{abc}
T_7	74.76^{cde}	71.30^{fg}	73.03^{ef}	15.13^{abcd}	15.62^{bcde}	15.38^{bcd}	2.68^{cdef}	2.77^{cdef}	2.73^{cdef}	34.87^{cd}	37.55^{bc}	36.21^{bcde}	10.59^{abcd}	11.07^{cdef}	10.83^{bcde}	8.17^{b}	8.61^{bcd}	8.39^{c}	2.42^{ba}	2.46^{abc}	2.44^{abc}
T_8	75.28^{bcde}	72.78^{cdef}	74.03^{cde}	14.78^{cde}	15.40^{cdef}	15.09^{def}	2.86^{bcde}	2.94^{bcde}	2.90^{bcde}	34.57^{de}	37.02^{cdef}	35.80^{ef}	10.05^{def}	10.73^{efgh}	10.39^{efg}	7.84^{cde}	8.45^{cde}	8.15^{de}	2.21^{ba}	2.28^{abc}	2.25^{abc}
T_9	75.34^{bcde}	73.04^{bcde}	74.19^{cde}	15.28^{abc}	15.75^{abcd}	15.51^{abcd}	2.64^{def}	2.72^{def}	2.68^{def}	35.07^{bc}	37.82^{ab}	36.45^{bcd}	10.69^{abc}	11.26^{bcd}	10.98^{bcd}	8.22^{b}	8.73^{b}	8.48^{bc}	2.47^{ba}	2.53^{ab}	2.50^{b}
T_{10}	76.06^{bc}	72.43^{def}	74.24^{cde}	15.42^{ab}	16.03^{ab}	15.73^{ab}	2.53^{ef}	2.60^{ef}	2.56^{ef}	35.35^{ab}	38.05^{ab}	36.70^{ab}	10.82^{ab}	11.74^{ab}	11.28^{ab}	8.31^{ab}	9.15^{a}	8.73^{a}	2.52^{ba}	2.59^{ab}	2.55^{b}
T_{11}	73.00^{f}	69.96^{g}	71.48^{g}	15.20^{abcd}	15.73^{abcd}	15.47^{abcd}	2.64^{def}	2.67^{def}	2.66^{def}	35.13^{abc}	37.95^{ab}	36.54^{abcd}	10.74^{abc}	11.21^{cde}	10.98^{bcd}	8.25^{b}	8.67^{b}	8.46^{bc}	2.49^{ba}	2.54^{ab}	2.52^{b}
T_{12}	73.77^{ef}	71.17^{fg}	72.47^{fg}	14.94^{bcde}	15.50^{cde}	15.22^{cde}	2.76^{bcdef}	2.83^{cdef}	2.80^{bcdef}	34.76^{cd}	37.48^{bcd}	36.12^{cde}	10.29^{bcde}	10.95^{cdefg}	10.62^{cdef}	7.95^{c}	8.55^{bcde}	8.25^{d}	2.33^{ba}	2.40^{abc}	2.37^{abc}
T_{13}	74.36^{def}	72.06^{def}	73.21^{ef}	15.31^{ab}	15.85^{abc}	15.58^{abc}	2.56^{ef}	2.61^{ef}	2.59^{ef}	35.19^{abc}	38.03^{ab}	36.61^{abc}	10.82^{ab}	11.40^{a}	11.11^{abc}	8.29^{ab}	8.79^{b}	8.54^{b}	2.52^{ba}	2.61^{ab}	2.57^{b}
T_{14}	74.85^{cde}	71.88^{ef}	73.37^{def}	15.55^{a}	16.15^{a}	15.85^{a}	2.42^{f}	2.51^{f}	2.46^{f}	35.56^{a}	38.39^{a}	36.98^{a}	11.13^{a}	11.93	11.53^{a}	8.44^{a}	9.16^{a}	8.80^{a}	2.69^{a}	2.77^{a}	2.73^{a}
SEM(±)	0.48	0.51	0.45	0.15	0.15	0.13	0.10	0.09	0.10	0.15	0.20	0.17	0.17	0.15	0.15	0.04	0.08	0.05	0.18	0.16	0.16
CD (P=0.05)	1.41	1.50	1.32	0.45	0.44	0.37	0.31	0.28	0.30	0.44	0.60	0.48	0.51	0.452	0.44	0.13	0.24	0.13	0.53	0.46	0.48

TSS, Total soluble solids. Treatment details are given under Materials and Methods.

Table 1 that among all the treatments the highest sugar: acid ratio (4.61, 4.77 and 4.69) in manual fruit thinning + GA_3 + ethephon + CPPU i.e. T_{14} while the lowest (2.77, 2.78 and 2.77) was in control (T_1) (Supplementary Table 1). This may be pertained to the fact that manual fruit thinning with plant growth regulators resulted in an increase in total sugar content and decrease in acidity level of fruits, leading to higher level of sugar: acid ratio.

With regards to fruit chemical attributes, highest ascorbic acid (35.56, 38.39 and 36.98 mg/100 g), carotenoid (3.28, 3.37 and 3.32 mg/100 g), and total phenols (22.99, 23.34 and 23.16 mg GAE/100 g) were observed in T_{14} (manual fruit thinning + GA_3 + ethephon + CPPU) while the lowest was recorded in T_1 (32.11, 33.26 and 32.68 mg/100 g ; 1.93, 1.97 and 1.95 mg/100 g and 18.80, 19.38 and 19.09 mg GAE/100 g) whereas, the highest anthocyanin (30.14, 31.87 and 31.01 mg/100 g) was recorded in T_3 (manual fruit thinning) which was significantly higher than all other treatments while the lowest (18.87, 18.97 and 18.92 mg/100 g) was and recorded in T_1 (control) (Table 3 and Supplementary Table 1). The higher chemical attributes in manual fruit thinning + GA_3 + ethephon + CPPU could be due to increased metabolite production in thinned vines that targets growing fruits and involves specific enzymes and metabolic ions. Ethylene raises the fruit's ethylene level, hastening the carotenoids that accumulate during fruit ripening and maturation. When combined, CPPU and gibberellin increase the synthesis of polyphenols, which raises their antioxidant activity. Increase in anthocyanin content of berries following cluster removal were also reported by Elmenofy *et al.* (2021) in Washington navel orange and Naveena Kumara *et al.* (2023) in mango.

From the results of the present investigation, it can be concluded that in commercial passion fruit cultivation, fruit thinning along with spraying of plant growth regulators, viz. GA_3, CPPU and ethephon could be implemented as crop regulating technique to improve yield and fruit quality. Among the different crop regulating techniques, treatment involving manual fruit thinning + GA_3 + ethephon + CPPU is considered as best crop regulating practice for sustainable fruit production of purple passion fruit in Mizoram, India condition.

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