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**Research Paper**

# Effect of Plant Density, Spacing and Trellising System on Productivity of Yellow Passion Fruit (*Passiflora edulis f. flavicarpa* O. Deg)

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## Abstract

**Horana Gold, the widely cultivated yellow passion fruit (*Passiflora edulis f. flavicarpa* O. Deg.) variety in Sri Lanka, has a high yield potential (50 t ha$^{-1}$), but its low average productivity (30 t ha$^{-1}$) creates supply and price issues. Plant density is considered as one of the major factors influencing the yield gap and high density planting is recognized as a successful strategy to increase crop productivity. Yield and fruit quality of Horana Gold passion fruit in presently recommended trellising system (vertical), spacing (2 m × 4.5 m) and plant density (1,111 plants/ ha) were compared with a vertical system with 2,222 plant density and 2 m × 2.25 m spacing, T- trellis system with two plant densities (1,777 and 888 plants /ha) in 2.5 m × 2.25 m and 2.5 m × 4.5 m spacing respectively at Fruit Research and Development Institute Horana and Mahaweli farm at Kattakaduwa. The highest productivity of 44.1 t ha$^{-1}$ was obtained with the high density (1,777) in T- trellis which was 51.5% and 52.6% higher than the productivity of 888 plants/ha in T- trellis system and 1,111 plants in vertical trellis system, respectively. High density planting in vertical trellis system did not increase the productivity and gave comparable productivity with lower density in both trellis systems. Significant differences were not observed in fruit weight, Juice content, soluble solids, titratable acidity and the soluble solids/ titratable acidity ratio in the fruits cultivated at the different spacing in both years at two locations. As the yield increases by more than 50% without affecting fruit quality, the spacing 2.5 m × 2.25 m of 1777 plant density in T- trellis system can be practiced in productivity improvement of yellow passion fruit.**

**Keywords: Passion fruit, Plant density, Productivity, Quality, Trellising system**

## Introduction

Passion fruit (*Passiflora edulis* Sims), a native of tropical America is a high value and export oriented crop. .The main economic importance of the fruit is related to concentrated juice processing, but other products can be prepared using the pulp in confectionery and candy making such as nectar, syrup, ice cream, and jelly (Modesta, 1990, Meletti and Molina, 1999). Passion fruit is grown in most tropical and sub-tropical parts of the world, and it is commercially grown in Australia, Hawaii, South Africa and Brazil. Passion fruit became a naturalized crop in most of the tropical and subtropical world covering South Africa, Hawaii, California, Florida and Sri Lanka.

There are two recognized forms of edible passion fruit: purple (*Passiflora edulis f. edulis* Sims) and yellow (*Passiflora edulis f. flavicarpa* O. Deg.). The yellow form is suitable for lower elevations and is less productive at higher elevations due to its sensitivity to low temperature. The purple form is productive at higher elevations (Rocky and Gautham, 2017). In general, the purple passion fruit is consumed fresh, whereas the yellow passion fruit is used in juice production due to a greater acidity, higher juice yield, and brilliant yellow color (Yuan and Baduge, 2018).

The yellow form is widely cultivated in Sri Lanka in an area of 580 ha with a production of 969 mt (Department of Census and Statistics, 2022). The production mainly contributes for juice extraction in local factories and to export. The amount of 107.2 mt of processed pulp valued Rs. 124.32 Mn was exported in 2023 (Sri Lanka Customs, 2023). The passion fruit is mainly cultivated in small orchards in the country on average 1/2 $ha^{-1}$, and is an important source of income for small-scale farmers. Yellow passion fruit has the potential for a rapid economic return with production and distribution throughout the year and has a high value of the fruit (Moreira *et al*., 2017).

"Horana Gold" is the mostly cultivated recommended yellow passion fruit variety in Sri Lanka having an average productivity of 30 t $ha^{-1}$. However, it is much lower than its potential yield of 50 t $ha^{-1}$. There are several management alternatives aiming to optimize the passion fruit production. High density planting has been performed in several Brazilian regions, encouraging the expansion of the volume of productive branches per area, which may consequently result an increase in production (Figueiredo *et al*.,2015, Weber *et al.*, 2016). The planting density might be influenced by several factors, such as the topography, the plant trellis system, the training and vigour of the plants and, especially, the edaphoclimatic conditions of the cultivation region (Yahya *et al*., 2013). Presently farmers in Sri Lanka practice 2m × 4.5m spacing and 1111 plants/ha in the vertical trellis system with a single wire in passion fruit cultivation according to the recommendations given by the Department of Agriculture (DOA.)

Higher plant densities can promote higher productivity during the first harvests and enable increased profitability, even when producers have to reform the orchards

every two years due to the occurrence of pests and diseases that cause depletion, lower production and the death of the plants (Hafle *et al*., 2012, Melo junior *et al*., 2012, Cavichioli *et al*., 2014). Increasing the planting density to 1,667 plants/ha enhanced productivity but the densification did not affect the quality of the fruits (Moreira, *et al*., 2017). The average productivity in India (5.02 t $ha^{-1}$), is comparatively lower to that of the other countries like Brazil, Australia, Colombia etc. (30-35 t $ha^{-1}$) adopting a high planting density at 2.0 × 1.25 m, inter and intra row spacing.

In this context, the present study was conducted to compare the higher plant density of vertical trellis system and lower and higher plant densities of T trellis system with the DOA recommended plant density and trellis system to increase productivity and quality of Horana gold passion fruit.

## Materials and Methods

The experiments were conducted at Fruit Research and Development Institute, Horana located in WLI agro-ecological region and the Mahaweli farm, Kattakaduwa located in DL1b in Sri Lanka during the period from 2021-2022.

### Treatments and experimental design

Four treatments were arranged to compare the productivity of the recommended row spacing and plant density in vertical trellis system ($T_4$) with doubled plant density in the vertical trellis system ($T_3$) and lower ($T_2$) and higher ($T_1$) plant densities in new T trellis system (Table 1).

Four treatments were evaluated in a Randomized Complete Block Design with two replications at both locations during two consecutive years. The experimental unit was a 135 $m^2$ plot consisting of 24, 12, 30 and 15 plants in $T_1$, $T_2$, $T_3$ and $T_4$ respectively.

### Trellis preparation

The T-trellis was made of galvanized pipes of 1.5 cm diameter. It consisted with 2 m tall posts with a 60 cm cross-piece at the top and 3 wires strung horizontally 15 cm apart along the top of each cross-piece. To withstand the weight of the vine and tension on the wire, the wires were strung through the holes drilled through the cross-arm. The vertical trellis consisted of concrete posts with one wire strung horizontally. The trellis wires were 16 gauged galvanized steel. Trellis height was 2 m from the ground. Trellis rows were oriented north-south direction for maximum exposure to sunlight.

**Table 1. Treatments and experimental design**

| Treatment | Trellising system | Spacing (m) (between rows x within row) | Plant Density |
|---|---|---|---|
| $T_1$ | T trellising system | 2.5 × 2.25 | 1,776 |
| $T_2$ | T trellising system | 2.5 × 4.5 | 888 |
| $T_3$ | Vertical trellising system | 2 × 2.25 | 2,222 |
| $T_4$ (control) | Vertical trellising system | 2 × 4.5 | 1,111 |

**Cultural practices**

Two- months old seedlings were planted at a spacing of 2.5 m × 2.25 m ($T_1$) and 2.5 m × 4.5 m ($T_2$) under T- trellis system while in the vertical trellis system the spacing were 2 m × 2.25 m ($T_3$) and 2 m × 4.5 m. One or two vigorous leaders were selected and trained along a stick to the top wire and removed the apical to allow side branches growing both directions along the wires of the trellises. A light pruning of extended laterals was carried out at the end of each harvest.

The fertilizer recommendation of the Department of Agriculture was followed in the experiment. Basal fertilizer was applied per planting hole at 45 g urea, 80 g TSP and 40 g MOP 3-5 days before transplanting. Three applications were done at same rate at 2, 6 and 10 months after transplanting the seedlings. Then, 80 g urea, 140 g TSP and 70 g MOP per plant were applied at 14, 18 and 22 months after transplanting.

Hand weeding was done around the plant and adjacent area was maintained by a grass cutter. Vines were irrigated with a drip system fitted with 2 emitters/ vine. Mature fruits were harvested at weekly intervals and data on yield/ vine were recorded. The green peel turns yellow as the fruits begin to ripen. These fruits were harvested at weekly intervals to record yield data. Quality parameters were measured when fruit peel had turned completely yellow.

Vines flowered throughout the year, but major blooms occurred in March-April and July-August in both locations. In yellow passion fruit, anthesis takes place around 12 noon. Artificial pollination was done after 1-2 hours of anthesis when stigma becomes receptive.

**Data collection**

The production (kg / plant) was determined by dividing weigh measurements of fruits/ experimental plot by number of plants in the plot. Productivity was determined for each planting density (t $ha^{-1}$) from weigh measurements of fruits/experimental plot.

Brix was measured by a hand held refractometer after extraction and homogenizing of the juice of randomly selected 30 fruits per plot. Titratable acidity (TA) was determined by titration with NaOH solution using phenolphthalein as an indicator. The acid percentage was calculated on the basis of weight as a citric acid equivalent. Then, the sugar/acid ratio (Brix/TA) was calculated.

**Statistical analysis**

One way ANOVA was performed to test treatment effects on yield and quality parameters. Blocking factors (location and year) were included in the model to control the environmental variability. Significant differences between treatments were determined by F- test at the 5% significance level.

## Results and Discussion

The location × treatment interaction was not statistically significant in both years indicating that the environmental conditions at FRDI, Horana and Mahaweli farm Kattakaduwa did not significantly influence yield and quality parameters

(Table 2). This suggested that the observed differences were primarily due to trellising systems and plant densities rather than location specific factors.

Significant differences were observed among the different treatments on the production of number of fruits per plant, yield (kg/plant) and productivity (t $ha^{-1}$) in two years (Table 3). However, average fruit weight, juice content and quality of the fruit was not significantly affected by the treatments (Table 4).

All treatments recorded a lower number of fruits/plant during its first year of bearing compared to the second year (Table 3). The observed results are promising in Minas Gerais, Brazil, the projection for the first harvest (off-season) and second harvest are 5.0 t $ha^{-1}$ and 25.0 t $ha^{-1}$ respectively, when the nutritional management used in the experiment was similar at the conventional spacing of 2m × 3 m with 1,666 plant density. The difference in production per plant between the first and second harvest occurred due to the conformation of the plants. In the first harvest, the plants at 3 m × 5 m and 3 m × 6 m spacing were not fully developed, *i.e.*, the secondary and tertiary branches (productive branches) were still developing. With the growth of new branches, assimilates were directed towards vegetative growth instead of production (Moreira *et al*., 2017).

Fruit yield (kg/ plant/year) was the highest under wider spacing and low density in both T- trellis and vertical trellis system. The fruit yield/ plant was 44.6% and 31.8% higher with the spacing of 2.5 m × 4.5 m compared to plants spaced at 2.5 m × 2.25 m in T- trellis in the first and second year respectively. In the vertical trellis system, the fruit yield per vine was doubled with the wider spacing of 2 m × 4.5 m compared to plants spaced at 2 m × 2.25 m in both years (Table 3).

**Table 2. Location x treatment interaction effect on yield parameters in both locations**

| Year | Location | Yield (t/ha) | Plot yield (kg/135 $m^2$) | Yield (kg/vine) | Number of fruits/vine | Fruit weight (g) |
|---|---|---|---|---|---|---|
| 1 | 1 | 24.3 [a] | 328.4 [a] | 18.2 [a] | 133.8 [a] | 135.6 [a] |
| 1 | 2 | 25.2 [a] | 340.5 [a] | 18.7 [a] | 137.7 [a] | 135.1 [a] |
| CV (%) | | 4.2 | 4.1 | 6.5 | 4.1 | 1.8 |
| 2 | 1 | 32.2 [a] | 435.2 [a] | 23.9 [a] | 177.1 [a] | 134.5 [a] |
| 2 | 2 | 32.6 [a] | 440.5 [a] | 24.1 [a] | 179.5 [a] | 134.0 [a] |
| CV (%) | | 5.9 | 6.0 | 6.3 | 5.9 | 1.9 |

*Means with the same letter are not significantly different*
*Year -1- 2021, Year 2- 2022, Loaction 1- FRDI,Horana, Location 2- Mahaweli farm ,Kattakaduwa*

**Table 3. Yield parameters of yellow passion fruit cultivated at different planting spacing, density and trellising systems during 2021 and 2022**

| Year | Treatment | Yield (t/ha/year) | Plot yield (kg/135 $m^2$/ year) | Yield (kg/ plant/ year) | Number of fruits/vine/ year | Fruit weight (g) |
|---|---|---|---|---|---|---|
| 1 | $T_1$ | 31.9 [a] | 430.8 [a] | 17.95 [c] | 133 [c] | 135.4 [a] |
| 1 | $T_2$ | 23.0 [b] | 310.8 [b] | 25.9 [a] | 192 [a] | 134.8 [a] |
| 1 | $T_3$ | 22.0 [b] | 296.1 [b] | 9.85 [d] | 74 [d] | 133.5 [a] |
| 1 | $T_4$ | 22.2 [b] | 300 [b] | 20 [b] | 150 [b] | 133.5 [a] |
| CV (%) | | 4.8 | 4.7 | 6.0 | 4.5 | 1.8 |
| 2 | $T_1$ | 44.1 [a] | 595.2 [a] | 24.8 [b] | 182 [b] | 135.2 [a] |
| 2 | $T_2$ | 29.1 [b] | 392.4 [b] | 32.7 [a] | 242 [a] | 135.1 [a] |
| 2 | $T_3$ | 27.6 [b] | 373.0 [b] | 12.4 [c] | 93 [c] | 133.8 [a] |
| 2 | $T_4$ | 28.9 [b] | 390.75 [b] | 26.05 [b] | 196 [b] | 133.0 [a] |
| CV (%) | | 5.2 | 5.2 | 5.5 | 5.0 | 1.8 |

*Means with the same letter are not significantly different at 0.05%*
*Year -1- 2021, Year 2- 2022*
*$T_1$- 1,776 plants/ha in 2.5 m × 2.25 m spacing in T- trellising system*
*$T_2$ -888 plants/ha in 2.5 m × 4.5 m spacing in T- trellising system*
*$T_3$ – 2,222 plants/ha in 2 m × 2.25 m spacing in vertical trellising system*
*$T_4$ – 1,111 plants/ ha in 2 m × 4.5 m spacing in vertical trellising system*

The increase of production in plants cultivated at greater spacing is agreed with the study of production viability of passion fruit at high planting density in Jequitinhonha valley, Brazil by Moreira *et al*. (2017). They stated that the production/ plant in the first harvest was 47.2% higher at the spacing of 3 m × 4.5 m compared to plants spaced at 3 m × 2m. In the second harvest, the response showed a linear increase with a higher production/ per plant at a spacing of 3 m × 6 m. The lower production per plant with narrow spacing of 3 m × 2 m and 3 m × 3 m was due to the smaller area occupied by these plants; these plants had a smaller number of branches, which resulted in a reduction in the number of flowering buds and a lower number of fruits/ plant (Hafle *et al*., 2012).

However, in terms of productivity (t $ha^{-1}$), it was the highest (44.1 t $ha^{-1}$) and significantly increased with higher plant density (1776 plants/ha) in T- trellis system which was 51.5% and 52.6% higher than the productivity of 888 plants/ha in T- trellis system and 1,111 plants/ha in vertical trellis system respectively. High density planting in vertical trellis system did not increase the productivity and gave a comparable productivity with the lower density in both trellis systems (Table 3). The vertical single wire did not provide enough space to grow more branches. The T- trellis system with 3 wires provided more area to produce higher number of branches and production of fruits per unit area. According to Komuro, (2008), the increase in the number of strings promoted

the increase of the growth of productive branches, number of fruits picked and mass per hectare in yellow passion fruit.

According to Cavichioli *et al*. (2014) the wider spacing within plants increases the number of fruits per plant and the narrow spacing results in a reduction of the number of flowers per plant due to high shading and reduction in the development of its branching. It has been verified that the difference in the number of fruits per plant did not reflect the difference in the yield because the reduction in the individual development was compensated by the higher plant density.

Joao *et al*. (2019) also investigated the effect of plant spacing on the yield of the yellow passion fruit accession 'Guinezinho' under saline water conditions over two consecutive growing seasons. The study compared a closer spacing of 2 m × 3 m with a broader spacing of 3 m × 3 m. In the first season, the closer spacing produced a yield of 23.7 t $ha^{-1}$, compared to 17.4 t $ha^{-1}$ in the broader spacing representing a 36.2% increase. In the second season, yields were 36.3 t $ha^{-1}$ and 26.2 t $ha^{-1}$ for the closer and broader spacings, respectively an increase of 38.5%. These results demonstrate that reduced plant spacing significantly enhances productivity, even under saline irrigation conditions.

Significant differences did not occur in fruit weight, soluble solids, titratable acidity and the soluble solids / titratable acidity ratio in the fruits cultivated at different spacing in both years at two locations. (Table 4 & Table 5). These results are important from the point of view of marketing, which enables the producer to adapt the best spacing without loss in the quality of the fruits.

**Table 4. Location x year interaction effect on quality parameters in both locations**

| Year | Location | Average Fruit weight (g) | Average Pulp volume (ml/fruit) | Titratable acidity (%) | Brix (% ) | Sugar/ acid ratio | weight/ pulp |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 135.6 [a] | 64.0 [a] | 3.7 [a] | 18.0 [a] | 4.9 [a] | 0.47 [a] |
| 1 | 2 | 135.1 [a] | 64.1 [a] | 3.8 [a] | 18.0 [a] | 4.8 [a] | 0.47 [a] |
| CV (%) | | 1.7 | 3.7 | 3.0 | 1.0 | 4.1 | 2.3 |
| 2 | 1 | 134.5 [a] | 62.0 [a] | 3.8 [a] | 18.0 [a] | 4.8 [a] | 0.46[a] |
| 2 | 2 | 134.0 [a] | 62.6 [a] | 3.7 [a] | 17.8 [a] | 4.8 [a] | 0.47[a] |
| CV (%) | | 2.0 | 3.1 | 3.6 | 1.4 | 4.1 | 1.9 |

*Means with the same letter are not significantly different*
*Year -1- 2021, Year 2- 2022, Location 1- FRDI,Horana, Location 2- Mahaweli farm ,Kattakaduwa*

**Table 5. Fruit quality parameters of yellow passion fruit cultivated at different planting spacing, density and trellising systems during 2021 and 2022**

| Year | Treatment | Average Fruit weight (g) | Average Pulp volume (ml/fruit) | Titratable acidity (%) | Brix (%) | Sugar/ acid ratio | weight/ pulp |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 135.4 [a] | 64.0 [a] | 3.7 [a] | 18.0 [a] | 4.9 [a] | 0.47 [a] |
| 1 | 2 | 134.8 [a] | 65.8 [a] | 3.8 [a] | 18.0 [a] | 4.8 [a] | 0.47 [a] |
| 1 | 3 | 133.5 [a] | 63.0 [a] | 3.7 [a] | 18.0 [a] | 4.8 [a] | 0.47 [a] |
| 1 | 4 | 133.5 [a] | 63.5 [a] | 3.8 [a] | 18.0 [a] | 4.8 [a] | 0.48 [a] |
| CV% | | 1.8 | 4.0 | 3.2 | 1.0 | 4.3 | 2.5 |
| 2 | 1 | 135.2 [a] | 62.5 [a] | 3.8 [a] | 17.9 [a] | 4.7 [a] | 0.46 [a] |
| 2 | 2 | 135.1 [a] | 63.0 [a] | 3.8 [a] | 18.0 [a] | 4.8 [a] | 0.47 [a] |
| 2 | 3 | 133.8 [a] | 62.8 [a] | 3.7 [a] | 18.0 [a] | 4.9 [a] | 0.47 [a] |
| 2 | 4 | 133.0 [a] | 61.0 [a] | 3.8 [a] | 17.8 [a] | 4.7 [a] | 0.46 [a] |
| CV% | | 1.8 | 2.9 | 3.5 | 1.2 | 3.9 | 1.8 |

*Means with the same letter are not significantly different*
*Year -1- 2021, Year 2- 2022*
*Treatment 1- 1,776 plants/ha in 2.5 m x 2.25 m spacing in T- trellis system*
*Treatment 2 -888 plants/ha in 2.5 m x 4.5 m spacing in T- trellis system*
*Treatment 3 – 2222 plants/ha in 2 m x 2.25 m spacing in vertical trellis system*
*Treatment 4 – 1,111 plants/ha in 2 m x 4.5 spacing in vertical trellis system*

Obtaining fruits with good classification guarantees the producer greater economic returns at the time of sale because at the fresh fruit market, size is one of the main parameters evaluated by consumers. The observed values are satisfactory with the technological quality of the juice required by consumers of fresh fruits or in industrial processing. Those values must be assured by the titratable acidity from 3.2 to 4.5%, soluble solids content from 15 to 16 Brix, juice yield around 40%, vitamin C content from 13 to 20 mg/100 ml, and average fruit weight above 120 g (Ruggiero *et al*., 1996 and Sao *et al*., 1999).

There were no significant differences in the average fruit weight, and it ranged from 133 g to 135.4 g in all treatments. The fruits can be classified as "extra A" (108-144 g), which is one median standard of classification according to the standardization carried out by the Quality Center for Horticulture in CEAGESP (Moreira *et al*., 2017). The fruit size is one important feature, especially when the destination is the fresh fruit market, which prefers the fruits of larger size. The average pulp volume ranged from 61-65.8 ml/fruit and it is satisfactory for fresh fruits or industrial processing (Table 5).

The average of soluble solids (Brix %) ranged between 17.8 and 18 % in the first and second years. (Table 5). These results are slightly higher than those reported in the literature, which varied from 11.65 to 17.29% (Araújo *et al*., 2005, Hafle *et al*., 2012, Cobra *et al*., 2015, Moreira *et al*., 2017). Fruits with high soluble solids are

the most desirable for industrialization because approximately 11 kg of fruits are needed with soluble solids between 11% and 12% to obtain 1 kg of concentrated juice with 50% Brix. Thus, the higher the total soluble solids, the lower the amount of pulp needed to obtain the product (Moreira *et al*., 2017).

As per the recommendation of 'Ministério da Agricultura e do Abastecimento', Brazil, there is a minimum value of 2.5% for the titratable acidity in passion fruit juice to be used in the industry, which enables the producer to market to both the fresh market and to the industry during the entire production period (Moreira *et al*., 2017). The values observed in both years were above of this minimum value. No variations in soluble solids and acidity favored the soluble solids /acidity ratio, which did not differ in the fruits from the different treatments in both years and locations. (Table 5).

According to the obtained results, the increase in planting density in T-trellis system promoted an increase in the productivity of yellow passion fruit from the first harvest without reducing the quality of fruits. However, the study conducted in functional analysis of trellising systems and their impact on quality and productivity in passion fruit (*Passiflora edulis f. flavicarpa* O. Deg.) cultivars in Colombia concluded that according to the Eco physiological requirements of passion fruit cultivation under tropical Colombian conditions, the trellising system, which presents the greatest advantages for cultural and phytosanitary management is the simple trellis, obtaining higher production volumes of optimum quality. Also, the trellis systems are the most important item, representing up to 70% of total production costs. (Cleves, 2021).

Therefore, a systematic study of disease intensity in different agro-climatic regions and an economic analysis of different treatments are needed for further interpretation of the result of the study.

## Conclusions

High plant density in T-trellis system enhanced the productivity of yellow passion fruit from the first year without reducing the quality of fruits. The highest productivity (44.1 t $ha^{-1}$) was obtained with the high density (1,776 plants/ha) in T- trellis at the second year of the crop and it was 54.3% and 51.7% higher than the productivity of 888 plants in T- trellis system and 1,111 plants in vertical trellis system, respectively. High density planting in vertical trellis system did not increase the productivity and gave a comparable productivity with lower density in both trellis systems. The plant densification in both trellising systems did not affect the fruit weight, juice content and quality of the fruits.

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