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Yellow passion fruit in overhead trellis system do not differ in diseases intensity and is more productive compared to vertical trellis system

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Abstract - Brazil is the largest producer of passion fruit worldwide, however diseases have been reducing passion fruit productivity, and limiting its cultivation for several years in a row in the same area. The proposal of this study was to evaluate diseases intensity and productivity of yellow passion fruit in vertical and overhead trellis systems, during two seasons, in annual cycle. The experiment was realized in a commercial orchard of yellow passion fruit in the municipality of Araquari, SC, in the 2013/14 and 2014/15 seasons. The treatments were vertical and overhead trellis systems, tested in a randomized complete block design, with eight replications. The agronomic practices were performed according to the culture recommendations and naturally pollinated althoght no disease control was applied. Anthracnose, bacterial blight, cladosporiosis and passion fruit woodiness severities were assessed in two seasons, from December to June, after establishment of the trellis systems. Production of fruits per plant and estimated productivity were determined in both seasons. There were no differences in diseases severity in both systems and seasons. The overhead trellis system was more productive than the vertical trellis system, 78.1% and 57.1% respectively, in the 2013/14 and 2014/15 seasons. Overhead trellis system showed to be the most adequate for yellow passion fruit production.

Index Terms: *Passiflora edulis flavicarpa* – plant architecture – disease severity – foliar diseases – productivity.

Maracujazeiro-amarelo no sistema de condução em caramanchão não difere na intensidade de doenças e é mais produtivo em relação ao sistema em espaldeira

Resumo - O Brasil é o principal produtor mundial de maracujá, mas as ocorrências de doenças têm reduzido sua produtividade e limitado seu cultivo por vários anos em sequência na mesma área. O objetivo deste trabalho foi avaliar a severidade de doenças e a produtividade nos sistemas de condução em espaldeira e em caramanchão durante duas safras, em cultivo anual. Nas safras de 2013/2014 e 2014/2015 o trabalho foi realizado em pomar comercial de maracujazeiro-amarelo em Araquari-SC, testando-se como tratamentos os sistemas de condução em espadeira e em caramanchão em DBC, com oito repetições. Foram realizados os tratos culturais recomendados para a cultura, polinização natural e avaliadas nas duas safras a intensidade da antracnose, da mancha-bacteriana, da cladosporiose e da virose do endurecimento no fruto, de dezembro a junho, a partir do estabelecimento dos sistemas de condução. A produção de frutos por planta e a produtividade estimada foram determinadas. Não houve diferenças nas severidades das doenças avaliadas nos dois sistemas e safras. O sistema em caramanchão mostrou-se mais produtivo (78,1% e 57,1%) do que o sistema em espaldeira, nas safras de 2013/2014 e 2014/2015, respectivamente, demonstrando ser o melhor sistema de condução para o maracujazeiro-amarelo.

Termos para Indexação: *Passiflora edulis flavicarpa* – arquitetura de planta – doenças foliares – severidade de doenças – produtividade.

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Introduction

The world production of yellow passion fruit (*Passiflora edulis* Sims f. *flavicarpa* Degener) is concentrated in South America, and Brazil is the world's largest producer. In the 2013/14 season, 41.5 thousand ha were cultivated with passion fruit, producing around 510 thousand t, and yielding 12.3 t/ha (IBGE, 2016). Brazil has a high potential for passion fruit production, however continuous reduction in crop production and in production area has been observed since 2010. This limitation has been attributed to improper management, low usage of improved cultivars and phytosanitary issues (MELETTI, 2011).

Leaf diseases of passion fruit are among the main phytosanitary issues. The most common foliar diseases are anthracnose, caused by the fungus *Colletotrichum gloeosporioides* Penz., cladosporiosis, caused by the fungus *Cladosporium herbarum* Link., bacterial blight, caused by the bacterium *Xanthomonas axonopodis* pv. *passiflorae* (Pereira) Gonçalves and Rosato, and passion fruit woodiness, the most important disease of the crop, primarily caused by cowpea aphid-borne mosaic virus (CABMV) (CERQUEIRA-SILVA et al., 2014) .

The anthracnose symptoms on leaves are irregular-shaped spots, light to dark brown, and undefined edges. Acervuli can be present on the upper and lower leaf surfaces. On fruits, anthracnose causes irregular or circular surface spots, cream to light brown, with water-soaked and undefined edges. Lesions evolve to light to dark brown, depressed and with soggy edges (MEDEIROS; PERUCH, 2012). Cladosporiosis symptoms are present on leaves, branches and fruits, forming circular-shaped depressions. Epithelial tissue ruptures and forms callus tissue. The pathogen may come with seedlings from the nurseries (SANTOS et al., 2008). Bacterial blight causes chlorosis, necrosis, canker and plant death .On leaves, the symptoms are translucid and anasarcous small spots, which become necrotic and reddish-brown, with chlorotic halo around spots (MUNHOZ et al., 2015). Passion fruit woodiness causes reduction in fruit size, fruit deformation and fruit hardening. The symptoms range from leaf mosaic and reduced leaf area to intense deformation, compromising plant lifespan, productivity and fruit appearance, which become unattractive for commercialization (CERQUEIRA-SILVA et al., 2014).

Several disease control tactics, such as use of fungicides and antibiotics, adequate spacing, use of resistant cultivars and windbreaks, have been recommended for the control of passion fruit diseases as general (OLIVEIRA et al., 2013). Besides that, few information are available at the literature proving those strategies could reduce disease and help maintain productivity in the crop production system. Some authors recommended cultivation of passion fruit in an annual production cycle (CERQUEIRA-SILVA et al., 2014; WEBER et al., 2016) . The most common trellis systems are vertical, which trains plants to grow in a vertical architecture, and overhead, in which plants are trained to grow horizontally. In Brazil, the most used trellis system is the vertical, due to its lower implantation cost and greater compatibility with crop mechanization (KOMURO, 2008). However, overhead trellis system has been adopted in some areas of Brazil, especially when reusing the remaining structures of vineyards (*Vitis* spp.) and chayote (*Sechium edule* (Jacq.) Swartz) crops (LIMA et al.; 2011) , or when growers have greater preference towards the system, as observed in the Southern Santa Catarina.

The sunlight exposure and duration of wetting period differ depending on the trellis system used (ORLANDO et al., 2003). The trellis system can cause differences in disease intensities, fruit yield and fruit characteristics. For grapevines (*Vitis labrusca* L.), leaves that are more exposed to the sun promote the differentiation of buds and favor the accumulation of fruit reserves. However, denser vegetative canopies provide lower productivity and fruit quality (ORLANDO et al., 2003) . The vertical trellis system can result in higher productivity, but lower precocity than the overhead trellis system (NORBERTO et al., 2008). As for diseases intensity, changes in the plant canopy architecture can reduce the dispersion of pathogens, and create an unfavorable microclimate for disease development (ANDO et al., 2007; SOUZA; RIBEIRO, 2016). By tradition, the vertical trellis system is used in Southern Minas Gerais to grow grapevines. In general, this system is considered to increase productivity and fruit quality, and reduce installation costs (NORBERTO et al., 2008).

Although different trellis systems have been compared for some crops, no information is available for yellow passion fruit. To date, no research has been published regarding the best trellis system to reduce diseases, and maintain or increase productivity. This study aimed to evaluate diseases intensity and productivity of yellow passion fruit vines in vertical and overhead trellis systems, during two seasons, in annual cycle.

Material and methods

Field experiments and treatments

The experiments were realized in a yellow passion fruit orchard in the municipality of Araquari, SC, with latitude 21º 42' 49" S, longitude 41º 20' 33" W and 8 m above sea level. (A2) The climate of the region is classified as Cfa by *Köppen*, a humid temperate climate characterized by hot summers. The soil is classified as Ortic Humic Quartzarenic Neosol, with good drainage, and low natural fertility. Soil analysis was done in June 2013, and resulted in the following chemical properties: (0.0 $cmol_c$ dm^{-3}); Ca (2.0 $cmol_c$ dm^{-3}); Mg (1.2 $cmol_c$ dm^{-3}); P (8.3 mg dm^{-3});

K (12.0 mg dm^{-3}); CEC $_{pH\ 7,0}$ (10.13 cmol$_c$ dm^{-3}); water pH (5.0); SMP index (5.5); H+Al (6.9 cmol$_c$ dm^{-3}); Al saturation (0.0 %); base saturation (31.89 %); sum of the bases (3.23 %), clay (7.0 %), and organic matter (1.8 %).

The experiments were realized in a randomized complete block design, with two treatments, vertical and overhead trellis systems, and eight replications. The two trellis systems evaluated were two-wire vertical and overhead. The vertical trellis system was set up as two wire strands, placed 1.4 and 2.1 m above ground level. The overhead trellis system consisted of wires interlacing every 0.7 m at a height of 2.1 m. Smooth number 12 wire was used in both systems for foliage wire. Each experimental plot consisted of five plants plus two in the borders for a total of seven plants. The total experimental area was approximately 600 m^2. Row spacing was 2.3 m, and space between plants was 2.0 m, with the posts spaced 6 m apart. The experiment was done in two subsequent cycles, the first was from August 2013 to June 2014 (2013/2104 season), and the second was from August 2014 to June 2015 (2014/2015 season).

General crop management and weather monitoring

In both trellis systems, yellow passion fruit was trained to a single cane, which was tied with soft string to the two wires. To stimulate the growth of lateral shoots, the apical bud was removed when plants passed approximately 0.10 m from the top wire. Lateral shoots were trained to grow in opposite direction to form a curtain in the vertical trellis system, and to develop a horizontal canopy on the framework in the overhead system.

Passion fruit plants were naturally polinated by carpenter bee (*Xylocopa* sp.), abundantly present in the experimental area and surroundings. During the drought periods, plants were watered using watering cans.

Minimum, maximum, and mean temperatures (^{o}C), precipitation (mm), relative humidity (%), and rainfall day data were obtained from the Automatic Meteorological Station (DAVIS®, model Vantage Plus) of the Instituto Federal Catarinense - Campus Araquari.

Disease assessment, yield and data analysis

Anthracnose, cladosporiosis, bacterial blight, and passion fruit woodiness severity were assessed every 30 days. The first evaluation was in December and the last one in June, during the 2013/14 and 2014/15 seasons, for a total of seven evaluations per season. The disease evaluations data were plotted in each disease progress curve. The evaluations started when the plants architecture was differentiated in the two trellis systems. In December of 2013 and 2014, a representative branch of each plant was tagged in each plot. Ten leaves per plant were evaluated from the base of the branch in each evaluation. In the vertical trellis system, the branch was tagged at a height of approximately 1.50 m, close to the lower wire. In the overhead system, the branch was tagged at a height of 2.10 m, which was just above the framework.

Anthracnose foliar severity was rated based on a disease scale of 0 - 4, adapted from Bouza (2009). Class 0 represents asymptomatic leaves; 1 - leaves with 1 to 10% of the area with symptoms; 2 - with 10 to 25%; 3 - with 25 to 50%; and 4 - with 50 to 100% of the area with symptoms. To assess cladosporiosis foliar severity, a disease scale of 0- 3, proposed by Junqueira et al. (2003), was used. Class 0 represents asymptomatic leaves, 1 - leaves with 1 to 10% of the area with disease symptoms; 2 - leaves with 11 to 30%; and 3 - more than 31% of the area covered with symptoms. To evaluate the bacterial blight severity, a disease scale of 0 - 4, proposed by Junqueira et al. (2003), was used. Class 0 represents asymptomatic leaves; 1 - leaves with 1 to 10% of the area with symptoms; 2 - leaves with 10 to 25%; 3 - leaves with 25 to 50%; and 4 - over 50% of the leaf area with symptoms. The foliar severity of the passion fruit woodiness was assessed using a ordinal rating scales of 0 - 3, adapted from Bouza (2009). Rating 0 represents leaves without mosaic symptoms; 1 - leaves presenting mild mosaic, and without foliar deformations; 2 - leaves showing mild mosaic, blisters and foliar deformations; and 3 - leaves showing severe mosaic, blisters and leaf deformations.

Besides foliar disease evaluations, cladosporiosis and passion fruit woodiness were also evaluated on plants, in the same period. A disease scale of 1 – 4, adapted from Bouza (2009), was used for cladosporiosis severity, in which the class 0 represents asymptomatic plants; 1 - plants with 1 to 10% of the area with symptoms; 2 - plants with 10 to 25%; 3 - plants with 25 to 50%; and 4 - plants with more than 50% of the area with symptoms. The severity of passion fruit woodiness on plants was determined by ordinal rating scales of 0 - 2, adapted from Bouza (2009). Rating 0 represents plants slightly infected, with mild mosaic symptoms, and leaves wrinkling; 1 - plants moderately infected, with mosaic symptoms and leaves wrinkling; and 2 - plants severely infected, with mosaic symptoms and severe leaf wrinkling.

The disease scores/rating from each plant were converted to a disease index (DI) proposed by Mckinney (1923), represented by DI (%) = $(\Sigma f * v/n * x) * 100$, where DI = disease index; f = number of leaves with a given score/rating; v = score/rating observed; n = total number of leaves evaluated; x = maximum scale score/rating. The severity of each disease in each plot was obtained by averaging the DI of the disease of interest in the five plants evaluated. The DI data collected over time from each plot were used to determine the area under the disease progress curve (AUDPC) (SHANER; FINNEY, 1977).

Harvest started as soon as the first fruits were maturating, and lasted from December to June, in both seasons. Fruits with yellow skin color up to 2/3 of the fruit, and falling fruits within the crown projection area were harvested twice a week. Harvested fruits from each plant were weighed in a semi-analytical scale BEL® SC310, in the Laboratory of Chemistry of the IFC - Campus Araquari. The productivity of each plot was estimated by averaging the production of each plant, and converting the area of the plot (21.5 m^2) to hectare.

The AUDPC and productivity data were first tested for normal distribution of the experimental error with the Kolmogorov-Smirnov test, at a 5% probability level. The homogeneity of the experimental error was tested with the Bartlett test, at a 5% probability level. After checking the ANOVA assumptions, the means were subjected to analysis of variance (ANOVA). Means that showed significant differences with the F-test, were separated and compared using Student's t test, at a 5% probability level. Statistical analyses were conducted using the software ASSISTAT 7.7 beta (SILVA; AZEVEDO, 2016).

Results and Discussion

In the 2013/14 season, the temperature during the epidemic ranged from 4.8°C to 36.3°C, with an average of 22.0°C. The relative humidity ranged from 80% to 89%, with an average of 84.3%. The monthly precipitation totals ranged from 54.8 to 319.6 mm, averaging 171.2mm. The days per month with precipitation ranged from 6 to 23 days, December and April, respectively. The average rainfall days was 18.1 per month (Figure 1A). In the 2014/15 season, the temperature during the epidemic ranged from 4.2°C to 37.2°C, with an average temperature of 21.9°C. The relative humidity ranged from 77% to 88%, with an average of 82.5%. The monthly precipitation ranged from 21.2 to 428.4 mm, with an average of 193.9 mm. days per month with precipitation ranged from 10 to 23, corresponding to October and January, respectively, with an average of 17.6 days with precipitation (Figure 1B).

There were no differences in the AUDPCs between the two trellis systems for all foliar and plant diseases evaluated, in both seasons. No difference was observed because the disease progress curves (DPC) were very similar between treatments (Figure 2)

To date, very little is known about passion fruit plant architecture, obtained from a training system, being conducive or not to diseases development due to the microclimate conditions created. Only few reports as abstracts in events have recommended not to use the overhead system, because higher diseases incidence and severity was observed (KOMURO, 2008; LIMA et al.; 2011). In contrast with the present study, Lima et al. (2011) suggested that the vertical system possibly allows reduction of phytosanitary problems. Considering that the alteration in the plant architecture may lead to a microclimate favorable to diseases incidence, Giacobbo (2002) analyzed peach (*Prunus persica* L. Batsch) brown rot incidence, caused by the fungus *Monilinia fruticola* (Wint) Honey, in four different training systems of peach, and no differences were observed between the systems. Luminosity, air circulation and moisture retention did not differ to the point of causing a range of disease intensities.

Changes in plant architecture may affect the microclimate and thus risks of infection (GILBERT, 2002). Higher plant densities tend to increase leaf moisture and wetness, making plant tissue more proned to infection by phytopathogens that prefer humid conditions. Many phytopathogens benefit from denser plant growth, because of the microclimate more humid and temperatures more suitable (GILBERT, 2002), then, changes in plant architecture may increase infection rates. In this study, the changes in yellow passion fruit architecture, by training the plants to the vertical and overhead systems, were not enough to change diseases intensity.

Anthracnose severity was initially low in both seasons, and reached a disease index (DI) of approximately 12% in the first season, and 17% in the second one. Foliar cladosporiosis showed higher initial DI in the first season (around 20%) than in the second season (around 8%). With the disease progress, the DI in both seasons reached approximately 40%. For cladoporiosis on plants, the disease had an initial DI of around 15%, and in June reached around 65% in the first season, and 75% in the second season (Figure 2A and 1B). Bacterial blight had an initial DI of approximately 10% in both seasons, reaching around 40% in June, with no difference between the two trellis systems. Passion fruit woodiness intensity, analyzed by the symptoms of CABMV infection in leaves, showed an initial DI close to 10%. The foliar CABMV symptoms progress increased, and, by the end of the evaluations, reached values of approximately 90% and 75%, in the 2013/14 and 2014/15 seasons, respectively. When the disease was evaluated in the plants, the DI in the second season was initially twice as less as the first season. However, in May, the DI reached 100% in both seasons (Figure 2A and 2B).

Low anthracnose intensity was observed in the first season in both vertical and overhead systems. The low disease intensity may have occurred because the area was previously used for eucalyptus (*Eucalyptus grandis* Hill ex Maiden) reforestation. Trees were removed to set up the trellis system experiment. Higher intensity was observed in the second season, probably because there was higher inoculum density compared to the first one, due to the previous cultivation. Anthracnose is favored by high temperatures, high relative humidity, and periodic rainfall (GONÇALVES JÚNIOR et al., 2007). The optimum temperature ranges from 20 to 30 ºC, the spore production is favored by temperatures around 27 ºC, and disease is more severe in rainy conditions, between temperatures of 22 to 28 ºC and high humidity (SERRA et al., 2008; SOUZA; RIBEIRO, 2016). The climatic conditions observed in this study were conducive to disease development, with high temperatures and high relative humidities. Both seasons were within the optimum range of temperature, humidity above 80%, and high precipitation. However, high rates of foliar disases were not observed.

Cladosporiosis symptoms began with the first rainfalls in November, becoming more severe from January to April, when new tissues were present (BULHÕES et al., 2012). This was observed in the evaluations made on leaves and plants in both systems. There was a considerable progress of the disease in both seasons, especially with the presence of tender tissue, which is more susceptible to new infections, and expansion of old lesions, due to the high relative humidity condition and frequent precipitations from January to May. With high humidity and moderate temperatures, around 15 to 22ºC, coinciding with blooming in spring and in January/February, the disease severity may progress considerably, increasing lesions numbers, expanding lesions, and leading to a greater pathogen sporulation (SUSSEL, 2015). Susceptibility of young tissues contributes to the increase of infections in the full vegetative development of the plant, as well as in the period of flowering, favoring the disease intensity in the plant's main reproductive flow (SUSSEL, 2015). In annual crop cycles, flowering occurs from November/December, wich coincides with the period

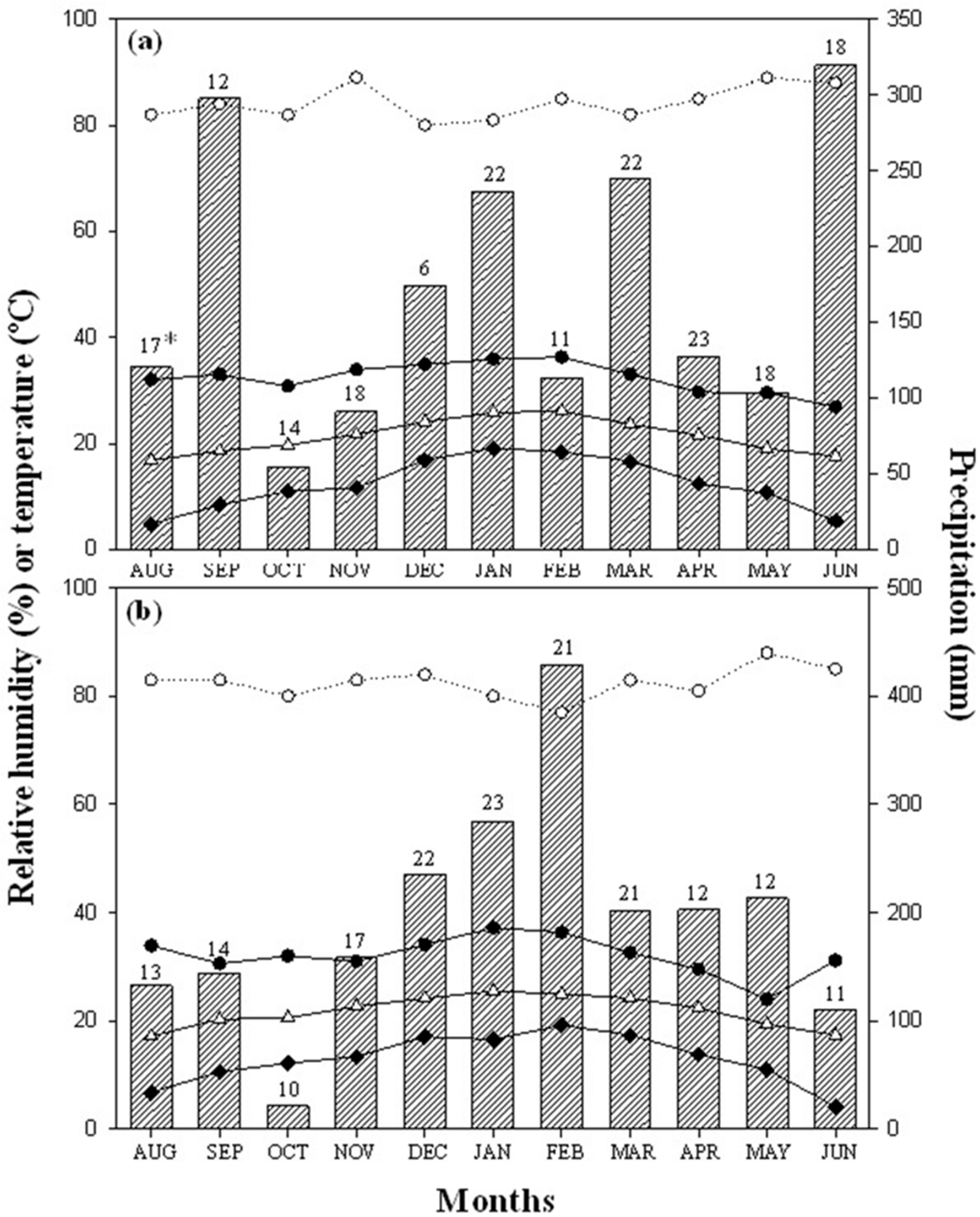

Figure 1 – Values of meteorological variables recorded during the epidemic in the 2013/14 (A) and 2014/15 seasons (B). Average relative humidity is represented by a dotted line with empty circles, precipitation (A2) by vertical bars and temperature by a solid line. The rainy days are represented by numbers above of vertical bars. Maximum, medium and minimum temperatures are represented by ━●━, ━Δ━ and ━♦━, respectively.

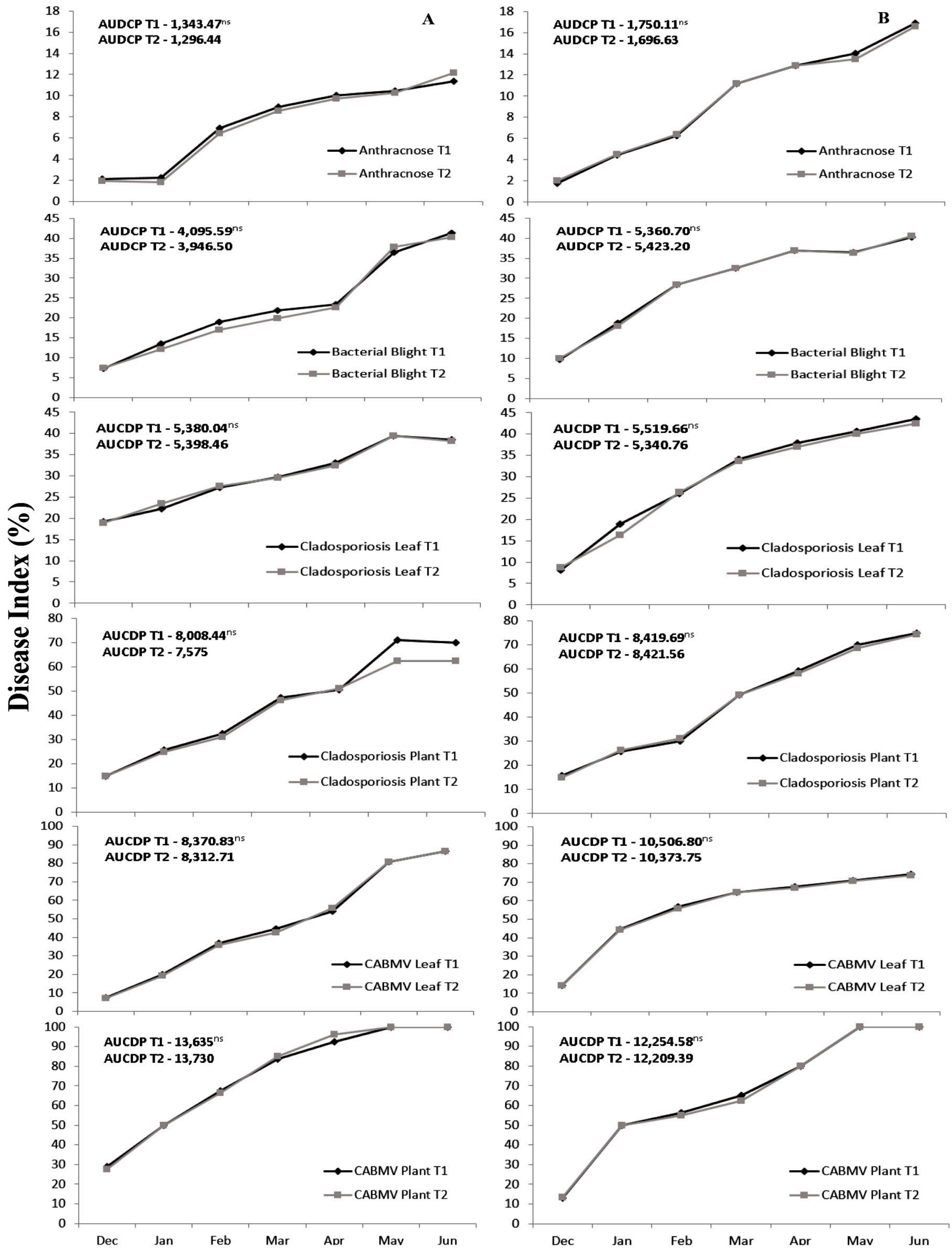

Figure 2 – Disease progression curve and area under the disease progress curve (AUDPC) of anthracnose, bacterial blight, cladosporiosis and passion fruit woodiness (CABMV) severity on yellow passion fruit leaves and plants under vertical (T1) and overhead (T2) trellis systems, in the 2013/14 (A) and 2014/15 (B) seasons, in Araquari, SC.

of greater susceptibility of the tissues.

The bacterial blight disease index was high, with substantial progress in the evaluation period in the two years of passion fruit cultivation, due to conducive temperature and humidity conditions as well as plant susceptibility. The ideal conditions for the development of the disease are temperatures above 30ºC and high relative humidity (MUNHOZ et al., 2015), which were observed at the most critical times in the two seasons. *Xanthomonas axonopodis* pv. *passiflorae* is transmitted mainly by splashing water or aerosols, and penetrate the plant through natural wounds or openings, such as stomata and hydathodes (MUNHOZ et al., 2015). The disease progress occurred due to the increase in the emission of new vegetative shoots from December to April, which are more susceptible to the bacteria. Frequent rainfalls and relative humidity supported leaf wetness, which was required for the causal agent to move to the natural openings and injuries. Then, pathogen infections increased substantially as well as the expression of the foliar disease symptoms.

The CABMV is transmitted by several aphids' species. Even orchards with pathogen-free seedlings may be infected by the virus brought from vectors or host plants. Disease symptoms, regardless of the plant architecture trained with trellis systems, were visible with a DI over than 10% in December, reaching 100% of the plants in May. Up to now, there is no permanent and effective procedures to control the disease, but there are several recommendations to increase the orchard lifespan and reduce the damage. The use of pathogen-free seedlings, the removal of old and abandoned orchards before the beginning of production, the care with pruning operations to prevent the mechanical transmission of the virus, the eradication of symptomatic plants and other hosts are recommended (CERQUEIRA-SILVA et al., 2014).

Although the yellow passion fruit cultivation is realized for up to three consecutive years in commercial orchard (HAFLE et al., 2009), when CABMV is present, the recommendation is for annual cycle management to increase productivity (SAMPAIO et al., 2008; WEBER et al., 2016), and to coexist with the disease. For polycyclic diseases, such as cladosporiosis, anthracnose, bacterial blight and fruit woodiness, the aerial dispersion of pathogens, as well as aphids, is an important factor in the spatial and temporal increase of epidemics, because these diseases are initiated by primary inoculum, and secondary inoculum causes several infection cycles in a season (GOBBIN et al., 2005). Thus, the annual crop cycles, in which the plants are kept in the orchard for about 10 to 11 months and eliminated after that, having a fallowing period of approximately 30 days, drastically reduce the primary inoculum to the next crop, and is an alternative to control the major diseases of passion fruit.

The productivity of the overhead trellis system was greater than the vertical system, with an increase of 78.1% e 57.1%, in the 2013/14 e 2014/15 seasons (Figure 3). The passion fruit productivity was around 40% higher in the overhead system compared to the two-wire vertical system, in both seasons. This finding supports the hypothesis that the overhead system is more productive in annual crop cycles. Although the information about passion fruit trellis systems are only in books, and no published researches comparing the tellis systems and the passion fruit plant architectures are available, some reports show that the production in the first year in the overhead system is four times superior to the vertical system, using artificial pollination (KOMURO, 2008; LIMA et al.; 2011). This is an important information, because nowadays the cultivation of yellow passion fruit, in the main producing regions, is in annual crop cycle. Reports also show that the productivity in the overhead system may be reduced by the possible loss of fruits that are above the wire framework in the overhead system and are not collected (LIMA et al.; 2011). However, this can be avoided by a careful harvest, making sure all fruits are collected.

It is necessary to point out that the overhead system presents problems for the accomplishment of some cultural treatments, most importantly because of the drift of spray from pesticides application that can affect the operator (LIMA et al.; 2011). However, the technology of pesticides application has advanced considerably, providing good equipment to be used in both trellis systems. With the new spraying technologies, it is possible to have good plant coverage with proper safety in the overhead system. The overhead system in annual crop cycle is a potential alternative for organic growers.

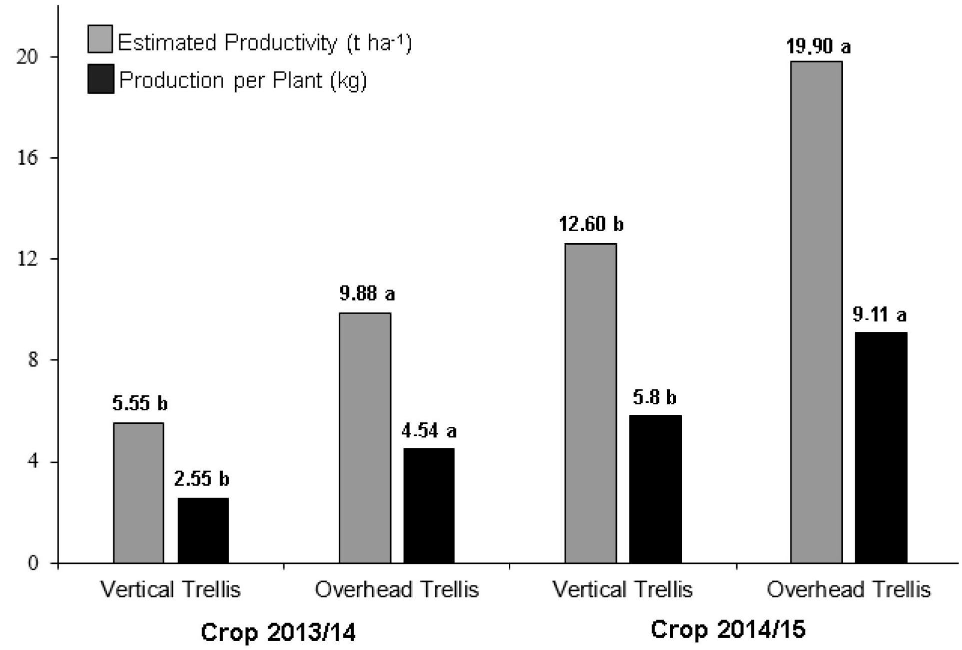

Figure 3 – Yellow passion fruit estimated productivity (t ha^{-1}) and production per plant (kg) under vertical and overhead trellis systems, in the 2013/14 and 2014/15 seasons, in Araquari, SC.

Conclusion

Yellow passion fruit plants in the vertical and overhead trellis systems in annual cycle do not differ in diseases intensity, as anthracnose, cladosporiosis, bacterial blight and passion fruit woodiness. Yellow passion fruit cultivated in annual cycle was significantly more productive in the overhead trellis system than in the vertical system.

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