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INFLUENCIA DEL SEXADO PRECOZ DE LA PLANTA DE PAPAYA (*Carica papaya* L.) EN LA PRODUCCIÓN Y CALIDAD DEL FRUTO EN UN CULTIVO BAJO INVERNADERO DEL SURESTE ESPAÑOL

INFLUENCE OF THE PREMATURE SEXING OF THE PAPAYA PLANT (*Carica papaya* L.) ON THE PRODUCTION AND FRUIT QUALITY IN A GREENHOUSE CROP IN THE SOUTHEAST SPAIN

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MIREILLE NATHALIE HONORÉ

TESIS PRESENTADA POR

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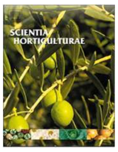
La tesis con título "*INFLUENCIA DEL SEXADO PRECOZ DE LA PLANTA DE PAPAYA (CARICA PAPAYA L.) EN LA PRODUCCIÓN Y CALIDAD DEL FRUTO EN UN CULTIVO BAJO INVERNADERO DEL SURESTE ESPAÑOL*" corresponde a un compedio de trabajos previamente publicados. A continuación se detalla el nombre y afiliación de cada uno de los autores, la referencia completa de la revista o editorial y el DOI de cada uno de ellos.



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(*) DDT: días después de trasplante, SST: sólidos solubles totales

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RESUMEN

En el presente trabajo se presentan los datos obtenidos en los ensayos realizados en el cultivo de papaya en tres invernaderos de tipo multitúnel, con ventilación natural situados en el Sureste de España. El primer ensayo se desarrolló en un ciclo largo durante dos campañas agrícolas (2016-2017 y 2017-2018) en el que se analizó el comportamiento de plantas hermafroditas sexadas de forma precoz mediante marcadores moleculares, una parte de ellas injertadas sobre su propio pie femenino, frente a plantas trasplantadas de modo tradicional (tres plántulas no sexadas), todas ellas del cultivar \`Intenzza´. Para las plantas sin injertar se compararon dos tamaños de plantas al momento del trasplante, plántulas en cepellón de 133 $cm^3$ y plántulas en cepellón de 2000 $cm^3$. Además, se plantó el cultivar \`Sweet Sense´ sexado de forma precoz.

En un segundo ensayo, durante esas dos mismas campañas, se cultivaron plantas de papaya sexadas precozmente del cultivar \`Intenzza´ con el objetivo de realizar un análisis de su rentabilidad económica y determinar de su viabilidad como alternativa a los cultivos intensivos tradicionales bajo invernadero que se realizan en la provincia de Almería.

En un tercer ensayo se realizó un ciclo corto (campaña 2017-2018) con el objetivo de comparar la producción de cinco cultivares de papaya sexados de modo precoz (\`Intenzza´, \`Sweet Sense´, \`Vitale´, \`Caballero´ y \`Alicia´) y uno además injertado (\`Intenzza´). En este tercer cultivo también se ensayó el uso de agrotextiles colocados alrededor de las piñas de frutos como medida de protección de los frutos frente a las bajas temperaturas durante el periodo invernal.

En el primer ensayo, las plantas sexadas de forma precoz obtuvieron una producción estadísticamente superior a las trasplantadas de forma tradicional, incluso cuando se injertaron sobre su propio pie. Los rendimientos obtenidos en el ensayo (262,8 a 325,2 $t\cdot ha^{-1}$), fueron superiores a los referenciados en diferentes continentes. Para el cultivar \`Intenzza´, el injerto de plantas hermafroditas sobre plantas femeninas obtuvo los mejores rendimientos (321,2 $t\cdot ha^{-1}$), con valores similares a los del cultivar \`Sweet Sense´ para plantas sexadas sin injertar (325,2 $t\cdot ha^{-1}$). El peso medio de los frutos fue superior en la segunda campaña (0,92-1,16 kg) a los de la primera (0,71-0,91 kg). Sin embargo, el número de frutos por planta fue mayor en la primera campaña (43,57-87,13) que en la segunda (37,95-56,45), siendo en ambos casos el cultivar \`Sweet Sense´ el que obtuvo los mayores valores (con significación estadística). El injerto no influyó significativamente en el contenido de sólidos solubles de los frutos. Las plantas trasplantadas con mayor tamaño (cepellón de 2000 cm^3) emitieron los primeros frutos en nudos más cercanos al suelo y entraron en producción de forma precoz.

El análisis económico realizado en el segundo ensayo demostró su viabilidad como alternativa dentro del modelo agrícola almeriense. El beneficio tras los 30 meses de cultivo en ciclo largo fue de +57.535 $€\cdot ha^{-1}$. Sin embargo, el agricultor interesado en producir papaya deberá de tener suficiente liquidez en los primeros once meses de cultivo, tras los cuales se observó una recuperación de parte de la inversión con los ingresos obtenidos por la venta de la papaya.

En el ciclo corto de producción, el cultivar \`Intenzza´ injertado fue el más productivo con 142,0 $t\cdot ha^{-1}$, produciendo los frutos con el contenido en solidos solubles totales más alto. El injerto de \`Intenzza´ tenía los entrenudos más cortos que la planta de \`Intenzza´ franca. Además, la altura del primer fruto para los árboles injertados fue menor que para los árboles francos.

La colocación de agrotextiles alrededor de los frutos al inicio del invierno, permitió un aumento estadísticamente significativo de las temperaturas mínimas y medias de 1 y 0,7ºC, respectivamente. La protección indujo precocidad de la producción sin aumentar el rendimiento final.

ABSTRACT

This paper presents the data obtained in the trials carried out in three multispan greenhouses with natural ventilation, cultivated with papaya crops, located in the southeast of Spain.

The first experiment was conducted during a long cycle crop (during the two annual cropping cycles 2016-2017 and 2017-2018). The growing of hermaphrodite plants with early sex identification made with molecular markers (some of them were grafted plants onto the rootstock of the female plant) was compared to traditionally transplanted plants (three unsexed seedlings). All of them were plants of the cultivar `Intenzza´. For ungrafted plants, two sizes of transplanted plants were compared, seedlings with a root ball of 133 cm^3 and with a root ball of 2000 cm^3. Seedlings of the cultivar 'Sweet Sense' with early-sex identification were also transplanted and assessed.

In the second trial, during those same two cropping cycles, early-sex identified papaya plants of the cultivar `Intenzza´ were cultivated with the aim of performing an analysis of their economic profitability and determining their viability as an alternative to the intensive and traditional Almeria greenhouse crops.

In the third trial a short cycle was carried out (season 2017-2018) with the aim of comparing the production of five cultivars of papaya early sexed (`Intenzza´, `Sweet Sense´, `Vitale´, `Caballero´ and `Alicia´) and also a grafted cultivar (`Intenzza´). In this third study, for the fruit's protection again low temperatures during the winter period, plant covers placed around the fruits were also tested to see their effect on the yield and the temperature.

In the first trial, the early-sexed plants and the grafted plants had a statistically higher production than those traditionally transplanted. The yields obtained in this trial (from 262,8 to 325,2 t-ha^{-1}) were higher than those referenced on different continents. The grafted of the cultivar `Intenzza´ obtained the best yield with 321,2 t·$ha^{-1}$, with similar values of the cultivar `Sweet Sense´, ungrafted and early sexed (325,2 t·ha^{-1}). The average weight of the fruits was higher in the second season (0,92-1,16 kg) than in the first season (0,71-0,91 kg). However, the number of fruits per plant was higher in the first season (43,57-87,13) than in the second season (37,95-56,45), being in both seasons the cultivar `Sweet Sense´ which obtained the highest values (with statistical significance). Grafting did not have a significant effect on the total soluble solids content of the fruits. Larger transplanted plants (2000 cm^3) bore the first fruit closer to the soil and produced early.

The economic analysis carried out in the second trial demonstrated that the cultivation of papaya was viable and that it could be considered as an alternative within the Almeria agricultural Model. The profit after the 30 months of the long-cycle culture was +57.535 €·ha^{-1}. Nevertheless, the farmer interested in producing papaya must have enough liquidity in the first eleven months of cultivation; after this period, it was observed that part of the investment was recovered with the incomes obtained from the sale of the papaya.

In the short production cycle, the grafted cultivar `Intenzza´ was the most productive with 142,0 t·$ha^{-1}$, producing the fruits with the highest total soluble solids content. The grafted plants of `Intenzza´ had the shortest internodes than the 'Intenzza' ungrafted plants. Furthermore, the height of the first fruit for grafted plants was lower than for ungrafted plants.

Placing a plant cover around the fruits at the beginning of winter, produced a statistically significant increase in the minimum and average temperatures of 1 and 0,7ºC, respectively. This protection from frost induced an early production but without increasing the final yield.

INTRODUCCIÓN

La papaya (*Carica papaya* L.) pertenece a la familia *Caricaceae*, y es la tercera fruta tropical más producida en todo el mundo, después del mango y de la piña. En 2018, la producción mundial ascendió a unos 13,45 millones de toneladas de papaya, un 2,45% más que en 2017, en una superficie total de 1.024.909 hectáreas en 65 países (FAO, 2020). Su comercio ascendió a cerca de 200.000 millones de dólares en 2009 (Evans y Ballen, 2012), siendo la especie económicamente más importante de la familia *Caricaceae* (Carvalho y Renner, 2012). El cultivo de la papaya se ha extendido durante las últimas décadas debido no solo a que su fruta es muy apreciada, sino por sus propiedades nutricionales y farmacológicas (Chan y Paull, 2008; Gonsalves, 1998; Niklas y Marler, 2007; Pinnamaneni, 2017). El 60% de la producción se produce en los países tropicales de Asia, el 29% en América latina y Caribe y el 10% en África. La papaya se produce principalmente en India, Brasil, México, República Dominicana, Indonesia y Nigeria. Estos países producen el 80,5% de la producción mundial. En 2018, produjeron respectivamente unos 5,98; 1,06; 1,03; 1,02; 0,88 y 0,83 millones de toneladas (FAO, 2020). Los rendimientos son muy desiguales entre estos países, oscilando entre los 29,81 $kg \cdot m^{-2}$ de la República Dominicana y los 0,76 $kg \cdot m^{-2}$ de Nigeria. Los Estados Unidos y Europa son los principales importadores mundiales. En 2018, la cuota de volumen para América del Norte fue del 64%, y para la Unión Europea del 18% (FAO, 2020). Los principales importadores de papaya en Europa en 2018, fueron los Países Bajos, España y Alemania con 5.507, 2.325 y 2.266 toneladas respectivamente (EC, 2020). España produce papayas principalmente en las Islas Canarias con 24.488,6 toneladas y una superficie cultivada de 875,7 hectáreas en el año 2018 (ISTAC, 2020). En la península ibérica española, existen plantaciones de papaya en la costa Mediterránea, en las provincias de Málaga, Granada, Almería y Murcia (Salinas et al., 2017a, 2017b), sumando aproximadamente unas 100 hectáreas.

Más allá de la comercialización de la fruta, el conocimiento de los beneficios nutricionales de las frutas tropicales está contribuyendo al crecimiento del consumo. El desarrollo de campañas de marketing por parte de la industria, con el objetivo de promover hábitos saludables y de informar sobre los beneficios nutricionales de las frutas tropicales, ha resultado ser un factor determinante. Estas campañas han ido especialmente dirigidas a países de Europa, donde el consumo per cápita de papaya aún no es significativo en relación con otros países como USA. Los últimos datos disponibles indican que el consumo medio de papaya en los Estados Unidos es de 0,6 kg en 2018 mientras que en la Unión Europea es de 0,1 kg, siendo el segundo mayor importador (Altendorf, 2019). La promoción de la fruta y de sus beneficios ha favorecido la demanda de importación y es un importante factor de crecimiento, especialmente en la Unión Europea, donde el conocimiento de la fruta por parte de los consumidores sigue siendo limitado. La papaya es una planta de gran valor medicinal. Su fruta es consumida por sus propiedades y bondades nutricionales y suscita la investigación en múltiples áreas de investigación y sectores industriales. Distintos descubrimientos realizados sobre los compuestos y extractos de partes de la planta de la papaya son objeto de análisis para la producción de complementos alimenticios y tratamientos medicinales. Las hojas, flores, frutos, semillas, raíz, corteza y látex de la papaya se utilizan en etnomedicina (Pinnamaneni, 2017). Contienen compuestos con propiedades antihelmínticas, antimicrobianas, antifúngicas, antiamebianas, hepatoprotectoras, abortivas y anticonceptivas, reductoras de la fertilidad masculina, inmunomoduladores y contra histaminérgicas (Adebiyi et al., 2002; Krishna et al., 2008; Milind y Gurditta, 2011; Nguyen et al., 2013; Okeniyi et al., 2007; Vij y Prashar, 2015). Algunos compuestos se utilizan o se investigan para el tratamiento o cura de diversas afecciones y enfermedades como son la malaria, el dengue, la diabetes, el cáncer, las infecciones bacterianas, las ascariasis, la disminución de plaquetas, los trastornos digestivos, la dispepsia, las quemaduras externas y escaldaduras y para el tratamiento del sistema genitourinario (Ahmad et al., 2011; Horn-Ross et al., 2000; Huet et al., 2006; Li et al., 2012; Nguyen et al., 2013, 2016; Otsuki et al., 2010; Pandey et al., 2017). En los últimos años, se ha producido un desarrollo notable de la investigación en torno a la papaya. Esta planta es interesante también en el campo de la genética dado que tiene su genoma completo secuenciado (Chávez-Pesqueira y Núñez-Farfán, 2017). Esto ha posibilitado avances en la investigación en este campo, gracias a la experimentación con la papaya (Ming et al., 2008; VanBuren et al., 2015; Wang et al., 2012). Es la primera especie con un cultivar transgénico que se libera para el consumo humano (Chávez-Pesqueira y Núñez-Farfán, 2017; Ming et al., 2008).

Numerosos estudios de investigación concluyen que *Carica papaya* L. es de origen mesoamericano (Carvalho y Renner, 2012; Chávez-Pesqueira y Núñez-Farfán, 2017; Jiménez et al., 2014; VanBuren et al., 2015). Se adapta en los límites de los 32 a 35° de latitud norte y de 32 a 53° de latitud sur, en las zonas tropicales y subtropicales (Alfonso García, 2010). Es una especie polígama – trioica. La multiplicación por semilla puede generar tres tipos de individuos con flores masculinas, femeninas y hermafroditas en plantas separadas (Urasaki et al., 2012). El sexo en la papaya es controlado por un par de cromosomas sexuales nacientes. Las hembras son XX, y dos cromosomas Y ligeramente diferentes distinguen a los machos (XY) y a las plantas hermafroditas (XY^{b}) (VanBuren et al., 2015). Las plantas con flores hermafroditas son las que producen las papayas con mejores características comerciales. El género hermafrodita es probablemente originario de la región del Pacífico Norte de Costa Rica (VanBuren et al., 2015). Para la propagación de la papaya y para establecer un cultivo, de forma tradicional se recurre al método de siembra de tres a cuatro plántulas en el mismo sitio. Así, cuando las plantas llegan al estado de la floración, se conserva la planta hermafrodita más vigorosa, con la inserción de las flores más cercana al suelo y se eliminan las otras plantas. Existe una probabilidad del 93.75% de obtener una planta hermafrodita sobre las 4 plantas sembradas o del 87.5% con tres plantas sembradas (siendo $½^{n}$ la probabilidad de tener solo plantas femeninas con "n" semillas por golpe). En general, las empresas productoras de semillas consiguen eliminar las plantas de género masculino de tal forma que de 100 semillas nacen, aproximadamente, 50 plantas hermafroditas y 50 femeninas. Establecer una plantación de papaya con la propagación tradicional implica esperar el estado de la floración (que se produce a las 8-12 semanas), e invertir agua, fertilizantes, tiempo y mano de obra en muchas plantas que serán femeninas. Para intentar ahorrar insumos, la biotecnología ha ido desarrollando técnicas para determinar el sexo de plantas de papaya en edad temprana y a un coste razonable. Numerosos autores (Albort-Morant et al., 2017; Chaves-Bedoya y Nuñez, 2007; Deputy et al., 2002; Ming et al., 2007; Saalau-Rojas et al., 2009; Sánchez-Betancourt y Núñez Zarantes, 2008; Urasaki et al., 2002) han desarrollado técnicas usando marcadores moleculares. Entre las dificultades de los procedimientos de sexado, destacan la determinación de marcadores lo suficientemente fiables como para asegurar una exactitud en la lectura de los resultados (Chaves-Bedoya et al., 2009; Chaves-Bedoya y Nuñez, 2007), la distinción de resultados de plantas hermafroditas de plantas masculinas (Chaves-Bedoya y Nuñez, 2007; Deputy et al., 2002; Urasaki et al., 2002, 2012), o la lectura de falsos negativos y falsos positivos (Saalau-Rojas et al., 2009). La determinación del sexo de *Carica papaya* L. puede realizarse en plantas de entre tres-cuatro semanas con trozos de hojas, lo que permite ahorrar tiempo e insumos a la hora de diseñar una plantación, con una probabilidad de obtener plantas hermafroditas entre el 92% y el 94%, pero no del 100% (Mora Newcomer y Bogantes Arias, 2005).

Con este avance en biotecnología, sería apropiado preguntarse si una plantación con plantas hermafroditas, cuyo sexo se ha determinado de forma precoz antes del trasplante, tendría una productividad igual o mayor a una con plantas sexadas de forma tradicional, tal y como suponen algunos autores en publicaciones sobre el sexado de la papaya con marcadores moleculares (Chaves-Bedoya et al., 2009; Saalau-Rojas et al., 2009). Además, sería pertinente querer comprobarlo ya que se ha afirmado que la planta sexada y sembrada precozmente no sufriría ninguna competencia por el espacio, la luz y los nutrientes, con otras tres plántulas plantadas y sexada de forma tradicional. Sería interesante comprobar en qué medida sería superior el rendimiento de la plantación y, al mismo tiempo, valorar cual sería el ahorro de insumos. El cultivo de la papaya tiene un crecimiento vegetativo muy rápido. Por este motivo, la mano de obra para operaciones culturales como el deshojado, las podas ligeras, el aclareo de botones florales y frutos malformados, en una plantación de papaya, es primordial. Son labores importantes para asegurar la calidad de la fruta. Ayudan a reducir la propagación de enfermedades y asegurar una ventilación óptima dentro de la plantación (de Souza Barros et al., 2009; Hoyos y Hurtado-salazar, 2017; Paéz Redondo, 2003; Rodríguez Cabello et al., 2014; Rodríguez Pastor et al., 1995; Zhou et al., 2000). La densidad y, por tanto, el marco de plantación, influyen sobre la necesidad de una mayor mano de obra, factor económico que repercute en la rentabilidad de la explotación. Por consiguiente, se deben tener en cuenta estos factores a la hora de diseñar la plantación ya que son factores determinantes del rendimiento y de la calidad de la producción (Rodríguez Pastor, 2002).

En el ámbito del modelo de producción hortícola en la provincia de Almería, se analiza la introducción del cultivo de papaya (*Carica papaya* L.) bajo invernaderos con ventilación natural y su rentabilidad. La especialización productiva de Almería, en lo que ha venido a denominarse "el modelo de agricultura de alto rendimiento del sureste de España", se basa en el cultivo de ocho hortalizas (tomate, pimiento, pepino, calabacín, berenjena, judía verde, melón y sandía) bajo invernadero con cubierta plástica. Actualmente, se encuentra en fase de madurez productiva y, tras desarrollar un potente canal de comercialización, está sometida a un incremento progresivo de la competencia de terceros países a través del abaratamiento de sus costes de producción, especialmente de la mano de obra y minimizando los costes de transporte (Alvarez y Del Corral, 2010; Aznar-Sánchez et al., 2011). Por lo que respecta a la comercialización, desde hace años, los ingresos de los productores se mantienen, principalmente por la estabilidad en promedio de los precios y el aumento de la productividad. Sin embargo, el coste de producción se incrementa año tras año, produciéndose una caída constante en el margen de beneficio por unidad de producto vendido. Ante esta situación de estabilidad de precios, caben dos sencillos análisis. Por un lado, habría que bajar la oferta, para atender a una demanda estable y, por otro lado, para no perder competitividad en el conjunto del sector, habría que ampliar la gama de productos que ofrece el modelo. En el contexto descrito, sería razonable preguntarse ¿por qué introducir una especie exótica como *Carica papaya* L. dentro del modelo de producción almeriense y por qué dirigir su comercialización al continente europeo? Una plantación de *Carica papaya* L. bajo invernadero, entra en producción en menos de 6 meses. El cultivo se adapta a las condiciones ambientales y a las estructuras productivas del sureste español. En la agricultura de alto rendimiento de Almería, los cultivos se desarrollan bajo diferentes invernaderos de cubierta plástica, con diferentes características con respecto a las superficies de los módulos, alturas y formas. Las plantas que tradicionalmente se han cultivado en estos invernaderos son diferentes cultivares de tomate, pimiento, berenjena, pepino, calabacín, melón, sandía y judías verdes. A excepción del tomate y la berenjena, el resto de estos cultivos se cultivan en ciclos cortos, aproximadamente de 5 a 6 meses y, en consecuencia, se pueden hacer dos plantaciones cada año. El tomate y la berenjena se pueden cultivar en ciclos cortos y largos. En un ciclo largo, las plantaciones se mantienen de 10 a 11 meses bajo el invernadero. En Almería, se podría aprovechar la experiencia de los semilleros para el establecimiento de las plantaciones de papaya y también la red de comercialización existente del sector hortícola almeriense. La alta tecnificación de los semilleros y la experiencia en producción integrada del sector hortícola, permitiría asegurar unos estándares de calidad para la producción de papaya a comercializar para el mercado europeo. Todos estos factores podrían ser relevantes para el posicionamiento de la producción española de papaya frente a las importaciones extracomunitarias. Paralelamente, la proximidad de los mercados de consumo al sureste español permite que la fruta sea cosechada en un estado de madurez más avanzado en comparación con los países exportadores de fuera de Europa, lo que supone una ventaja que mejora la calidad y el sabor de la papaya, permitiendo ofrecer frutos más dulces a los consumidores. Para la comercialización, son preferibles papayas con un tamaño de 500 a 800 g (tamaño D a F, Codex STAN 183-1991). Las variedades de pequeño tamaño generalmente se valoran bien para la venta al por menor. En cambio, para la industria de productos de cuarta gama, las variedades con un tamaño superior al tamaño F también son muy valoradas.

En 2012, en Almería empezaron los primeros ensayos de este cultivo, con la intención que se convirtiera en una nueva oportunidad para la diversificación de productos cultivados bajo invernadero (Hueso et al., 2017). Tímidamente, los agricultores comenzaron con una superficie inicial de 30 ha de papaya plantadas bajo invernadero en Almería. Las variedades inicialmente elegidas fueron \`BH-65´, Eksotica´, \`First Lady´. En 2014, se ensayaron otras variedades como \`Intenzza´, \`Siluet´, \`Sensation´, \`Red lady´, \`Tainung 1´ y \`Calimosa´ (Hueso, 2016). Para la producción de la papaya bajo invernadero, con las estructuras ya existentes en la provincia, son preferibles las variedades de porte bajo, con entrada en producción en menos de 8 meses, con tamaño mínimo de frutos de 800 g, de forma aperada y con productividad superior a los 15 $kg \cdot m^2$, afianzándose variedades como \`Intenzza´, \`Siluet´ y \`Sensation´. Siguen existiendo dudas respecto a las expectativas del consumidor de los mercados europeos, ideales para la comercialización de la papaya almeriense, debido a la proximidad y considerados como nicho de mercado. Deben seguir realizándose ensayos de variedades para determinar las que mejor se adaptan al clima de la provincia de Almería, sea en ciclo corto o largo y, determinar su productividad.

Sin embargo, partiendo del hecho que la papaya es un cultivo de áreas tropicales y subtropicales, para buscar su adaptación al clima de Almería es preciso innovar en la protección del cultivo dentro del invernadero. Es un cultivo sensible a las bajas temperaturas. Nakasone y Paull, (1998), indicaron que la temperatura óptima para el crecimiento de la papaya está entre 21 y 33°C. Señalaron también que si la temperatura cae por debajo de 12-14°C durante varias horas por la noche, el crecimiento y la producción se ven gravemente afectados. En Almería, los meses más fríos (con temperatura media inferior a 12°C) son los de noviembre a marzo. Las temperaturas frías pueden causar daños por frío en la fruta y, por lo tanto, la calidad comercial de la misma puede ser inaceptable. Las lesiones por frío se producen a temperaturas demasiado bajas para un crecimiento normal pero superiores a la congelación. Cuando las plantas que crecen a una temperatura relativamente más cálida (25–35°C) se exponen a temperaturas más frías (10–15°C), se producen daños por frío (Taiz et al., 2015). En Almería, esta situación puede ocurrir con frecuencia durante el invierno y la primavera cuando la temperatura dentro del invernadero puede elevarse por encima de los 20°C y caer durante la noche por debajo de los 10°C. Por esta razón, muchos agricultores instalan algún material, como pantallas aluminizadas o doble techo sobre el cultivo, para minimizar el choque térmico en los cultivos hortícolas (Molina-Aiz et al., 2019). Sería interesante innovar e investigar sobre el uso de sistemas pasivos de climatización para mejorar el ambiente dentro del invernadero y disminuir la amplitud térmica durante los meses de más frío en Almería (final de noviembre a marzo).

La papaya es una fruta que suscita el examen en múltiples áreas de investigación y sectores industriales. Existen avances científicos que demuestran su importancia tanto en ingeniería agronómica como en ciencias de la salud (Ahmad et al., 2011; Aziz et al., 2015; Bron y Jacomino, 2006; Calegario et al., 1997; Campostrini y Glenn, 2007; Chaves-Bedoya y Nuñez, 2007; Deputy et al., 2002; Dhekney et al., 2016; Domínguez de María et al., 2006; Gonsalves, 1998; Li et al., 2012; Miller y McDonald, 1999; Ming et al., 2007; Nguyen et al., 2013, 2016; Niroshini et al., 2008; Nunes et al., 2006; Pathak et al., 2019; Paul y Pandey, 2014; Sharma et al., 2016; Siddique et al., 2014; Siriamornpun y Kaewseejan, 2017; Tabassum y Khan, 2020;

Tecson Mendoza et al., 2008; Teixeira da Silva et al., 2007; Thérien et al., 2017; Tsai et al., 2016; Urasaki et al., 2002; Williams et al., 2013; Workneh et al., 2012).

El interés por la investigación sobre la papaya se ha ido incrementando, especialmente en los últimos 20 años. Para comprobarlo, realizamos un análisis bibliométrico en enero de 2019, con todas las publicaciones sobre la papaya en las revistas indexadas en los últimos 50 años, dentro de la base de datos SCOPUS. Para ello, el término papaya se utilizó como parámetro de búsqueda en los campos de `título´, `resumen´ y `palabras clave´. El período de análisis comprendió desde 1969 hasta 2018. Ante la posibilidad de duplicidad de datos, no se incluyeron en la muestra final documentos de trabajo, libros y documentos de conferencias (Perea-Moreno et al., 2017). La muestra final incluyó un total de 5679 artículos. Las variables seleccionadas para el análisis fueron el número de artículos, el año de publicación, las revistas, las áreas temáticas, los diferentes autores, la institución, el país de afiliación de los autores y las palabras clave. Los distintos indicadores de la producción científica utilizados fueron el recuento de documentos para evaluar la productividad de autores, instituciones y países; y el recuento del número de citas, el índice H y el factor de impacto SCImago Journal Rank (SJR) para el impacto de los trabajos. Los hallazgos más destacados fueron los siguientes: El número de artículos publicados se ha incrementado, pasando de 13 en 1969 a 303 en 2018. Esta variable presenta una tendencia de crecimiento exponencial, acentuada a partir de 1998, fecha a partir de la cual se publica el 85% del total de los artículos analizados. El número medio de referencias por artículo ha pasado de 8,50 a 36,82. El número de citas experimentó un crecimiento exponencial, pasando de 7 en 1970 (año con el primer dato disponible) a 9839 en 2018. El número promedio anual de citas por artículo aumentó de 0,37 en 1970 a 16,81 en 2018. El número de revistas donde se publicaron artículos sobre papaya aumentó desde las 10 de 1969 hasta las 223 de 2018. El autor que más ha publicado es Messias Gonzaga Pereira, afiliado a la `Universidade Estadual do Norte Fluminense de Brazil´, que acumula un total de 72 artículos. Pereira tiene un índice H en los artículos de la muestra de 12, un total de 457 citas obtenidas durante el período de estudio y un promedio de 6,35 citas por artículo. En segundo lugar, se encuentra Ray Ming de la `University of Illinois at Urbana-Champaign´, estadounidense. Este autor tiene un total de 48 artículos sobre papaya, acumulando la mayor cantidad de citas del grupo de autores más prolíficos con un total de 2444, un número promedio de citas por artículo de 50,92 y un índice H de 21. En tercer lugar, se sitúa Paul Hutton Moore con 37 artículos. Moore tiene el mayor índice H junto con Gonsalves (22) y acumula un total de 2131 citas, y un promedio de 57,59 citas por artículo. Dennis Gonsalves, que ocupa la quinta posición con 32 artículos (empatado con David J. Buttle), tiene el mayor número promedio de citas por artículo que es de 73,09. Peng Zhou (en novena posición), de la `Chinesse Academy of Tropical Agricultural Sciences´ es el autor que se ha incorporado a esta línea de investigación más recientemente y, en un período de 10 años, ha conseguido situarse dentro del ranking de los autores más prolíficos en la publicación sobre papaya con un total de 27 artículos. Las revistas más productivas en la publicación sobre papaya son estadounidenses o europeas. Dentro de las 20 mejores, sólo encontramos dos revistas de India (en duodécima y decimoctava posición) y una de Brasil (en cuarta posición), siendo los dos primeros países en producción de papaya. Analizando los países más prolíficos en la publicación sobre papaya durante el período de 1969-2018, en primer lugar, se encuentra India con un total de 867 artículos. Este país ha acumulado 7958 citas, tiene un promedio de 9,18 citas por artículo y un índice H de 41. La India tiene el menor promedio de citas por artículo. El segundo país con mayor número de artículos es Estados Unidos con un total de 841. Este país acumula el mayor número de citas de todo el grupo con un total de 23904. Tiene un promedio de 28,42 citas por artículo y el mayor índice H que es de 71. Estados Unidos ha sido el país dominante en la investigación sobre papaya desde el inicio del período de estudio, pero en la última década ha sido superado no sólo por India, sino también por Brasil. Brasil se sitúa en tercer lugar en cuanto a número de artículos en el período completo con un total de 805. Brasil tiene el segundo mayor número de citas con un total de 8348, un promedio de 10,37 citas por artículo y un índice H de 42. Ya con menor número de artículos, a estos tres países les siguen China con 345, México con 254, y Malaysia con 249. Reino Unido, que ocupa la novena posición con 203 artículos, es el país con el mayor número de citas por artículo con 30,45. Le sigue Alemania con 29,13 y los Estados Unidos con 28,42.

1.1. Objetivos de la investigación

OBJETIVO GENERAL

El objetivo general de esta investigación es el de comprobar la influencia del sexado de forma precoz, antes del trasplante, de *Carica papaya* L. sobre la producción y la calidad de la cosecha, cultivada bajo un invernadero situado en el Sureste Español.

OBJETIVOS ESPECÍFICOS

Los objetivos específicos de este trabajo son los siguientes:

1. Describir el efecto del sexado prematuro y del injerto de *Carica papaya* L. sobre la productividad y la calidad en un cultivo bajo invernadero en Almería.
2. Estudiar la productividad de cinco cultivares de papaya sexados de forma prematura, y cultivados bajo invernadero en ciclo corto. Dentro de los cinco cultivares, estudiar el comportamiento de un cultivar injertado respecto a la planta franca.
   La técnica de injerto, que los viveros en Almería han realizado durante más de 30 años, es una técnica aplicable a la planta de papaya siguiendo el método de empalme como se hace en especies de solanáceas como el tomate y la berenjena. Por lo tanto, se decidió llevar a cabo este tratamiento de la planta de papaya hermafrodita injertada en una planta femenina. En el presente estudio, los objetivos fueron comparar los potenciales agronómicos y comerciales de diferentes cultivares de papaya, trasplantados después de su identificación sexual y cultivados en un invernadero comercial durante un ciclo corto (máximo 18 meses) en el sudeste de España y comercializado bajo las normas europeas. Este ciclo permite cosechar pasando un solo invierno el cultivo, que es una temporada muy desfavorable para la papaya en la región y, además, permite el uso de invernaderos con estructuras más bajas, que son los invernaderos utilizados por la mayoría de los productores de la región.
3. Realizar un estudio comparativo de la rentabilidad del cultivo de papaya en invernadero respecto a otros cultivos hortícolas dentro de las condiciones de cultivo del campo almeriense.
   El objetivo de este estudio fue valorar la calidad de papaya obtenida y realizar una estimación de la rentabilidad del cultivo de esta especie cultivada bajo invernadero en el sureste de España, tras la realización de un estudio de campo. Asimismo, se ofrece una comparación de la rentabilidad obtenida del cultivo de papaya, con una serie de alternativas de cultivos hortícolas que se vienen desarrollando en la provincia desde hace décadas.
4. Comprobar el efecto del uso de un método de protección de la piña de fructificación de la papaya (uso de agrotextiles) sobre la temperatura y la producción, dentro de un invernadero, durante el periodo invernal.

1.2. Materiales y métodos

Se detalla a continuación la metodología empleada para el desarrollo de los estudios y trabajos realizados en el campo.

1.2.1. Ubicación de los ensayos realizados en campo

Los diferentes ensayos tuvieron lugar en la Fundación finca experimental UAL-ANECOOP Centro "Catedrático Eduardo Jesús Fernández Rodríguez" de la Universidad de Almería (36°51′ Latitud Norte 2°17′ Longitud Oeste y altitud de 90 metros sobre el nivel del mar) en Retamar, provincia de Almería (Fig. 1). Los distintos ensayos fueron desarrollados desde la primavera del año 2016 hasta el verano del año 2018.

Figura 1. Vista panorámica de la finca experimental UAL-ANECOOP en Retamar (Almería)

1.2.2. Equipos, infraestructuras y control del ambiente

Para el desarrollo de los ensayos, se utilizaron tres naves de invernadero con las mismas características constructivas, denominadas en la Fundación como naves U3, U4 y U5. Los invernaderos eran de tipo multitúnel, con ventilación pasiva y sin calefacción. Tenían cada uno una superficie de 1800 m^2. Las cumbreras del invernadero estaban orientadas E-O. Contaba con cinco módulos de las siguientes dimensiones: 5,7 m de altura en cumbrera; 4,5 m a las canaletas; 8 m de ancho y 45 m de largo (Fig. 2). La cubierta del invernadero era de polietileno translúcido de baja densidad, tricapa, de 200 micras de espesor y tres años de duración.

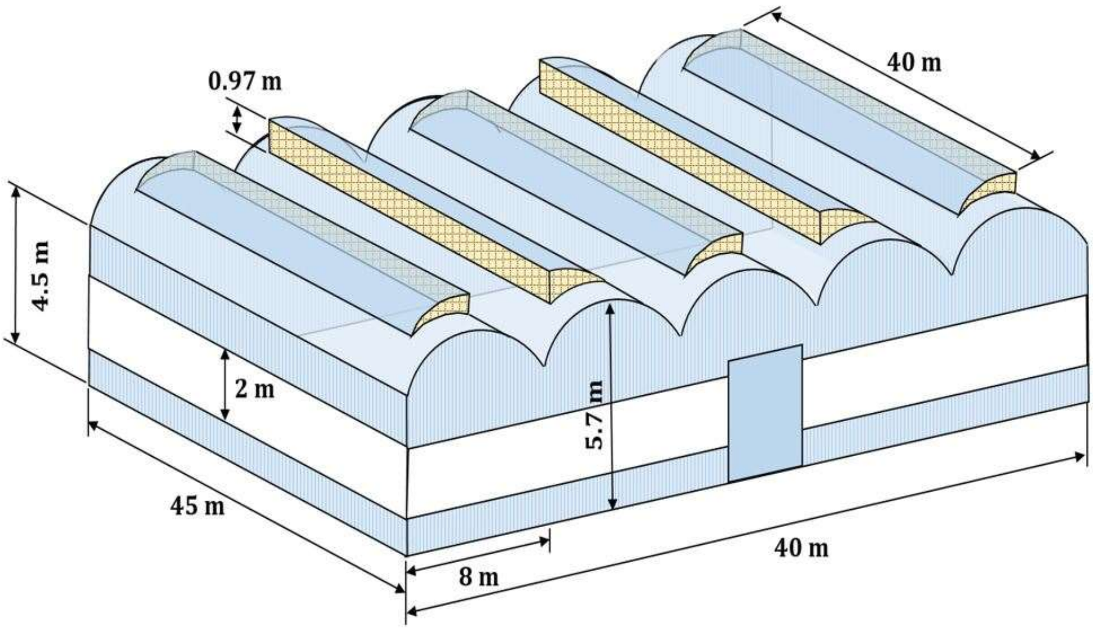

Figura 2. Esquema de uno de los módulos de invernadero del ensayo experimental.

El pasillo central tenía una superficie de 90 m^2. El invernadero tenía aperturas cenitales en cada uno de los cinco módulos, accionadas con motores y sistema de piñón-cremallera, cuya apertura estaba controlada por sensores de temperatura.

En esta parte de la región andaluza, de junio a septiembre, los vientos predominantes soplan de Este a Oeste, son cálidos. El primer año, para evitar la disminución brusca de la humedad relativa dentro del invernadero, se colocaron láminas de polietileno blanco/negro sobre el suelo (acolchado), en líneas alternas, para crear pequeños embalses de agua y aprovechar la evaporación de la misma. Incluso en esas fechas se incorporaba al pasillo centro del invernadero agua por nebulización (Fig. 3). A partir del otoño, las entrelíneas no acolchadas se acolcharon con plástico negro (Fig. 4). El acolchado en otoño/invierno de toda la superficie de suelo, se hizo como estrategia para disminuir la humedad relativa del ambiente reduciendo la probabilidad de aparición de enfermedades fúngicas y bacterias.

Figura 3. Plantación de papaya del ensayo experimental dentro del invernadero U3 con nebulización en el pasillo central (23 de agosto de 2017), 518 DDT (*).

(*) DDT, días después de trasplante

Figura 4. Colocación de plástico acolchado blanco y negro para controlar la humedad relativa ambiental. (a) embalses artificiales de agua colocados durante la primavera y el verano (b) plástico negro colocado durante el invierno

Durante el período de invierno, el invernadero se mantenía con las bandas laterales protegidas con plástico. A mediados de mayo, se realizaba labor para quitar la protección de plástico de parte de la banda Norte y Sur (Fig. 5).

Figura 5. Vista lateral de los invernaderos U3 y U4 en la finca experimental UAL-ANECOOP, con parte de las bandas sin protección y ventanas cenitales abiertas, 590 DDT.

Para el control ambiental dentro del invernadero, se disponía de una sonda Elektronik - EE210 que registraba la temperatura y la humedad en los rangos [-15°C; +40°C] y [0-100%] respectivamente. Dada la sensibilidad del cultivo al frío, cabe señalar que los meses de noviembre a febrero, fueron los meses en los cuales las temperaturas mínimas dentro del invernadero fueron las más bajas. Se registró la temperatura mínima absoluta de 4,7ºC en enero de 2017 y de 3,6ºC en diciembre de 2017.

A lo largo de los ciclos de cultivo, la protección fitosanitaria se realizó utilizando técnicas de control integrado. Durante el invierno, las lesiones en las cicatrices de los peciolos, en algunos casos colonizadas por *Botrytis cinerea* pudiendo llegar hasta causar la pudrición del vástago, fueron controladas con la aplicación de arcillas naturales. Se observaron también leves ataques de *Oidio caricae* al final del invierno y principio de primavera, que no tuvieron incidencia sobre el desarrollo de la plantación ni de la producción, controlándolo con aplicaciones de azufre coloidal pulverizándolo sobre la planta. Respecto a plagas, los ataques de araña roja (*Tetranichus urticae*) fueron controlados con sueltas de *Phytoseiulus persimilis* y *Amblyseius californicus,* además de la aparición ocasional de *Stethorus punctillum.* Los ataques de pulgones (*Aphis gossypii*) fueron controlados con la utilización de plantas banker de cebada infectadas con *Rhopalosiphum padi*, pulgón específico del cereal. Sobre ellas se realizaban las sueltas de *Lysiflebus testaceipes* y *Aphidius colemani* para la multiplicación de estos insectos auxiliares.

1.2.3. Suelo y fertirrigación

El suelo estaba protegido con el sistema arenado, típico de la región, descrito por Camacho y Fernández (Camacho Ferre y Fernández Rodríguez, 2000). Los cultivos precedentes en este suelo fueron las hortalizas (tomate, pimiento, calabacín y pepino) durante trece años.

Se analizó el suelo antes de cada experimento para comprobar los índices de fertilidad y su textura.

Antes de la puesta del cultivo, se realizó en el suelo arenado una labor de retranqueo, incorporando al mismo los elementos necesarios, según análisis mencionado, para que todos sus parámetros quedasen en condiciones normales de fertilidad. Se incorporaron 10 $kg \cdot m^{-2}$ de estiércol semihecho. Todos los macro y micronutrientes estaban en valores aceptables. El suelo tenía una textura franco-arcillosa con 0,45% de materia orgánica y valores de pH y conductividad eléctrica (CE), en el extracto de saturación, de 7,80 y 4,65 $dS \cdot m^{-1}$ respectivamente.

La nutrición de las plantas se hizo a través de riego localizado de alta frecuencia (riego por goteo), con emisores de descarga de 3 $L \cdot h^{-1}$ y una densidad de 1,6 goteros/m^2. Cada línea de plantas tenía dos líneas portagoteros de polietileno de baja densidad de diámetro 16 mm, con los emisores a una distancia de 37 cm entre ellos.

El control para la incorporación de agua con los elementos nutritivos al suelo se hizo con tensiómetros, iniciando el riego cuando los mismos marcaban 20 cbar hasta que bajaban a 10 cbar (primavera-verano), siendo los valores en otoño-invierno 35 a 18 cbar respectivamente. El fertilizante empleado fue realizado *ad hoc* para el cultivo. Se le denominó UNIQUA TROP® y tenía las siguientes características (% p/p): Nitrógeno nítrico (N) 2,9; Pentóxido de fósforo (P_2O_5) 1,3; Óxido de potasio (K_2O) soluble en agua; 5,7; Óxido de calcio (CaO) soluble en agua 2,2; Óxido de magnesio (MgO) soluble en agua 0,5; Microelementos: Hierro (Fe) quelatado con ácido etilendiamino-N- (2 hidroxifenilacético)- (EDDHA), Zinc (Zn) ácido etilendiaminotetraacético (EDTA); Manganeso (Mn) EDTA. Solución libre de cloruros < 0,3 % de Cloro.

Una semana después del trasplante, se inició la nutrición elevando la conductividad eléctrica (CE) del agua de riego en 0,5 $dS \cdot m^{-1}$, para de modo progresivo llegar a 2 $dS \cdot m^{-1}$ en el invierno, máxima CE aplicada desde la primera cosecha hasta el final del ensayo. El agua empleada tenía una CE de 1,4 $dS \cdot m^{-1}$ y un pH de 7,13. Los nutrientes disueltos en el agua de riego se incorporaron para obtener las siguientes concentraciones máximas en la solución: NO^{3-}: 16 $mmol \cdot L^{-1}$; H_2PO^{4-}: 1,4 $mmol \cdot L^{-1}$; SO_4 $^{2-}$: 1,7 $mmol \cdot L^{-1}$; HCO^{3-}: 0,5 $mmol \cdot L^{-1}$; K+: 8 $mmol \cdot L^{-1}$; Ca^{2+}: 6 $mmol \cdot L^{-1}$; Mg^{2+}: 2 $mmol \cdot L^{-1}$. EL fertilizante realizado *ad hoc*, "Uniqua Trop®" de Megasa, tenía la composición mencionada en el párrafo anterior y se añadió una mezcla de microelementos con 7,5 % de Fe, más Mn, Cu, Zn, B y Mo, a un ritmo de 20 $g \cdot m^{-3}$ de agua de riego utilizada.

1.2.4. Preparación del material vegetal

En los invernaderos multitúnel, se plantaron distintos cultivares de papaya, todos híbridos (Fig. 6). En la nave U3, para el ensayo se trasplantaron plántulas de forma tradicional con tres plantas por golpe y plántulas hermafroditas sexadas de forma precoz con marcadores moleculares (Chaves-Bedoya et al., 2009). En los ensayos realizados en las naves U4 y U5, se utilizaron únicamente variedades de papaya hermafroditas sexadas de forma precoz. Se preparó el material vegetal en el semillero, dónde se realizó el sexado precoz. Allí se prepararon los dos formatos de plantas utilizadas (cepellones de 133 cm^3 y 2000 cm^3). Se prepararon también plantas injertadas sobre el portainjerto de una planta femenina y el cultivar a ensayar hermafrodita, con el objetivo de obtener datos de desarrollo, producción y calidad de la fruta obtenida de este tipo de plantas. En todos los ensayos, la densidad fue de 2700 plantas/ha.

Figura 6. Detalle de las operaciones de trasplante en el invernadero U4 (marzo 2016). a) Disposición de las plantas según el replanteo, b) formación del hoyo con ahoyadora, c) incorporación de fibra de coco en el fondo del hoyo, d) separación del contenedor del cepellón, e) comprobación de la sanidad de las raíces, f) trasplante, g) incorporación de fibra de coco para completar los huecos que quedaban entre cepellón y hoyo, h) presión para facilitar el contacto de las raíces con el suelo, i) colocación de suelo y arena

Las plantas con un cepellón de 133 cm^3 tenían aproximadamente una altura de 20 cm, mientras que las del cepellón de 2000 cm^3 tenían una altura de 60 cm (Fig. 7).

Figura 7. (a) Plántulas de *Carica papaya* L. con cepellón de 133 cm^3 preparadas para trasplante, (b) Plantas de papaya sexadas, hermafroditas con cepellón de 2000 cm^3.

En función de la fecha de trasplante para cada ensayo realizado, el semillero efectuó la siembra en una fecha determinada obteniendo plantas con relación adecuada entre altura de la misma y volumen de cepellón. Los trasplantes dentro de los invernaderos U3 y U4 se realizaron en marzo de 2016. El trasplante del invernadero U5 se realizó en mayo de 2018. Los ciclos de producción en los invernaderos U3 y U4 fueron de dos campañas, mientras que el que se desarrolló en el invernadero U5 fue de una campaña (ciclo corto). Se eligieron variedades de porte y vigor medio y/o por su tolerancia al frío, para comprobar su desarrollo bajo invernadero.

En cada experimento, la disposición de las plantas se hizo de tal forma que los tratamientos y variedades fuesen repartidos al azar dentro de cada invernadero, excepto en la nave U4 que tenía plantas del mismo tipo (plantas hermafroditas). Para cada tratamiento (T_i) correspondían 3 repeticiones (R_i). Un bloque (T_iR_i) correspondía a una fila de árboles. Las características de las variedades testadas en los experimentos se indican en la tabla 1.

Tabla 1. Descripción de los cultivares de papaya empleados en los experimentos

Cultivar (Comercializador)	**Peso del fruto (g)**	**Calibre según la norma de la FAO[a]**	**Características comerciales**	**Potencial de producción en (t/ha)**	**SST[b] Dulzor medido en °Brix**
\`Intenzza´ (Semillas del Caribe)	1500-2200	I, J	Desarrollado para mercados de papaya de tamaño mediano o tipo \`Formosa´. El amarillo brillante de su piel resalta en los anaqueles resultando atractiva para el consumidor. Pulpa roja en estado de maduración. Alta uniformidad en tamaño y forma lo que facilita el empaque de la fruta en cajas	100-150	10-13
\`Sweet Sense´ (Semillas del Caribe)	1200-1800	H, I	En su punto de maduración ideal, su exterior es amarillo, con un extraordinario color salmón en su interior. Papaya clasificada tipo \`Baby´	100-130	10-13
\`Vitale´ (Semillero Vitalplant)	>1000	G, H, I, J	Planta de vigor medio y porte abierto	- (c)	- (c)
\`Caballero´ (CapGenSeeds)	650-900	E, F, G	Variedad híbrida de papaya adaptada a invernadero. Porte muy bajo (enano), lo cual la hace idónea para estructuras con poca altura (invernaderos bajos). Presenta una vegetación media-baja, lo que le permite aumentar en un 10% la densidad de plantación. Frutos muy homogéneos en forma	- (c)	14-15
\`Alicia´ (CapGenSeeds)	750-1100	F, G	Variedad de papaya adaptada a invernadero. Porte muy bajo y de vegetación normal, con entrenudos cortos. Buena tolerancia al frío. Permite recolectar la fruta con un estado de madurez avanzado.	- (c)	- (c)

[a]Food and Agriculture Organization of the United Nations (FAO)
[b]Sólidos solubles totales (SST)
[c]Información no facilitada por el comercializador

1.2.5. Procedimientos de muestreos y estudio de parámetros botánicos o biológicos

Durante los diferentes ensayos se han realizado las mediciones de varios parámetros botánicos y biológicos sobre la plantación y los frutos. En cada ensayo, a partir de la primera cosecha, se realizó la pesada de todos los frutos, para todos los tratamientos y todas las repeticiones. Los frutos cosechados fueron pesados con una báscula BBA422-60LA BASIC (Mettler Toledo, L'Hospitalet de Llobregat, España) con una capacidad máxima de 60 kg y 1 g de sensibilidad. Se contabilizaron todas las piezas cosechadas. Las cosechas se han realizado cuando los frutos alcanzaban el estado de maduración definido por Santamaría Basulto et al., (2009). Se recolectaban entre el estado 2 y 3 en función de la estación (cerca del 2 desde la primavera hasta el otoño y más cerca del 3 en invierno). El índice de madurez 2 se corresponde con la epidermis verde y una franja amarilla bien definida (fruta de color amarillo entre el 25 y el 33 %). El índice de madurez 3 se corresponde con una o más franjas de color naranja en la piel (fruta de color amarillo entre el 33 y el 40 %). La figura 8 muestra los índices de maduración óptimos 2 y 3 de la papaya para el cultivar `Intenzza´. La cosecha se realizó una vez a la semana en el invierno y hasta cuatro días a la semana durante la primavera-verano. La fruta cosechada y seleccionada sin defectos comerciales, tal y como se define en la norma de la FAO (Food and Agriculture Organization of the United Nations - FAO, 2011), fue comercializada por la empresa BIOSABOR, S.A.T. El departamento comercial de esta empresa fue dictaminando el proceso de comercialización e indicando en todo momento (cada semana) el índice de maduración que solicitaban los clientes en destino. De este modo, se fueron ajustando los parámetros de cosecha.

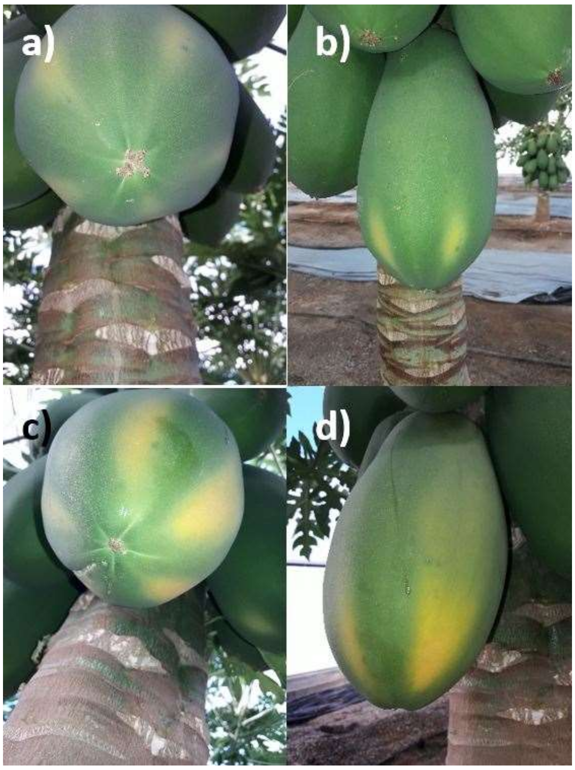

Figura 8. Estado de maduración 2 y 3 en papaya (*Carica papaya* L.) cv. `Intenzza´: a) estado 2, vista transversal de la fruta; b) estado 2, vista longitudinal del fruto; c) estado 3, vista transversal de la fruta; d) estado de maduración 3, vista longitudinal de la fruta.

Con los datos anotados en cada cosecha, se evaluaron el número de frutos por árbol, la producción en kg·m^{-2} y el peso medio de la fruta para cada variedad (Fig. 9).

Mensualmente, se realizaba la medición de los sólidos solubles totales (SST) expresados en °Brix. Se recogía para cada tratamiento y repetición, dos piezas al azar dentro de las filas de árboles durante la cosecha. Y, con al menos un 15% del peso total de la pieza recolectada, cortada longitudinalmente (considerando más del 15 % del peso total de la fruta de papaya), se realizaba la medición (Fig. 10). Se utilizaba una báscula de precisión NewClassic ML6001E (Mettler Toledo, L'Hospitalet de Llobregat, España) para pesar la pieza de papaya utilizada a la que se le determinaban los SST. Tenía una capacidad máxima de 6200 g y una sensibilidad de 0,1 g. Se pelaba el trozo y se descartaban las semillas. Se reducía la pulpa en trocitos rallándola. Con una prensa de ajo, se extrajo el jugo de la pulpa machacada, que pesaba aproximadamente 8 g. Los SST expresados en °Brix se medían con un refractómetro digital Pal-1 (Atago Co., LTD., Tokio, Japón) que tenía un rango de medición de 0 a 53 °Brix y

una sensibilidad de 0,2 °Brix. El instrumento se calibraba con agua destilada. Se hacían tres medidas independientes por fruta, recogiendo en cada momento una nueva parte de la pulpa machacada. Se evaluaron las medias de todas las medidas realizadas y el valor máximo para cada tratamiento.
Además, se tomaron datos morfológicos sobre la planta, específicamente: altura desde el pedúnculo del primer fruto cosechado hasta el suelo, número de nudos (cicatrices foliares) desde el suelo hasta el primer fruto cosechado, y el perímetro del vástago medido a unos 10 cm por encima del suelo. Estos parámetros se midieron durante cada ciclo de producción. Para la obtención de datos morfológicos, se utilizó una cinta métrica de 5m de longitud y graduada en mm. Se midieron estos parámetros en todos los árboles de la plantación.

Figura 9. Operaciones de recuento y evaluación de los datos de producción durante la cosecha. a) medición de la altura de emisión del primer fruto y recuento de los nudos, b) recuento de los frutos, c) d) y e) pesada de los frutos durante la cosecha, f) paletización de la cosecha para su comercialización.

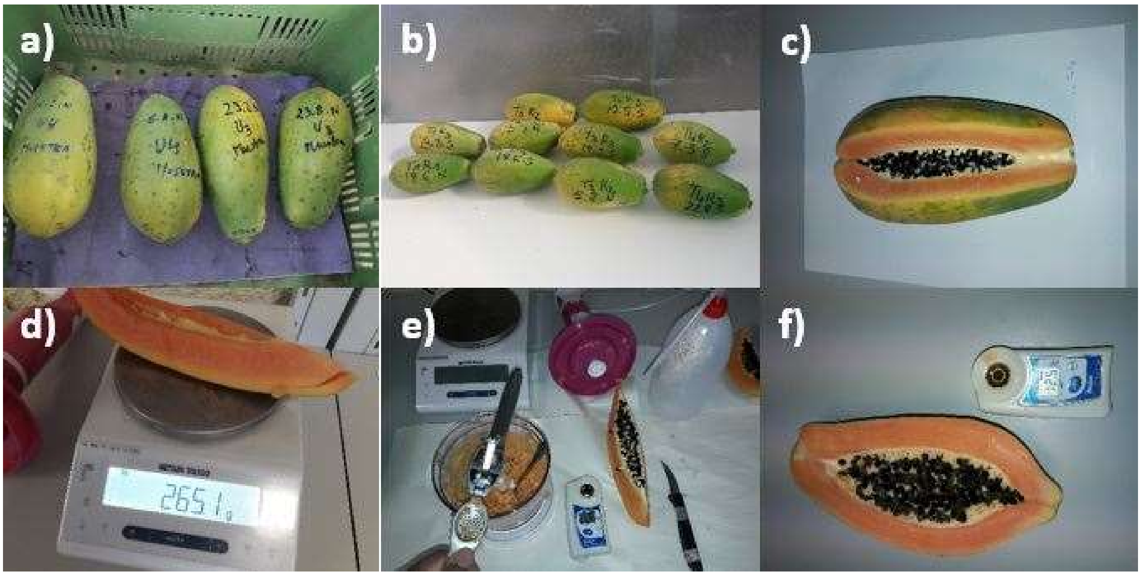

Figura 10. Realización de la medición de los sólidos solubles totales. a) selección de las piezas durante la cosecha. b) disposición de las piezas a evaluar. c) corte longitudinal de la pieza a analizar. d) pesada de las piezas en el laboratorio. e) trituración y extracción del zumo. f) medición de los SST con el refractómetro.

1.2.6. Colocación de agrotextiles sobre los frutos

Durante el invierno, las bajas temperaturas son un factor limitante de la producción en el sur de España. Como medida para proteger la fruta y para comprobar su efectividad sobre la producción y el rendimiento, se ha colocado una manta térmica (agrotextil) alrededor de la fruta, en los vástagos. Cada lado del invernadero tenía 26 filas de plantas, pero el experimento se llevó a cabo en la parte Sur entre la fila 10 y la fila 17 incluida, en una superficie de 229,63 m^2 (Fig. 11). Las mantas estuvieron colocadas sobre 30 árboles en una superficie de 111.11 m^2, desde el 11 de diciembre de 2017 hasta el 19 de abril de 2018, es decir 129 días. Todas las plantas estaban sexadas y el cultivar empleado fue `Intenzza´. La densidad era la misma que en los otros ensayos descritos anteriormente (2700 plantas/ha) y recibieron el mismo cuidado respecto a labores culturales, nutrición, aporte de agua y control climático. Las plantas fueron de cepellón de 2000 cm^3 (ver apartado 1.2.5). Las cosechas se realizaban tal como se describe en el apartado 1.2.5.

La temperatura y la humedad se midieron cerca de la fruta con un registrador de datos resistente a la intemperie HOBO Pro v2 U23-001 (Onset Computer Corporation, Bourne, EE. UU.), con sensores incorporados de temperatura y humedad relativa, con precisión de ±0,21°C (midiendo de 0 a 50°C) para la temperatura relativa, y con precisión de ±2,5% (midiendo de 10% a 90%) para la humedad relativa. En cada fila de árboles sin protección de agrotextil, se colocó un sensor en el quinto árbol de la fila a una altura de 1,5 m sobre el suelo. En la fila de árboles con el agrotextil, se colocaron dos sensores a 1,5 m sobre suelo. Uno de ellos fue colocado dentro del agrotextil, y el otro fue colocado afuera, protegido por una caja abierta para evitar el registro de la radiación solar directa (Ver Fig. 11). Los datos se registraban cada minuto por los sensores.

Figura 11. Fotos del ensayo con agrotextiles. a) Visión panorámica de las filas 10 a 17 de los árboles de papaya con o sin el agrotextil en el ensayo experimental, 288 DDT, b) Visión de la fila 14 del ensayo con agrotextiles puestos alrededor de los vástagos de *Carica papaya* L. *cv*. `Intenzza´, c) Detalle de los sensores Hobo Pro v2 instalados dentro y fuera del agrotextil en una caja de protección contra la radiación solar, de "tipo abierto", d) Visión de la fila 15 con árboles sin agrotextil, y sensor Hobo Pro v2 (d).

1.2.7. Cálculos y datos económicos de los cultivos

Para poder realizar el estudio comparativo de la rentabilidad del cultivo de papaya bajo invernadero, respecto a otros cultivos hortícolas dentro de las condiciones del campo almeriense, se han utilizado los resultados de la comercialización del invernadero U4. La comparación económica se realizó en virtud de los principios de maximización de los beneficios por parte de los agricultores. Por lo tanto, para evaluar la oportunidad de las alternativas de cultivos alternativos, el beneficio neto antes de impuestos (NPbt) se ha utilizado para cada posible combinación de cultivos (Colla et al., 2017; Garcia et al., 2019; Testa et al., 2014). NPbt se calculó como una desviación entre los ingresos anuales totales de ventas (TAR) y los costos totales (TC) incurridos en cada campaña:

$$NPbt = TAR - TC \tag{1}$$

siendo NPbt: el beneficio neto antes de impuestos (€); TAR: los ingresos Anuales Totales (€); TC: los costos totales (€). La estructura de ingresos y gastos que se siguió para llevar a cabo esta investigación fue la que se empleó para la parcela experimental (invernadero U4) dentro de la Finca experimental UAL-ANECOOP Centro “Catedrático Eduardo Jesús Fernández Rodríguez” de la Universidad de Almería, que es donde se llevó a cabo el experimento. Además, se siguió la estructura de costes proporcionada por (Toresano Sánchez y Camacho Ferre, 2012) para Agroseguros, S.A.-España, cuyos datos no han sido publicados y que corresponden a la Prestación de Servicios PS20120000000000184 de la Oficina de Transferencia de Resultados de Investigación (OTRI) de la Universidad de la Universidad de Almería.

Para comparar los cultivos, se tomaron como referencia cinco alternativas de cultivo diferentes, obtenidas con las especies con los que se trabaja en el modelo agrícola almeriense (cuatro cucurbitáceas, tres solanáceas y una leguminosa). En este sentido, se desarrolló un cultivo diferente después de cada ciclo de producción o campaña agrícola, excepto en el caso del tomate de ciclo largo. Las primeras cuatro alternativas se componen de cultivos desarrollados en ciclos cortos de seis meses (es decir dos cosechas por año). Para la quinta alternativa se ha contemplado el inicio del ciclo de cultivo con un cultivo de calabacín (un ciclo corto de 6 meses), al cual le suceden dos cosechas de tomate, en ciclo largo (12 meses), hasta completar un período total de 30 meses.

Estos cultivos alternativos son habituales en el modelo de agricultura intensiva del sureste español (Valera Martínez et al., 2016). Las alternativas hortícolas estudiadas para la comparación económica con el nuevo cultivo de papaya fueron las siguientes:

Alternativa 1: sandía (2016) +tomate (2016) + calabacín (2017) + pimiento (2017) + sandía (2018).
Alternativa 2: tomate (2016) + pepino (2016) +berenjena (2017)+judía verde (2017)+melón (2018).
Alternativa 3: melón (2016) + pimiento (2016) + sandía (2017) + tomate (2017) + melón (2018).
Alternativa 4: calabacín (2016)+berenjena (2016)+melón (2017) + pimiento (2017) + sandía (2018).
Alternativa 5: Calabacín (2016) + tomate (2016-2017) + tomate (2017-2018).

Las características técnicas de las infraestructuras productivas, para obtener datos económicos con respecto al coste de inversión y sus correspondientes depreciaciones, son las siguientes:

El cultivo de papaya se ha desarrollado bajo un invernadero multitúnel como se ha descrito anteriormente en el apartado “1.2.2. Equipos, infraestructuras y control del ambiente”.

Las hortícolas de ciclo largo se han cultivado bajo un invernadero tipo Almería tipo "raspa y amagado" con 6,00 m de altura a cumbrera, 5,00 m de altura bajo canal (amagado) y 4,70 m de altura en bandas (Valera Martínez et al., 2016).

Las hortícolas de ciclo corto se han cultivado bajo invernadero tipo Almería tipo "raspa y amagado", con 4,50 m de altura a cumbrera; 3,50 m de altura bajo canal (amagado) y 3,00 m de altura en bandas. Estas dimensiones son las del "invernadero de moda" obtenido por Valera et. al. (Valera Martínez et al., 2016).

El resto de las infraestructuras de producción, el control del clima y el sistema de riego fueron las mismas en los diferentes casos analizados. Los costos de energía en el cultivo de papaya y en las alternativas hortícolas fueron los mismos en este estudio. Los invernaderos tenían ventilación natural pasiva sin ningún sistema de calefacción.

Por su parte, el importe de los ingresos totales del cultivo de papaya se obtuvo del valor real en euros de la producción que se vendió durante el ensayo de campo correspondiente en el invernadero U4 desde 2016 a 2018 (tal y como se comentó en el apartado 1.2.5.). En el caso de las alternativas hortícolas (Alternativa 1 a Alternativa 5), el valor de los ingresos totales se calculó multiplicando el rendimiento medio (kg·m^{-2}) de cada cultivo por el precio medio de campaña correspondiente (€/kg) (Tabla 2).

Tabla 2. Superficie, producción y precio medio de las hortícolas de 2016 a 2018

Cultivo	**2016**			**2017**			**2018**		
	superficie (ha)	**Producción (t)**	**(€·kg^{-1})**	**superficie (ha)**	**Producción (t)**	**(€·kg^{-1})**	**superficie (ha)**	**Producción (t)**	**(€·kg^{-1})**
Sandía	8590	532288	0.318	8940	558223	0.327	9860	512742	0.407
Melón	2467	96417	0.470	2220	93527	0.448	2290	91656	0.535
Calabacín	7630	434195	0.489	7970	448975	0.681	7860	456045	0.555
Pepino	5026	438870	0.418	4980	422214	0.640	5099	443604	0.501
Berenjena	2300	184161	0.371	2150	168046	0.728	2209	181130	0.513
Tomate	10940	1107706	0.527	10220	1008867	0.714	10380	996254	0.621
Pimiento	9491	665922	0.824	10310	694402	0.908	10181	732989	0.755
Judía verde	1340	26453	1.455	1030	21001	1.747	510	10224	1.584

*Elaboración propia con datos del Gobierno de la Junta de Andalucía (Junta de Andalucía-Consejería de Agricultura Pesca y Desarrollo Rural., s. f.; Toresano Sánchez y Camacho Ferre, 2012)

En cuanto a los gastos corrientes, se consideró que el asesoramiento técnico era el mismo para los ocho cultivos estudiados. La preparación del suelo se ha modulado en función de la duración del ciclo del cultivo en cuestión (6, 12 o 30 meses). La cubierta y la estructura dependían del tipo de invernadero utilizado. Las medidas de la cubierta de plástico y los costes laborales para sustituirla dependían también de las dimensiones y de la estructura del invernadero. Para las semillas y la producción de las plántulas, los datos fueron obtenidos en función de los costes para cada año.

En el caso del agua, de los fertilizantes, de los productos fitosanitarios, de los costos de mano de obra, de los tutores, de los insectos auxiliares y de la gestión de los residuos generados durante el cultivo, se siguieron las directrices marcadas individualmente para cada cultivo y ciclo por Toresano y Camacho (Toresano Sánchez y Camacho Ferre, 2012). Se tuvo en cuenta el peso de la mano de obra en función del porcentaje que ésta representa sobre el volumen de gasto corriente de los distintos cultivos (Tabla 3).

Tabla 3. Porcentaje económico del peso de la mano de obra sobre los gastos corrientes de los cultivos hortícolas que se producen en el sureste de España (Toresano Sánchez y Camacho Ferre, 2012)

Cultivo	Tomate	Pimiento	Pepino	Berenjena	Calabacín	Judía verde	Melón	Sandía
Porcentaje	52,66	47,32	45,40	52,07	86,44	42,00	22,33	21,19

1.2.8. Estadísticas y métodos de cálculos

Para la evaluación del rendimiento, el peso medio de la fruta y el número de frutos por planta, se analizaron los datos para cada tratamiento con el peso y el recuento de todos los frutos cosechados de todos los árboles. En los que respecta a los datos morfológicos, se analizaron los datos medidos en todos los árboles de cada tratamiento. Los sólidos solubles totales (SST) expresados en ºBrix, se midieron mensualmente. Fueron evaluados mensualmente a partir del primer mes de recolección, y durante todo el ciclo de producción. Para el ciclo largo de dos campañas, la evaluación se hizo durante seis meses la primera campaña, y durante nueve meses para la segunda campaña. La evaluación de las medias de los valores recolectados y anotados, para cada tratamiento de papaya (T_i) se realizó mediante un análisis de la varianza (ANOVA). Los datos fueron sometidos a análisis de varianza (ANOVA), considerando un dato significativo si el *p* valor fuese inferior a 0,05. Las diferencias entre los valores medios de cada tratamiento se compararon utilizando la Diferencia Mínima Significativa de Fisher (LSD), utilizando el software de análisis de datos STATGRAPHICS® Centurion XVIII Versión 18.1.06 (64 bits) (Statpoint Technologies, Warrenton, Estados Unidos de América, Inc. (1982–2018).

1.3. Resultados y discusión

1.3.1. Efectos del tamaño de las plántulas de papaya con determinación precoz del sexo sobre el rendimiento y la calidad en un cultivo bajo invernadero en Europa Continental (Artículo 1. Effects of the size of papaya (*Carica papaya* L.) seedling with early determination of sex on the yield and the quality in a greenhouse cultivation in continental Europe)

Existieron diferencias significativas entre tratamientos. La planta sexada aumentó la producción total, incluso cuando se injertó sobre su propio pie. La planta injertada (con cepellón de 2000 cm^3) produjo significativamente más que la planta sin injertar y de mismo tamaño de cepellón. La cosecha de la primera campaña fue determinante para la cosecha global. Considerando el tipo de cultivar, *Carica papaya* L. cv. \`Sweet Sense´ produjo más que *Carica papaya* L. cv. \`Intenzza´ en cualquiera de las formas plantadas. Los resultados obtenidos en este experimento, rendimientos desde 262,8 a 325,2 $t \cdot ha^{-1}$, fueron superiores a los obtenidos en diferentes ensayos en Costa Rica por Guzmán Díaz, (1998); Jiménez Díaz, (2002), por Escamilla García et al., (2003) en México, por Bhalerao y Patel, (2015); Jeyakumar et al., (2010); Singh et al., (2010) en India o por Migliaccio et al., (2010) en Florida.

Para todos los tratamientos y, analizando las dos campañas de producción consecutivas, se obtuvo la fruta con mayor peso en el segundo ciclo de producción. Estos datos coinciden con los obtenidos por Pérez Hernández, (2016), donde los frutos cosechados en el segundo ciclo pesaban más que los obtenidos en el primer ciclo en un experimento realizado con diez variedades diferentes. El peso medio de los frutos de las plantas injertadas fue mayor que en plantas sin injertar. Otros autores como Lima et al., (2018) observaron que los parámetros de longitud y diámetro del fruto son mayores, ensayando con el cultivar

`Tainung Nº1’ injertado frente a otros cultivares testigo sin injertar. El peso medio del fruto es un parámetro de importancia en la producción, tanto por su influencia en el rendimiento, como por la demanda que exigen los mercados de frutos de determinado tamaño. El tamaño de la pieza es fundamental para el marketing, la gestión comercial, la logística, la distribución y el empaque.

Respecto al número de frutos durante el primer ciclo, las plantas sexadas tuvieron un mayor número de frutos de forma significativa, respecto a las plantas sin sexar. En todos los tratamientos, en el segundo ciclo, el número de frutos por planta fue menor respecto al primer ciclo. Carica papaya L. cv. `Sweet Sense´ produjo más frutos que `Intenzza´. Se formaron dos bloques con diferencias significativas respecto al cultivar. Existe una relación entre tamaño de fruto y número de frutos por planta, observándose en los diferentes cultivares el marcado poder genético sobre el tamaño y el peso. Las plantas injertadas produjeron más frutos por árbol respecto a las plantas sin injertar de mismo tamaño en los dos ciclos.

Respecto a los SST, teniendo en cuenta las dos campañas, las plantas de cepellón de 133 cm^3 junto con las plantas injertadas (de cepellón de 2000 cm^3) dieron los frutos menos dulces. Las plantas sexadas y de cepellón de 2000 cm^3, de los cultivares `Intenzza´ y `Sweet Sense´ han producido los frutos más dulces. Los frutos procedentes de la planta injertada de `Intenzza´ fueron menos dulces que los procedentes de planta de `Intenzza´ franca, en las dos campañas. Probablemente este aspecto fuera debido a la mayor carga de frutos, significativamente más alta, para las plantas injertadas respecto a los otros tratamientos, y a la mayor competencia que estas plantas tuvieron respecto a las demás por el espacio durante el cultivo. En todos los casos y para todos los formatos de plantas del experimento, pudo llevarse a cabo la venta de los frutos de papaya en diversos países europeos. La fruta procedente de los ensayos fue puesta en el mercado a través de una Sociedad mercantil de comercialización que opera en la región, especialista en la introducción de nuevos frutos en los mercados europeos.

Las plantas con cepellón de 2000 cm^3 con equilibrio entre la biomasa aérea y las raíces, tuvieron tendencia a dar los frutos más bajos y en un nudo más cercano al suelo. Fueron más precoces con respecto a la fecha de plantación. Los datos obtenidos, en cuanto a la altura del primer fruto, son coincidentes con los que exponen Alonso Esquivel et al., (2008); De Lima et al., (2010); Escamilla García et al., (2003); Pérez Hernández, (2016). Las plantas injertadas fueron las que obtuvieron los frutos más bajos de forma significativa respecto a todos los otros formatos.

1.3.2. La producción y calidad de distintas variedades de papaya cultivadas bajo invernadero en un ciclo corto en Europa Continental. (Artículo 2. The production and quality of different varieties of papaya grown under greenhouse in short cycle in Continental Europe)

Respecto al rendimiento para este ciclo corto, existieron diferencias significativas entre los tratamientos. *Carica papaya* L. cv. `Intenzza´ injertada fue el cultivar más productivo con una producción de 14,20 $kg{\cdot}m^{-2}$. `Sweet Sense´ y `Alicia´ conformaron otro bloque estadístico con 12,58 y 12,38 $kg{\cdot}m^{-2}$ respectivamente. El resto de los cultivares `Caballero´, `Intenzza´ y `Vitale´ fueron sensiblemente menores en el rendimiento, con 11,02; 9,59 y 4,82 $kg{\cdot}m^{-2}$ respectivamente. Las plantas injertadas produjeron más que las plantas francas. Pecanha et al., (2010) observaron que las plantas injertadas respecto a plantas sin injertar mantenían un alto intercambio de gases y eficiencia fotoquímica en las hojas y en consecuencia una mayor ganancia de carbono. El sistema foliar del injerto optimizaría la circulación de los asimilados durante la fotosíntesis.

Para el peso medio del fruto, los frutos procedentes de *Carica papaya* L. cv. `Vitale´ fueron los más pesados con un valor de 1,405 kg. Les siguieron los frutos del cultivar `Intenzza´

con 1,279 kg. Ambos valores los clasifica el CODEX 183-93, norma de calidad de la Papaya (FAO, 2011) como papaya de calibre H (1104-1500 g). El resto de los frutos procedentes de los demás cultivares, estaban clasificados como papaya de calibre G (801-1100 g).

Respecto al número de frutos cosechados por árbol, hubo diferencias significativas en este parámetro para la mayoría de los tratamientos. \`Sweet Sense´ e \`Intenzza´ injertada sobre su propio pie femenino, fueron las plantas con un mayor número de frutos producidos, con 43,67 y 42,43 frutos por árbol. \`Caballero´ y \`Alicia´ estuvieron en el mismo grupo produciendo respectivamente 40,20 y 39,65 frutos por árbol. \`Vitale´ es el cultivar que menos produjo con 11,97 frutos por árbol y con una productividad muy baja (4,82 $kg{\cdot}m^{-2}$).

La evaluación de los SST (expresados en °Brix) se hizo para la media, para los valores máximos y los valores mínimos. En las tres valoraciones que se hicieron, hubo diferencias significativas entre tratamientos. \`Vitale´ e \`Intenzza´ injertada forman el grupo de los cultivares con los frutos que tuvieron el valor más alto de °Brix. Los frutos procedentes de \`Alicia´ e \`Intenzza´ son los que obtuvieron los valores menores de SST. Lo mismo sucede cuando se analizan las medias de las máximas y de las mínimas. Los valores mínimos medios obtenidos están entre 9,59 y 8,76°Brix. Los valores medios tuvieron valores de entre 9,14 y 10,00°Brix. Se pudo observar un aumento de los SST en la medición que se realizaba a los 10 días en los frutos seleccionados para la medición inicial. El valor ascendía a un 10,33% más, considerando los valores máximos absolutos. Todas las medidas que se hacían a posteriori, y medidas sobre el mismo fruto conservado a 15°C, daban como resultado un valor superior a los anteriores. Esta observación es muy interesante para los frutos comercializados durante el invierno y presentados en los estantes de los minoristas. Los frutos de *Carica papaya* L. son climatéricos. Su maduración evoluciona y el valor gustativo aumenta inexorablemente cuando el cliente final de la cadena comercializadora lo compra en la sección de la frutería. Los valores obtenidos en SST para frutos procedentes del cultivar \`Intenzza´ injertado, son mayores que para los obtenidos de \`Intenzza´ franca y significativamente diferente en el primer ciclo, lo que no ocurría en el experimento de ciclo largo (apartado 1.3.1). Este fenómeno controvertido podría probablemente ser explicado por las mayores temperaturas registradas durante el ensayo en el invernadero que albergó el experimento de ciclo corto con respecto al de ciclo largo. Cabrera et al. (2019) observaron que mayores temperaturas provocan un registro de SST más alto respecto a otras plantas testigo cultivadas en temperaturas más frescas.

Existen diferencias significativas entre tratamientos, para la altura a la cual se cosecha el primer fruto. Por orden creciente, los cultivares cuya altura del fruto cosechado es menor son \`Intenzza´ injertada, \`Vitale´, \`Intenzza´, \`Sweet Sense´, \`Alicia´ y \`Caballero´.

Respecto al perímetro del vástago, existieron diferencias significativas entre tratamientos. Los cultivares \`Caballero´ y \`Alicia´ tenían la mayor longitud del perímetro; 46,57 y 46,53 cm respectivamente. Los otros cultivares \`Sweet Sense, Intenzza injertada, Intenzza y Vitale) por orden decreciente, tenían los perímetros de 44,17; 40,78; 37,65 y 36,68 cm respectivamente.

Los datos del número de entrenudos confirman que los cultivares \`Caballero´ y \`Alicia´ son más vigorosos, tal como indicaba su ficha técnica. Se observó que la planta injertada de \`Intenzza´ tenía los entrenudos más cortos que en su versión sin injertar. Además, la altura del primer fruto para los árboles injertados fue menor que para los árboles sin injertar par el cultivar \`Intenzza´. Los ensayos de De Lima et al., (2010); Lima et al., (2018); Senthilkumar et al., (2014) confirman este hecho. Los injertos de papaya florecen antes, emiten el primer fruto a una altura más baja respecto a plantas sin injertar, y entran en producción precozmente.

1.3.3. Análisis del beneficio del cultivo de papaya bajo invernadero como alternativa a la horticultura intensiva tradicional en el sureste español. (Artículo 3. Profit analysis of papaya crops under greenhouses as an alternative to traditional intensive horticulture in Southeast Spain)

Cuatro de las cinco combinaciones de cultivos hortícolas estudiadas arrojaron pérdidas en el periodo analizado (febrero 2016 a julio 2018). Sólo la combinación denominada "Alternativa 5" y el cultivo de papaya presentaron beneficios con +32.896 y +57.535 euros por hectárea respectivamente. Dentro del modelo intensivo de producción hortícola, se explica que el sector hortícola esté declarando unas cuentas de resultados positivos por la renuncia de los costes de mano de obra de la familia y/o del propietario que participan en las labores agrícolas (Valera Martínez et al., 2016). Los costes de amortización de las instalaciones productivas (invernadero, sistema riego y balsas), que son los más importantes dentro de los costes fijos son menores para los agricultores que ya han pagado el coste de la inversión. Para los otros, teniendo en cuenta que la superficie media de las explotaciones es superior a la de nuestro estudio es difícil imaginar una agricultura rentable. El horizonte no es prometedor para los agricultores que se encuentran en dificultad para recuperar el coste de las inversiones.

Teniendo en cuenta el escenario del cultivo de la papaya del experimento llevado a cabo, es importante señalar que el agricultor que se interesa por esta alternativa deberá de tener suficiente liquidez hasta los once meses después del inicio del cultivo. En el ensayo, fue a partir de este periodo cuando se observó una recuperación de parte de la inversión con los ingresos obtenidos por la venta de la papaya.

1.3.4. Efecto sobre la temperatura de una cubierta ligera de agrotextil que envuelve la fruta de Carica papaya en un invernadero mediterráneo de ventilación pasiva. (Artículo 4. Effect on temperature of lightweight plant cover enveloping papaya fruit (Carica papaya L.) in a naturally ventilated Mediterranean greenhouse)

Las temperaturas del aire se incrementaron (con diferencia estadística significativa) alrededor del vástago de la papaya envuelta con agrotextil ligero, alrededor de 1 y 0,7ºC para la temperatura mínima y la temperatura media respectivamente. La temperatura de aumento pareció haber inducido una precocidad en la producción. El aumento de las temperaturas pudo haber provocado el incremento de las unidades de calor en la fruta observándose un adelanto de la producción, aunque no un aumento del rendimiento. Cabrera et al. (2019) describieron este fenómeno en un ensayo realizado con papayas del cultivar `Sweet Mary´ en las Islas Canarias. Observaron que los sólidos solubles totales eran más altos en las frutas que recibieron mayor cantidad de calor por esta sometidas a temperaturas más altas.

Aunque no se haya observado una diferencia significativa, el rendimiento de los árboles de *Carica papaya* L. cv. `Intenzza´ envueltos con el agrotextil fue mayor que para los que estuvieron sin él. El rendimiento durante el experimento fue respectivamente de 4,3 $kg{\cdot}m^{-2}$ y 3,5 $kg{\cdot}m^{-2}$ en cada caso. No hubo diferencia significativa en el número de frutos por árbol en ambos casos.

Colocar un agrotextil envolviendo los frutos, durante el invierno para las papayas de ciclo de otoño, podría ser un método económico para inducir la precocidad y mejorar la calidad de la fruta. Sería interesante comprobar en una unidad experimental de mayor superficie, con más plantas y, con varios cultivares en la provincia de Almería, si la cubierta tiene realmente un impacto positivo sobre la precocidad y la calidad de la fruta. El ensayo se realizaría en un ciclo largo (dos campañas) de cultivo comercial con la colocación del agrotextil sobre los frutos ya cuajados y formados.

1.4. Conclusiones

De los resultados obtenidos en los trabajos expuestos analizando cultivos de papaya bajo invernadero en el Sureste de España se han obtenido las siguientes conclusiones:

1. En el *cv.* \`Intenzza´, las plantas hermafroditas sexadas de forma precoz mediante marcadores moleculares obtuvieron una producción estadísticamente superior a las trasplantadas de forma tradicional, incluso cuando se injertaron sobre su propio pie femenino.
2. Los rendimientos obtenidos en un ciclo largo (dos campañas agrícolas) fueron de 262,8 a 325,2 $t{\cdot}ha^{-1}$.
3. En el *cv.* \`Intenzza´, el injerto de plantas hermafroditas sobre plantas femeninas obtuvo rendimientos de 321,2 $t{\cdot}ha^{-1}$, valores similares a los obtenidos en el *cv.* \`Sweet Sense´ franco sexado precozmente (325,2 $t{\cdot}ha^{-1}$).
4. Las plantas trasplantadas con mayor tamaño de cepellón (2000 cm^3), emitieron los primeros frutos en nudos más cercanos al suelo siendo su producción más precoz.
5. El análisis económico realizado sobre el cultivo de papaya bajo invernadero en las condiciones del ensayo demostró su viabilidad, pudiendo ser alternativa a diferentes rotaciones de cultivos que se hacen en dos campañas agrícolas.
6. En las condiciones de producción experimentadas el productor que decida cultivar papaya, debe tener liquidez en los primeros once meses de cultivo, a partir de los cuales se recupera parte de la inversión a través de los ingresos obtenidos por la venta de la cosecha.
7. En un ciclo corto, el *cv.* \`Intenzza´ injertado, obtuvo una producción de 142,0 $t{\cdot}ha^{-1}$, cifra superior a la obtenida del mismo *cv.* franco y también superior a los otros cuatro *cv.* empleado en el ensayo (\`Sweet Sense´, \`Vitale´, \`Caballero´ y \`Alicia´). Esa forma de cultivo dio los frutos con el contenido en solidos solubles totales más alto.
8. \`Intenzza´ injertada fue la forma de cultivo más precoz.
9. La protección de las piñas de fruto de papaya utilizando agrotextiles en finales de otoño-invierno, elevó de modo significativo las temperaturas mínimas y medias de 1 y 0,7ºC, respectivamente, induciendo precocidad en la cosecha.

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1.6. Publicaciones

Efectos del tamaño de las plántulas de papaya con determinación precoz del sexo sobre el rendimiento y la calidad en un cultivo bajo invernadero en Europa Continental

(Artículo 1. Effects of the size of papaya (*Carica papaya* L.) seedling with early determination of sex on the yield and the quality in a greenhouse cultivation in continental Europe)

ARTÍCULO 1

Autores: **M.N. Honoré, L.J. Belmonte-Ureña, A. Navarro-Velasco, F. Camacho-Ferre**

Effects of the size of papaya (*Carica papaya* L.) seedling with early determination of sex on the yield and the quality in a greenhouse cultivation in continental Europe

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Effects of the size of papaya (*Carica papaya* L.) seedling with early determination of sex on the yield and the quality in a greenhouse cultivation in continental Europe

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A R T I C L E I N F O

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A B S T R A C T

One of the major problems when planting papaya using traditional methods is sex identification of the plant to obtain the highest yield from hermaphrodite fruits. The problem derives from the competence between plants, before sex identification, when three to four plants are planted together. This problem was solved applying a R.A.P.D. technique (Randomly Amplified Polymorphic DNA) in early sex-identification in the laboratory of the nursery with the first true leaf of the plant. Furthermore, economic costs and wasted vegetal material caused by removing female plants from production can be avoided by grafting hermaphrodite plants onto female plants. The nursery facilities for horticultural plants in Almería allow herbaceous grafting work, as well as the production of balanced relationship between aerial and root biomass. For this reason, an experiment was conducted to evaluate yield parameters in the planting of large and small, sex-identified plants. The plants grown were the main papaya cultivar produced in Continental Europe, called 'Intenzza', and a new cultivar called 'Sweet Sense'. Within a greenhouse cultivation system in the South of Europe, the early stage sex-identified plants transplanted as "large plant" size gave higher yields in contrast with traditional methods of planting papaya, but the technique does not affect fruit size and retains sweetness. From a morphological point of view, although the growing and development technique is different it does not cause significant differences in the papaya by the time of harvest.

1. Introduction

Papaya (*Carica papaya* L) comes from the South of Mexico and Nicaragua (Chan and Paull, 2008) and is a widely produced crop in the tropics. Until very recently, the cultivation of this plant was carried out in tropical or subtropical regions where the possibility of frost was very scarce.

Papaya cultivation is economically important. In 2016, papaya was grown on land of 451181 ha worldwide. The top five producing countries were: India with 5699000 t, Brazil with 1424650 t, Mexico with 951922 t, Indonesia with 904284 t and Nigeria with 836702 t. The yields in kilos per unit of area varied greatly depending on the producing countries, from 9.06 $kg{\cdot}m^{-2}$ in Indonesia to 0.85 $kg{\cdot}m^{-2}$ in Nigeria. Mexico, India and Brazil produced between 4.28 and 5.69 $kg{\cdot}m^{-2}$ (FAO, 2018).

The largest papaya importers in Europe are United Kingdom, Holland and Germany who purchase fruit from Brazil 33,200 t, Ecuador 3800 t, Ghana 1250 t and Jamaica 914 t (EC, 2015).

In Europe, important figures related with papaya consumption are being consolidated due to its nutritional properties. Papaya is a rich source of antioxidant nutrients, B vitamins, potassium and magnesium, which are elements that prevent and improve digestive system disorders and heart diseases (Karunamoorthi et al., 2014). Nowadays, papaya is the third most consumed tropical fruit, after mango and pineapple (FAO, 2018). Increased consumption by European populations provides large opportunities to increase the range of fruit and vegetable products grown in Europe. The proximity of consumer markets to southeast Spain allows fruits to be harvested at a more advanced stage of maturity compared to exporting countries from outside Europe, a timeline which improves the taste of the papaya.

The Canary Islands is Europe's largest papaya producer with cultivation on 350 ha (Pérez Hernández, 2016). This cultivation area is expanding while the area used for growing tomatoes is contracting. Papaya can be grown in Continental Europe. In 2012, cultivation first

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began in the province of Almería, with 6000 m^2. The production obtained was marketed locally as "papaya of Almería". Early on, studies took place to understand the adaptation of this crop to the greenhouse production system used in southeast Spain, as well as understand different cultivation practices which could improve yield.

Sex-determination in papaya plants is an intriguing system (Chaves-Bedoya et al., 2009). Scientific articles on this topic date from 1938 (Hofmeyr, 1938), quoted by Saalau-Rojas et al., 2009). At the end of the last century, after failed attempts to study sex identification, molecular research began to produce positive results for identification markers. Deputy et al. (2002) research from Hawaii stands out because they described the way to determine the sex of papaya seedlings in laboratory, a procedure subsequently replicated in Asia and America. This method, with minor modifications, is used in the development of the sex-identification techniques, and some experiments are made to determine the cheapest way to extract DNA from samples of papaya seedling. A major problem when cultivating papaya are the measures needed to obtain a hermaphrodite plant. If planting sex-unidentified plants, three to four plants have to be planted together in order to make the probability of growing a hermaphrodite plant higher than 90 %. Once the hermaphrodite plant is identified, it is kept until it finishes its vegetative cycle, and then the remaining two to three plants that are not hermaphrodite are removed (Saalau-Rojas et al., 2009; Mora and Bogantes-Arias, 2004).

The identification technique using molecular markers has been carried out for more than 15 years in different places worldwide and produces excellent results (Sondur et al., 1996; Deputy et al., 2002; Ming et al., 2007; Hsu et al., 2012; Tsai et al., 2016). This method, however, makes the price of sex-identified plants high, so many researchers and producers of papaya question the development of this technique at business level. Nevertheless, currently all commercial plantations of papaya in Continental Europe are sex-identified at early stage using molecular techniques.

In 2004, a research group from the Molecular Genetics Laboratory in the Biotechnology and Bioindustry Centre of Colombia decided to use molecular techniques for early sex-identification of the papaya plants for two reasons. First, because in Colombia the cultivation of papaya is economically important, and second, because the plant has a small genome. By 2008, they could make an early sex-identification when the plant was in a cotyledon state or in first true leaf. Although, using molecular markers, this technique had the capacity for the design of large scale production. The research group concluded that the papaya genotypes changed from one region to other because of the environmental interaction (Chaves-Bedoya et al., 2009). In 2009, the Biotechnology Laboratory of plants of the University of Costa Rica, carried out sex-identification with molecular techniques using the Pococí cultivar on a sample of 1500 plants. The results obtained had 98 % certainty, with 46 % of hermaphrodite plants and 54 % of female plants (Saalau-Rojas et al., 2009).

In order to simplify the agronomic handling of cultivation and improve yield, Vitalplant Nursery and the AGR-200 "Plant Production in Mediterranean Crop Systems" Research Group of the University of Almería, after four years of experiments, examined the combination of the application of molecular techniques to identify the sex of papaya plants in the early stages of growth together with herbaceous grafting techniques on a large-scale, pioneered by nurseries of Almeria in Europe almost 30 years ago. They found that the better adaptation of cropping cycles saved time, space and costs. Furthermore, when the sex of the plant is identified before the plant is transplanted in the field, there is an improvement of the production of fruits and the crop yield. In addition, inputs such as fertilizers and water are saved.

Considering the observations on commercial yields of papayas grown in the region of Níjar-Almería, we concluded that there was a variable effect of the entry into production of the plant, depending on the size (growth and development) in the transplant.

All the aforementioned information led Vitalplant Nursery to

Picture 1. Plastic mulch films filled with water, between the rows of the papaya trees to take advantage of water evaporation. 49 days after transplanting.

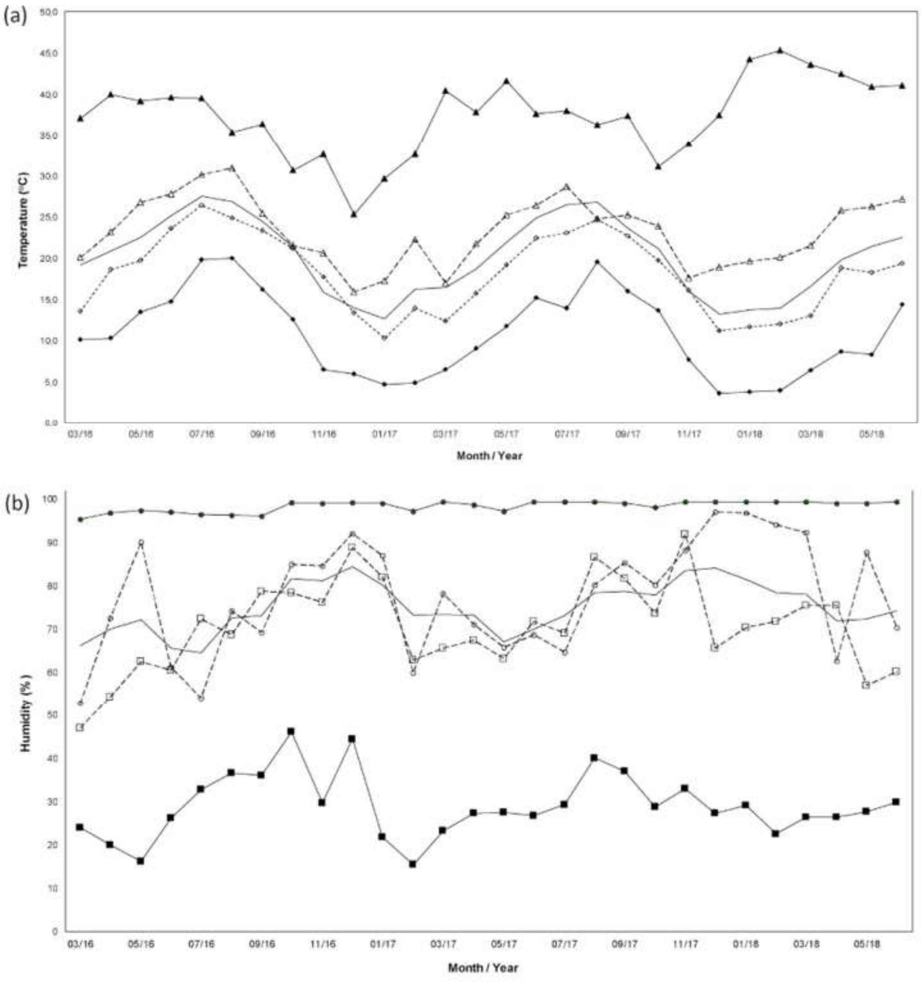

Fig. 1. Air temperature and humidity levels during the growing season of the Papaya trees inside the greenhouse during the experiment, Almeria (36°51′47.927″N, - 2°17′2.391″W); being Minimum temperature (-♦-); Medium temperature (—); Maximum temperature (-▲-); Maximum of minimum temperature (--□--); Minimum of maximum temperature (--Δ--); Minimum humidity (-■-); Medium humidity (-♦-); Maximum humidity (-■-); Maximum of minimum humidity (--□--); Minimum of maximum humidity (--○--).

incorporate 15 ha of sex-identified papaya plants at business level, which were transplanted in Almería, Málaga and Murcia from March to May 2016.

Into the collaboration between "Vitalplant Nursery" and the AGR-200 Research Group of the University of Almería, the aim of the current study was to investigate the effects of different transplanting systems (plant size, sex-identification and grafting) of papaya crop on the yield and on harvest quality in a naturally ventilated greenhouse.

2. Materials and methods

2.1. Experimental greenhouse and equipment

The experiment was conducted in an experimental plot called "Catedrático Eduardo Fernández", which belongs to the Foundation of the University of Almería-Anecoop, and is located in a place called "Los Goterones" in Almería, 36° 51′ North latitude and 2° 17′ West Longitude, at 90 m above sea level.

The plants were transplanted in a multi span tunnel type greenhouse with an area of 1800 m^2, a gutter height of 4.50 m and a ridge height of 5.70 m. The ridges of the greenhouse were East-West oriented. It had five tunnels 8 m wide by 45 m long. The covering was made of three layers of plastic film (low-density polyethylene, 200 microns thick). The greenhouse had five zenithal roof vents, which were opened by engines and a rack and pinion mechanism and controlled by humidity and temperature sensors. The control of temperature and humidity were measured at a height of 4 m, using the Elektronik - EE210 sensor with measuring range -15 °C to + 40 °C and relative humidity ≤100 %. Due to the climatology of the region, from June to September three continuous side vents were opened and the East oriented side vents was closed. Wind is warm in this orientation and such that there is an excessive decrease in the relative humidity inside the greenhouse. To avoid this decrease of the relative humidity, white plastic mulch film was placed on the soil, in alternate lines, forming small reservoirs which were filled with water to produce evaporation (Picture 1). In winter, this mulch film was not filled with water and the alternate lines were mulched with black plastic film because covering the whole soil surface decreases relative humidity and avoids some fungal diseases. The infrastructures were used as has been previously stated. The temperature and relative humidity in the environment throughout the whole cultivation period were: absolute maximum temperature 45.3 °C, mean maximum temperature 37.4 °C; absolute minimum temperature 3.6 °C, mean minimum temperature 10.8 °C; mean temperature was 20.2 °C. With respect to relative humidity, the mean was 75.0 %, and recorded an absolute maximum of 99.4 % and a minimum absolute of 15.5 % (Fig. 1).

The soil used was enhanced to place its quantitative parameters of nutrients and organic matter within the range of fertile soils. Specifically, in that soil which was covered with sand, the sand was removed and 10 $kg{\cdot}m^{-2}$ of fresh manure was added before covering over with sand. The macro and micronutrients were at acceptable values. The soil was protected with sand covering, which is typical in this region, as described by Camacho Ferre and Fernández Rodríguez (2000). Tomato, pepper, courgette and cucumber have been grown in this soil for thirteen years.

Irrigation was carried out through a localized irrigation system of high frequency (drip irrigation) using discharge emitters with a flow rate of 3 $L·h^{-1}$, with a density of 1.6 emitter/m^2. Irrigation control was made with tensiometers. Irrigation was carried out from the end of March to the beginning of November, with a range of 20-10 cbar, and the rest of months with a range of 35-18 cbar. Fertilisers was applied throughout the irrigation water.

2.2. Plant material, sowing and planting

The vegetal material used was 'Intenzza' and 'Sweet Sense' papaya seeds, both cultivar (*cv*) belonging to the "Semillas del Caribe" company. These specific *cv* were chosen because they are cultivars trending and are in the top of the most planted cultivars grown under greenhouse in Continental Europe. Meanwhile, different comparative experiments are being conducted to find a papaya fruit with a smaller size and good adaptation to climate and soils in southeast Spain. To conduct the experiment in the field, the plant material was prepared in the nursery. The "Vital Plant" nursery prepared the different plants, described as following. All the plants of each treatment (T), prepared in the nursery, were transplanted in the experimental greenhouse, at the same time.

T0- *C. papaya* cv. 'Intenzza' with a root ball of 133 cm^3 and an approximate plant height of 20 cm. Three plants were planted together in the field. When the plants flowered, two plants were removed and only one plant was left (so far, the farmers used to do it in that way). The sowing date was 11th January 2016. The sex-identification in field was made between 67 and 75 days after transplanting (DAT).

T1 – *C. papaya* cv. 'Intenzza' with early sex-identification, with a root ball size of 133 cm^3 and an approximate plant height of 20 cm. The sowing date was 11th January 2016 and the early sex-identification was made on 1 st February, when the plant was still in the nursery, 19 days after sowing (DAS).

T2 – *C. papaya* cv. 'Intenzza'with a root ball (plantpot) of 2000 cm^3 and an approximate plant height of 60 cm. The sowing date was 10th October 2015 and the early sex-identification was made on 20th November 2015 (40 DAS).

T3 - *C. papaya* cv. 'Intenzza' with a root ball (plantpot) of 2000 cm^3 and an approximate plant height of 60 cm. The sowing date was 10th October 2015 and the early sex-identification was made on 20th November 2015 (40 DAS). Grafting was made through "splice grafting" of the hermaphrodite plant on the female plant (both of the same cultivar) on 15th December 2015 (65 DAS).

T4 – *C. papaya* cv. 'Sweet Sense' with a root ball (planpot) of 2000 cm^3 and an approximate height of 60 cm. The sowing date was 10th October 2015 and the early sex-identification was made on 20th November 2015 (40 DAS) - (Table 1).

The transplant of the treatments was made on March 23rd, 2016. Three replications of the five treatments were made, distributing them at randomised blocks.

Each experimental plot was 110 m^2 and 28 plants were transplanted into each plot (In T0, 84 plants distributed in 28 groups of three plants). The distribution of the treatments plants was made in paired and staggered rows with 2.20 m between paired rows, 1.00 m between lines and 2.00 m between plants. Under these divisions, there was a density of 2700 plants/ha.

The total area of the experiment is 1650 m^2 which are used for growing, the other 150 m^2 of greenhouse are used as corridors and edge effect plants.

2.3. Fertigation and crop protection

The soil had a clay loam texture with 0.45 % of organic matter and pH and electrical conductivity (EC) values, in the saturation extract, of 7.80 and 4.65 dS m^{-1} respectively.

The water used had an EC of 1.4 dS m^{-1} and a pH of 7.13. Nutrients were applied by drip irrigation to obtain the following maximum concentrations in the solution: NO_3–: 16 $mmol·L^{-1}$; H_2PO4–: 1.4 $mmol·L^{-1}$; SO_4^{2-}: 1.7 $mmol·L^{-1}$; HCO_3–: 0.5 $mmol·L^{-1}$; K^+: 8 $mmol·L^{-1}$; Ca^{2+}: 6 $mmol·L^{-1}$; Mg^{2+}: 2 $mmol·L^{-1}$. A fertiliser, "Uniqua Trop®" by Megasa, was specifically made for this purpose with the following composition: NPK + Ca + Mg: 2.9 - 1.3 - 5.7 (2.2 - 0.5).

One week after transplanting, the addition of the fertiliser began. Additionally, the EC of irrigation water increased by 0.5 $dS·m^{-1}$ until it progressively reached 2 $dS·m^{-1}$, the maximum amount reached of EC by addition of nutrients. A mix of microelements were added to this fertiliser with 7.5 % of Fe, with Mn, Cu, Zn, B and Mo, at a rate of 20 $g·m^{-3}$ of irrigation water used. Throughout the crop, two foliar analyses were made, and the parameters that were measured (N, P, K, Ca, Mg, Na, Fe, Mn, B, Cu, Zn, Mo) showed normal results in the petiole of the papaya leaf. This tissue was chosen because the content of minerals is more stable than in the leaf blade. The sufficiency ranges of the nutrients found in this vegetal part are taken from Jones et al. (1991), according to the table shown by Osuna Enciso et al. (2015).

Currently, in southeast Spain, papaya does not display important pathological problems. In the experiment, *Tetranichus urticae* attacks were controlled with *Phytoseiulus persimilis* and *Amblyseius californicus* releases, in addition to the occasional appearance of *Stethorus punctillum*. *Aphis gossypii* attacks were controlled with preventive *Lysiflebus testaceipes* and *Aphidius colemani* releases on cereal banker plants, which were infected by us with a specific aphid, *Rhopalosiphum padi*. In winter, small attacks of *Botrytis cinerea* appeared on the injuries in the stem, which caused the fall or removal of the petioles, and we controlled this with Samurai® - Nutricrop paste (a product made from natural clays that isolates the internal tissues of the plant from the outside environment). At the end of winter, moderate *Oidium caricae* attacks appeared which were controlled by applying Ospo V®- Agrotecnología sulphur (a product made from vegetal extracts, flavonoids, alkaloids, phenols, macro and microelements, polysaccharides and microorganism extracts) and Lareki greens®- Biofungitek, (a product made from potassium carbonate and vegetal extracts).

2.4. Indices maturity stage for harvesting

The fruit harvest was carried out from October 2016 to the beginning of August 2017, and it began 193 DAT (first season). Then, it began at the end of August 2017 until the middle of June 2018 (second season). Within the mentioned periods, the harvest was carried out every week, according to the index maturity stages of Santamaría Basulto et al. (2009) between the index maturity stages 2 and 3. The maturity stage 2 corresponds with green skin with well-defined yellow stripe (yellow colouring fruit between 25–33 %). The maturity stage 3 corresponds with one or more orange coloured stripes in skin (yellow colouring fruit between 33–40 %). In the spring-summer weeks, the harvest was only carried out at maturity stage 2. The harvest was carried out one day per week in winter and until four days per week in spring-summer.

2.5. Methodology for the measurement of fruit quality and the morphological data collection

The parameters assessed were total yield (kg), average fruit weight (AFW), number of fruits per plant and the total soluble solids (TSS). Fruit yield, AFW and the number of fruits per plants were assessed by measuring fruit weight and counting the number of fruits harvested in each harvesting. The fruits harvested were weighted with a BBA422-60LA BASIC (Mettler Toledo, L'Hospitalet de Llobregat, Spain) scale with a maximum capacity of 60 kg and ± 1 g sensitivity.

The TSS expressed as ºBrix, were measured monthly. It was estimated with two fruit from each replication of each treatment, picked at random at the moment of the harvesting. There were three replications for each treatment. A piece of each fruit picked for the TSS determination was cutting lengthwise (considering more than 15 % of the total weight of the papaya fruit). A NewClassic ML6001E (Mettler Toledo, L'Hospitalet de Llobregat, Spain) precision scales was used to weigh the piece of papaya used for the TSS determination. It had a maximum capacity of 6200 g and ± 0.1 g sensitivity. The piece was peeled, and the pulp was mashed (discarding the seeds). With a garlic press, the juice was extracted from the mashed pulp, which weighted approximately 8 g. TSS (ºBrix) was measured with a digital refractometer Pal-1 (Atago Co., LTD., Tokyo, Japan) that had a measuring range from 0 to 53 °Brix and ± 0.2°Brix sensitivity. The instrument was calibrated with distilled water. Three independent measures were made per fruit, picking at each time a new part of the mashed pulp. Means differences and maxima of TSS, for each treatment were assessed.

Additionally, morphological data about the plant was gathered, specifically: height from the peduncle of the first harvested fruit to soil, number of nodes from the soil until to the first harvested fruit, and the perimeter of the stem measured 10 cm above the ground. These parameters were measured on the 37th week of 2016 in the first season, and between the 47th week of 2017 until the 2 st week of 2018 during the second season (Table 2). After the end of the first season, the height from the soil to the peduncle of the first fruit harvested was also measured in the second season, as well as the number of nodes where the fruit was found. The morphological data was taken using a measuring tape with a total length of 5 m and was graduated in mm.

2.6. Statistical analysis

For the assessment of the yield, the average fruit weight and number of fruits per plant, the data were analysed for each treatment with the weight and the count of all the harvested fruits. For the morphological data, the data measured on all the trees of each treatment were analysed. The total soluble solids (TSS) expressed as ºBrix, were measured monthly. It was estimated with two fruit from each replication of each treatment, picked at random at the moment of the harvesting. The TSS were assessed during six months in the first season, and during nine months for the second season. It is detailed in Table 4. We analysed a sample of thirty fruits for each treatment. Mean differences among the different papaya treatments (T) were determined by an analysis of variance (ANOVA). The data was subjected to analysis of variance (ANOVA), considering a significant data if $p \leq 0.05$. Differences between the average values of each treatment were compared using the Fisher's Least Significant Difference (LSD), using the data analysis software STATGRAPHICS® Centurion XVIII Version 18.1.06 (64-bits) (Statpoint Technologies, Warrenton, United States of America, Inc. 1982–2018).

3. Results and discussion

3.1. Yield

The values of the yields for the different treatments are between 12.14 and 17.50 kg·m^{-2} in the first season and between 12.45 and 15.22 kg·m^{-2} in the second season. For all seasons, the total yield is between 26.28 and 32.52 kg·m^{-2} at the end of the experiment (Table 2). In the harvests carried out between the 41 st week in 2016 and the 31 st in 2017 (81 harvests for the first season), there were significant differences between treatments, however, in the harvests carried out between the 35th week in 2017 and the 25th week in 2018 (68 -second season) there were not significant differences (Table 2). In this second season, the harvest did not decrease, which contrasts with the results obtained by different authors that reported lower than 20 – 25 t·ha^{-1} (Saran et al., 2016). In the total harvest obtained throughout its vegetative cycle there are significant differences (Table 3), therefore, it can be deduced that the harvest obtained in the first season determines the total harvest. T3 and T4 are treatments from which more yield was

Table 1
Definition of the treatments (T) of *Carica papaya* L. for the experiment.

Treatments	Plant	Root ball size	Sowing date	Sex-identification date	Grafting date
T0	*C. papaya* cv. 'Intenzza'	133 cm^3	11-01-2016	———	———
T1	*C. papaya* cv. 'Intenzza' early sex identification	133 cm^3	11-01-2016	01-02-2016	———
T2	*C. papaya* cv. 'Intenzza' early sex identification	2 L	10-10-2015	20-11-2015	———
T3	*C. papaya* cv. 'Intenzza' early sex identification and grafting	2 L	10-10-2015	20-11-2015	15-12-2015
T4	*C. papaya* cv. 'Sweet Sense' early sex identification	2 L	10-10-2015	20-11-2015	———

*The different dates in the cultural practices are due to the necessary adjustment to achieve that all the plants come to the transplanting date in optimal conditions (relationship aerial biomass/root biomass).

Table 2
Total yield, average fruit weight, number of fruits per plant, height of the first fruit, number of nodes until the first fruit and stem perimeter for the five treatments of Papaya grown under greenhouse in Almeria.

Harvest 2016–2017 (From week 41 in 2016 to week 31 in 2017) 81 harvests, first harvest season						
Treatments	T0	T1	T2	T3	T4	p-value
Total yield (kg·m^{-2})	12.14 a	14.89 ab	15.18 b	16.91 b	17.50 b	0.0019
Average fruit weight (kg)	0.82 b	0.87 bc	0.91 c	0.88 bc	0.71 a	0.0000
Number of fruits per plant	43.57 a	52.86 ab	55.90 b	63.73 b	87.13 c	0.0000
Height in cm of the first fruit measured in week 37 of 2016	97.60 a	78.20 b	58.70 d	55.40 d	68.80 c	0.0000
Number of nodes until first fruit measured in week 37 of 2016	28.10 b	27.10 b	31.40 c	23.00 a	23.00 a	0.0000
Perimeter of the stem measured in cm. Week 37 of 2016	38.60 a	41.40 ab	42.30 b	43.40 b	43.20 b	0.0298
Harvest 2017–2018 (From week 35 in 2017 to week 25 in 2018) 68 harvests, second harvest season						
Treatments	T0	T1	T2	T3	T4	p-value
Total yield (kg·m^{-2})	14.14 a	13.89 a	12.45 a	15.22 a	15.01 a	**0.1989**
Average fruit weight (kg)	1.14 a	1.16 a	1.13 a	1.15 a	0.92 b	0.0000
Number of fruits per plant	43.18 a	40.72 a	37.95 a	44.28 a	56.45 b	0.0000
Height in cm of the first fruit measured in week 47 of 2017 until week 2 of 2018	246.00 c	236.00 bc	227.70 b	216.60 a	250.00 c	0.0001
Number of nodes until first fruit measured in week 47 of 2017 until week 2 of 2018	86.50 a	87.60 a	100.00 b	91.30 a	101.40 b	0.0000
Perimeter of the stem measured in cm. Week 2 of 2018	56.80 a	58.90 a	56.70 a	56.30 a	53.30 a	**0.0563**

Means followed by different letters are significantly different at the $p < 0.05$ level.

obtained, with 32.12 and 32.52 kg·m^{-2} respectively. T0, T1 and T2 form another statistical group that obtained 26.28, 28.78 and 27.63 kg·m^{-2} respectively. T1 can also form a group with T3 and T4. The sex-identified plant tends to increase total yield, even when it is grafted onto its own rootstock - although of different sex, it shows significant differences. With respect to the different cultivars, in all the methods of planting, the *C. papaya* cv. 'Sweet Sense' produces a higher yield than the *C. papaya* cv. 'Intenzza'.

Throughout the harvest, T0 kept constant, and the treatment was less productive, however, in the case of T2 (large plant) was always higher than T1 (small plant) until the 12th week in 2018, and there were not significant differences in the total yield.

The results obtained in this experiment, yields from 262.8 to 325.2 t·ha^{-1}, are higher than those obtained in studies from Costa Rica by Guzmán Díaz (1998), which varied between 40–70 t·ha^{-1}, and Jiménez Díaz (2002), who obtained 89 t·ha^{-1}, in a three-year cycle. In Mexico, Escamilla García et al. (2003) conducted experiments to study the effects of organic, mineral and foliar fertilisation on the development and yield of *C. papaya* cv. 'Maradol' and obtained 27.94 t·ha^{-1}. In India, Singh, et al. (2010) conducted experiments to assess the effects of micronutrients on growth, yield and quality of papaya, and reported yields between 65–93 t·ha^{-1}. In other experiments in India, Jeyakumar et al. (2010), studying the application of fertigation reported yields between 139.3–184.9 t·ha^{-1}, and Bhalerao and Patel (2015) obtained between 51.83–80.76 t·ha^{-1} in an experiment that assessed the effects of different micronutrients on yield and quality of papaya. Migliaccio et al. (2010) carried out an experiment in Florida (USA) on plant response to evapotranspiration and soil water and obtained yields between 153–192 t·ha^{-1}.

3.2. Average fruit weight (AFW)

Throughout the harvest of the first season, significant differences were observed between the 'Intenzza' and 'Sweet Sense' fruit cultivars. Within the 'Intenzza' fruits, there are also significant differences between the fruits obtained from large sex-identified plants and sex-unidentified plants (Table 2).

In the harvest carried out in the second season, the significant differences were among cultivars, but not among the different cultivation methods (treatments T0, T1, T2 and T3), which included small sex-unidentified plants, small sex-identified plants, large sex-identified plants and grafted plants on the rootstock of the same female cultivar (Table 2). In all the treatments, higher weight fruits were obtained in the second season than in the first season.

These data are consistent with the data obtained by Pérez Hernández (2016), in an experiment conducted with ten different cultivars, where the fruits harvested in the second season weighed more than those obtained in the first season.

The average fruit weight is a significant parameter within production, because of its influence on yield as well as the market demand for fruits with a specific size. According to Codex 183–1993 on papaya quality (FAO, 2011), the average size of papaya fruits of 'Intenzza' cultivars correspond with size code G (from 801 to 1100 g), while the 'Sweet Sense' cultivar mainly corresponds with size code F (from 701 to 800 g), although it can be also G. The major papaya importers in Europe market papaya per units and not by weight (retail sale), therefore, the "Average Fruit Weight" parameter has importance with respect to marketing, distribution and packaging of the fruits. The weight obtained in the fruits has an acceptable demand in the European market and they can be sold in many countries.

3.3. Number of fruits per plant

There were significant differences in fruits per plant in the first season, T4 ('Sweet Sense') showed the highest value with 87.13 fruits per plant. T1, T2 and T3, early sex-identified 'Intenzza' plants did not

Table 3
Total yield, average fruit weight and number of fruits per plant for the five treatments of Papaya grown under greenhouse in Almeria.

Total Harvest 2016–2018. 149 harvests						
Treatments	T0	T1	T2	T3	T4	*p-value*
Total yield (kg·m^{-2})	26.28 a	28.78 ab	27.63 a	32.12 b	32.52 b	0.0025
Average fruit weight (kg)	0.96 b	1.00 b	1.01 b	1.00 b	0.80 a	0.0000
Number of fruits per plant	86.75 a	93.58 a	93.85 a	108.01 b	143.58 c	0.0000

Means followed by different letters are significantly different at the $p < 0.05$ level.

Table 4
Averages of Total soluble solids (TSS) content and maximum values of TSS content, obtained with papaya fruits for each treatment (T) of the experiment considering the first harvest season, the second harvest season and considering all the harvests.

Harvest 2016–2017 (February to July 2017. Weeks 5–29), first harvest season						
Treatments	T0	T1	T2	T3	T4	p-value
AVERAGE Soluble solids º Brix	9.50 a	9.60 a	10.10 b	9.30 a	10.00 b	0.0000
MAX Soluble solids º Brix	9.80 a	9.90 a	10.40 b	9.60 a	10.20 b	0.0001
Harvest 2017–2018 (September 2017 to May 2018. Weeks 38/2017 to 22/2018), second harvest season						
Treatments	T0	T1	T2	T3	T4	p-value
AVERAGE Soluble solids º Brix	9.10 a	9.50 ab	9.90 b	9.60 ab	10.00 b	0.0227
MAX Soluble solids º Brix	9.50 a	9.80 ab	10.30 bc	10.20 bc	10.50 c	0.0034
Total harvest 2016–2018 (February 2017 to May 2018), all the harvests						
Treatments	T0	T1	T2	T3	T4	p-value
AVERAGE Soluble solids º Brix	9.20 a	9.50 a	10.00 b	9.50 a	10.00 b	0.0002
MAX Soluble solids º Brix	9.60 a	9.80 a	10.30 b	9.90 a	10.40 b	0.0000

Means followed by different letters are significantly different at the $p < 0.05$ level.

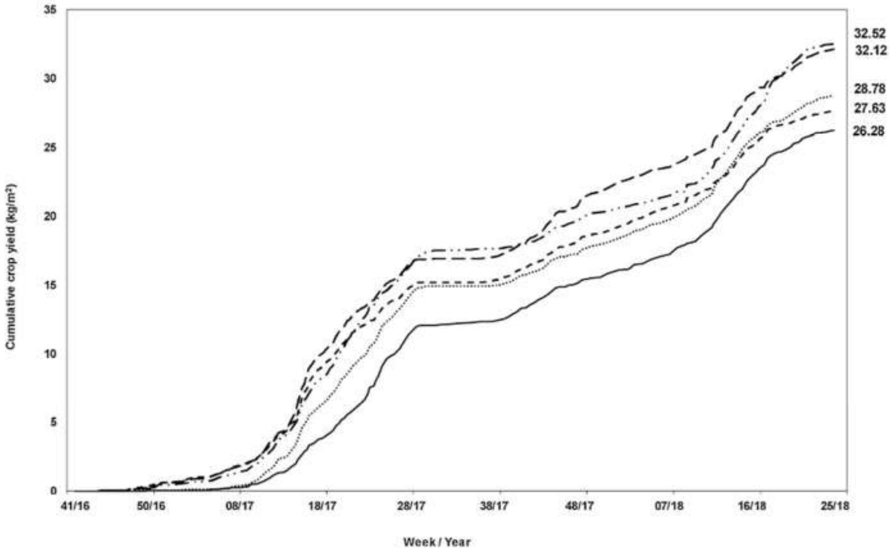

Fig. 2. Cumulative crop yield for the five treatments of Papaya grown under greenhouse in Almeria; T0 *C. papaya* cv. 'Intenzza' with root ball size of 133 cm^3 (—); T1 *C. papaya* cv. 'Intenzza' with early sex-identification and root ball size of 133 cm^3 (······); T2 *C. papaya* cv. 'Intenzza' with early sex-identification and root ball size of 2 L (——); T3 *C. papaya* cv. 'Intenzza' with early sex-identification, grafted and with root ball size of 2 L (– – –); T4 *C. papaya* cv. 'Sweet Sense' with early sex-identification and root ball size of 2 L (–..–..–..–).

show significant differences, although there is a trend of a higher number of fruits in large plants, even grafted on their own female rootstock. T0 can form a group with T1 (both small plants), although they gave the lowest number of fruits in this season. In season 2, two blocks are formed with significant differences according to the cultivar. In all the treatments, the number of fruits is lower in the second season. Throughout the two harvests, there are significant differences, so that 'Intenzza' grafted on its own female rootstock and 'Sweet Sense' gave the highest number of fruits (Table 3). Although the higher number of fruits of 'Sweet Sense' (T4) cultivar were of smaller size, the total yield increased and was equal to grafted 'Intenzza' (T3), as was stated previously in the yield section.

There is a relationship between fruit size and number of fruits per plant. In the different cultivars, the effect of genetic components on fruit size and weight can be observed. The number of fruits obtained in each of the cultivars can be considered as high, hence its repercussion on yield. Comparison with other cultivars, as used in other experiments, would provide nothing to this parameter.

3.4. Total soluble solids

The analysis of total soluble solids was made for the ºBrix average and for the maximum ºBrix in fruits. There were significant differences between treatments in both measurements in the first season. T0, T1 and T3 form the group of fruits with the lowest ºBrix and the fruits coming from T2 and T4 have the highest ºBrix. Once again, in the second season harvest, the fruits coming from T0, T1 and T3 were less sweet and T2 and T4 improved compared with the first season. In the case of maximum ºBrix, T0 and T1 are the lowest.

If we consider the total harvests carried out in the two seasons, T0, T1 and T3 produced the less sweet fruits and T2 and T4 the sweetest fruits (Table 4).

The average minimum values obtained varied from 9.10 to 10.10°Brix. The absolute maximum values had values between 9.50 and 10.50°Brix.

These values were similar to those obtained by Pérez Hernández (2016), for the 'Intenzza' cultivar grown in the Canary Islands although, in this case, Pérez Hernández observed two peaks of 12°Brix. The values are also similar to the results obtained by Santamaría et al. (2015) in Costa Rica. Semillas del Caribe, the company that produces 'Intenzza' claims that the ºBrix are between 10 - 13 Semillas del Caribe (2015a). In the case of 'Sweet Sense', the figures obtained are between 11 and 14°Brix Semillas del Caribe (2015b). The data obtained in the experiment permitted the sale of papaya fruits in different European countries. (Fig. 2)

3.5. Height from the soil and node in which the first flower appears

In the first season there were significant differences with respect to height between the soil and where the first fruit was harvested; T0 is the treatment where the first highest fruit was harvested, followed by T1. These two treatments used smaller plants when transplanting, as previously indicated when the treatments were described. T2, T3 and T4, which used large plants produced its first fruit closer to the soil. Although the same situation happens with the fruit harvested in the second season for Intenzza cultivar, the behaviour of Sweet Sense is different because it had a higher distance between nodes - data that can be observed studying the two parameters, height and number of nodes (Table 2). The transplant made with big plants, and which are in balance between aerial biomass and root biomass, have a trend to give lower fruits located in a node closer to the soil, and have an earlier planting date.

The results obtained with respect to the height of the first fruit, are consistent with those obtained by Pérez Hernández (2016) for 'Intenzza' and those reported by Alonso Esquivel et al. (2008) for two cultivars belonging to the germplasm bank located in the Scientific-Technological Unit (UCTB), based at Jagüey Grande, Matanzas, Cuba. Moreover, the results are 20 cm higher than those obtained by Escamilla García et al. (2003) in Mexico for the *C. papaya* cv. 'Maradol'.

3.6. Perimeter of the stem

During the collection of data in week 37 of 2016, the plants transplanted in small rootballs, T0 and T1, compared to those transplanted in large rootballs (T2, T3 and T4) showed significant differences in the perimeter of the stem. Yet, in the collection of data from week 2 of 2018 there were no significant differences. This perimeter is higher than the perimeter obtained by Alonso Esquivel et al. (2008) in Cuba, although these authors did not state when the measurement is taken with respect to transplanting. In the last measurement taken, the longitudes of the perimeter between 53.30 and 58.90 cm which correspond to a diameter of 16.96 and 18.75 cm, respectively, were enough to support the load of the fruits and the plant was neither bent nor had fallen over at any time.

4. Conclusions

The production obtained using plants whose sex has been identified at early stage, and which have been transplanted with a large rootball, the yield is higher than all the results reported around these parameters in crops from other continents.

The grafting of hermaphrodite plants onto female plants using the Intenzza cultivar is a viable choice, particularly for yield.

The plant sexed early, which is transplanted with a large rootball, gives a higher yield than the plant transplanted with small rootball.

The different treatments used did not have an influence on the average fruit weight, nor on the content of soluble solids.

The perimeter of the stem when the plant was fully developed, and the height with respect to soil of the first fruit harvested, did not show significant differences, however, there were significant differences in the first season in favour of the transplantation of large plants.

CRediT authorship contribution statement

M.N. Honoré: Methodology, Investigation, Writing - original draft, Writing - review & editing. **L.J. Belmonte-Ure□a:** Methodology, Writing - review & editing, Funding acquisition. **A. Navarro-Velasco:** Conceptualization, Resources, Project administration. **F. Camacho-Ferre:** Conceptualization, Methodology, Resources, Writing - original draft, Writing - review & editing, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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La producción y calidad de distintas variedades de papaya cultivadas bajo invernadero en un ciclo corto en Europa Continental.

(Artículo 2. The production and quality of different varieties of papaya grown under greenhouse in short cycle in Continental Europe)

ARTÍCULO 2

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Article

The Production and Quality of Different Varieties of Papaya Grown under Greenhouse in Short Cycle in Continental Europe

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Abstract: In Europe, papaya consumption is growing due to its nutritional properties. The proximity of consumer markets to Southeast Spain allows fruits to be harvested at a more advanced stage of maturity compared to exporting countries from outside Europe, a timeline which improves the quality of the papaya. Experiments have been carried out to assess the adaptation of papaya to protected cropping systems (under greenhouse) in the region. In this paper, we showed the results obtained in an experiment with five varieties, taking the most cultivated variety as control, which was grafted on its own female rootstock, in addition to another four new varieties that were introduced. Transplanting was made with early sex-identified plants in the nursery. Cultivation was developed in a 446-day cycle, almost 15 months and fruits were always harvested from the soil, due to the height that the plant reached in that period. The best yield parameters and fruit characteristics were obtained from hermaphrodite Intenzza papaya grafted on female papaya rootstock, although there were also other varieties which gave results that made possible its cultivation under this production system.

Keywords: cultivars of *Carica papaya*; greenhouse; Continental Europe; grafting; yield; total soluble solids

1. Introduction

In 2017, papaya was grown on land of 449,054 ha worldwide. The top five producing countries that year were: India with 5,940,000 t, Brazil with 1,057,101 t, Mexico with 961,768 t, Indonesia with 875,112 t, and the Dominican Republic with 869,306 t. The yield in kilos per unit of area varied greatly depending on the producing countries, from 28.16 kg·m^{-2} in the Dominican Republic to 3.98 kg·m^{-2} in Brazil. Indonesia, Mexico, and India produced between 9.21 and 4.43 kg·m^{-2} [1].

In Europe, papaya consumption is growing due to its nutritional properties. Nowadays, papaya is the third most consumed tropical fruit in Europe. Papaya fruit is a rich source of antioxidant nutrients, B vitamin, potassium, and magnesium, which are elements that prevent and improve digestive system disorders and heart diseases [2].

Cultivation of papaya under greenhouse in Continental Europe has been demonstrated with different experiments carried out in the southern coast of Spain. The varieties assessed in preliminary studies were BH-65, Red lady, Tainung 1, and Siluet [3–5]. The proximity of consumer markets to Southeast Spain allows fruits to be harvested at a more advanced stage of maturity compared to exporting countries from outside Europe, a timeline which improves the quality and the taste of the papaya, giving sweeter fruits for consumers. In addition, consumers prefer a papaya with a size from 500 to 800 g (size D to F, Codex STAN 183-1991) [6]. The papaya, like Formosa, is also well valued, but the average weight is more common from 801 to 1800 g (between size G and I, Codex STAN 183-1991) [6]. Varieties with small pieces are generally well valued for retail sale. Conversely, for the industry of fourth range products, varieties with a size higher than size F are also well appreciated. During shelf life, fresh-cut papaya goes through a process of degradation. The flesh color and loss of the texture have an impact on the appearance, which are visual factors of quality for the consumer. On the other hand, the color of the skin gives an idea about its stage of maturity [7]. Furthermore, the contents of soluble solids and the shape of fruits are genetic factors which are associated with quality [6,8]. However, before evaluating all those parameters for the fresh market or for the fourth range products in the industry, researchers of the AGR-200 group of the University of Almeria are concentrated on finding some varieties with a similar higher yield production of the first varieties evaluated in the region and which is generally commercialized in Europe. They are focused on the growth of papaya in greenhouse and want to determine the effect of the plants' size on the yield crop. In 2016, they conducted an experiment with sex-identified plants in a greenhouse in Almería, which was sowed with different sizes of rootball. The main cultivars which were evaluated and sowed were hybrids of a very small height and low vegetation which allows increasing the planting density in the greenhouse. Varieties like "Sweet Sense", and "Intenzza" were assessed. On the other hand, the grafting techniques that nurseries in Almería have done for more than 30 years, according to different works made by the AGR-200 research group of the University of Almería, is a technique applicable to the papaya plant following the splice method [9] as it is done in *Solanaceae* species such as tomato and aubergine, therefore, it was decided to conduct this treatment of hermaphrodite papaya plant grafted onto a female plant.

In the present study that was carried out by the AGR-200 group, this time the aims were comparing the agronomic and commercial potentials of different cultivars of papaya, transplanted after their sex-identification and grown in a commercial greenhouse during a short cycle (maximum 18 months) in Southeast Spain and commercialized under European norms. This cycle allows harvesting from the soil, that papaya plants spend only a winter, which is a very unfavourable season for papaya in the region, and in addition to this, it allows using greenhouses with lower structures, which are the greenhouses used by most of the producers in the region.

In high-yielding agriculture of Almería, crops are developed under different greenhouses made of plastic, with different characteristics with respect to areas, heights, and shapes. Plants that have traditionally been grown in these greenhouses are different cultivars of tomato, pepper, aubergine, cucumber, courgette, melon, watermelon, and green bean. Except for tomato and aubergine, the rest of these crops are grown in short cycles, approximately 5–6 months and consequently, two plantations can be done each year. Tomato and aubergine can be grown in short and long cycles. In a long cycle, plantations can last 10–11 months under the greenhouse. In the different papaya experiments that have been carried out in the region, long cycles have been used which leads to keeping papaya plants under cultivation between 22 and 28 months, therefore, the way of harvesting has to be changed because the height that plants reach requires mechanical means to harvest the fruits. This circumstance also requires that cultivation has to be made under high greenhouses (with a minimum distance of 4.5 m to the gutter) and other crops cannot be grown until more than two years have elapsed.

The papaya cultivation is new and reduced in the region and the land. The pathological problems that papaya shows in Southeast Spain are under control.

2. Materials and Methods

2.1. Experimental Greenhouse and Equipment

This study was conducted between April 2017 and July 2018, in a 1800 m^2 multi-tunnel greenhouse in the experimental farm UAL-ANECOOP Center "Catedrático Eduardo Jesús Fernández Rodríguez" of the University of Almería (36°51′ North latitude, 2°17′ West Longitude and altitude of 93 metres above sea level) in Retamar (Almería). The ridges of the greenhouse were east-west oriented. It had

5 modules of the following dimensions: 5.7 m in ridge height, 4.5 m in gutters, 8 m wide, and 45 m long (Figure 1). The crops rows were aligned north to south.

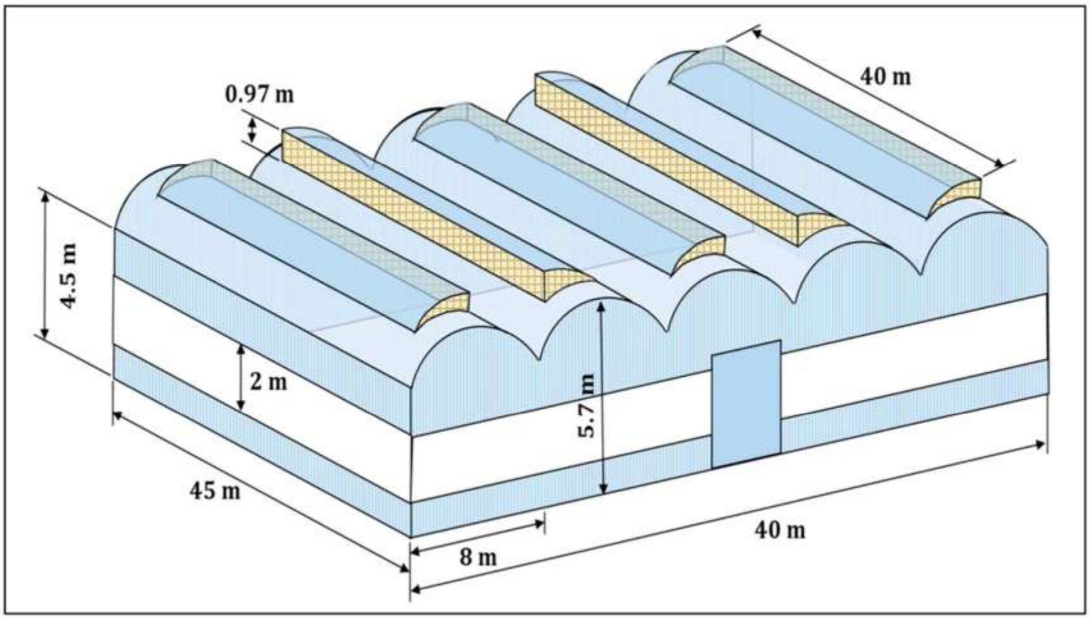

Figure 1. Outline of the experimental trial greenhouse located in the Southeast Spain.

Most of the greenhouse farmers have the Almería-type "raspa y amagado" greenhouse, the most common in the area, with a maximum height of 4 m [10]. To reproduce the dimension conditions in this particular type of greenhouse for the present study, the monitoring of the crop was carried out only during a short production cycle in a multi-tunnel type greenhouse.

The covering of the greenhouse was made of a three-layer thermal plastic of 200 microns thick, low density polyethylene film (LDPE). The greenhouse had zenithal windows vents in the five modules, which worked with engines and a rack and pinion mechanism, whose opening was controlled by temperature and wind sensors. In this part of the Andalusian region from June to September, the prevailing winds blow from the east to west, and it is a hot wind. To avoid the decrease of the relative humidity inside the greenhouse, white plastic mulch film was placed on the soil, in alternate lines, forming small reservoirs which were filled with water to produce evaporation. In winter, this much film was not filled with water and the alternate lines were mulched with black plastic film. This method avoided some fungal diseases as covering the whole soil surface decreased relative humidity. During the winter period, the greenhouse was maintained with the side walls closed. In mid-May, the side walls were opened.

2.2. Climatic Conditions

The temperature and humidity were measured at 4 m above the ground with the Elektronik E+E210 sensor, with a temperature range of (−20 °C to +80 °C) and a humidity range of (0%–100%). With the ventilation conditions stated as previously, the temperature and humidity were the following. During the experiment, the coldest month was December 2017 with the average minimum temperature of 14.9 °C and the coldest day being 3.8 °C. July 2017 was the hottest month with the average maximum temperature of 28.4 °C and the hottest day being 42.3 °C. With respect to relative humidity, November 2017 was the month with the highest average humidity of 81.7% and recorded an absolute maximum of 98.4%. The lowest average humidity was 60.3% in May 2017 and in February 2018 was recorded the minimum absolute humidity of 18.9% (Figure 2).

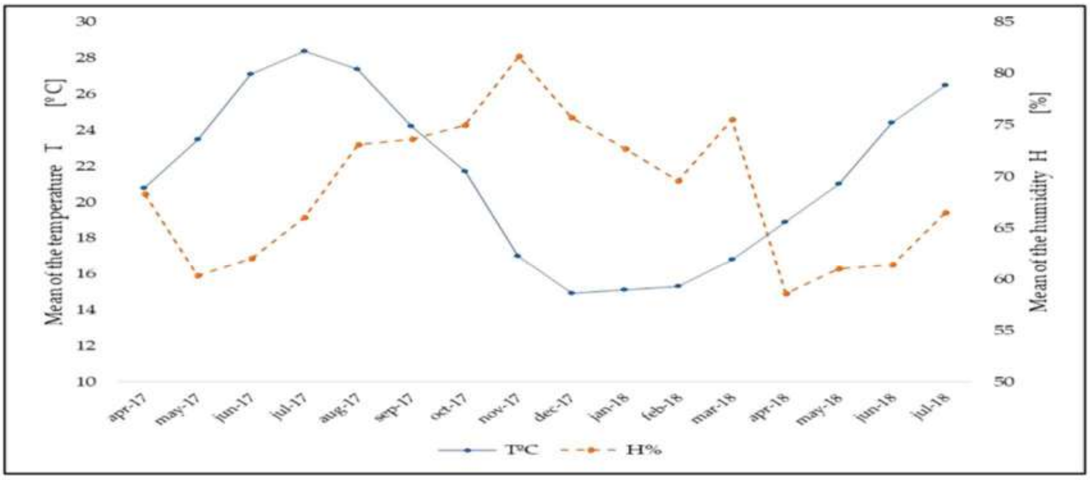

Figure 2. Average of the temperature T (-): and humidity H (—) inside the greenhouse during the experiment.

2.3. Experimental Procedures

The cultivation was carried out in a soil protected with sand, which is typical in this region, as described by Camacho and Fernández the most used-in greenhouses of Almería [11,12]. A total of 10 kg·m^{-2} of fresh manure were added to the soil. Therefore, the nutrients and the organic matter were adequate within the range of fertile soils. Tomato, pepper, courgette, and cucumber were grown in this soil for 13 years.

A drip irrigation system was used with flow rate emitters of 3 L·h^{-1} and a density of 1.6 emitter/m^{-2}. Fertilization and irrigation were applied simultaneously with the drip irrigation. The inline lateral pipes were north-south oriented, as the plants are. From April to October 2017, the irrigation control was made with tensiometers. The range of control was 20–10 cbar, and from November to 18th June of 2018, the range was 35–18 cbar.

2.4. Fertigation

The soil had a clay loam texture. The soil pH was 7.80, and organic matter content was 0.45%. The electrical conductivity (EC) values, in the saturation extract, was 4.65 dS·m^{-1}.

The water used had an EC of 1.4 dS·m^{-1} and a pH of 7.13. The fertigation was applied with the drip irrigation to obtain the following maximum concentrations in the solution: NO_3^-: 16 mmol·L^{-1}; $H_2PO_4^-$: 1.4 mmol·L^{-1}; SO_4^{2-}: 1.7 mmol·L^{-1}; HCO_3^-: 0.5 mmol·L^{-1}; K^+: 8 mmol·L^{-1}; Ca^{2+}: 6 mmol·L^{-1}; and Mg^{2+}: 2 mmol·L^{-1}. A fertilizer called "UniquaTrop®", made by the company Megasa was specifically made for this purpose with the following composition: NPK+Ca+Mg: 2.9–1.3–5.7 (2.2–0.5).

Seven days after transplanting (dat), the addition of the fertilizer began. The EC range (+0.5 a +2.0) dS·m^{-1} of irrigation water increased progressively and it never exceed 0.5 dS·m^{-1} in the increases made. A mix of microelements were added to this fertilizer with 7.5% of Fe, 2.5% of Mn, 0.15% of Cu, 0.1% of Zn, 1.25% of B, and 0.25% of Mo. The rate of this mix was 20 g·m^{-3} of irrigation water used.

2.5. Field Layout and Plant Material

Four papaya varieties were planted to assess the potential yield of each variety and to compare them with the most used variety under greenhouse in Southeast Spain, which is the Intenzza variety. Another treatment was also made with this Intenzza variety; it was grafted on a female rootstock of the same variety. All the varieties were early sex-identified when they were in a cotyledon state, 40 days after sowing (das) in Vitalplant nursery, in such a way that the transplant was made with one plant per pot. The plants were prepared in the nursery with an approximate height of 60 cm, in a rootball pot of 2 L. The treatments made were:

T0: Intenzza.

T1: Hermaphrodite Intenzza onto female Intenzza.

T2: Sweet Sense.

T3: Vitale.

T4: Caballero.

T5: Alicia.

The total area of the experiment was 588.84 m^2. Three replications for each treatment were made. Each elemental plot was 32.7 m^2. The elemental plots were distributed at randomized blocks. The experiment was carried out in the north side of the greenhouse, and a plot of 266.6 m^2 was used as edge effect plants. The south plot of the greenhouse (both separated by a central corridor) of 855 m^2 was also planted with papaya. The area of the corridor was 90 m^2. The planting density was 2700 plants/ha. The distribution of plants was made in paired and staggered rows, with 2.20 m between paired rows, 1.00 m between lines, and 2.00 m between plants.

Since 2014, in the southeast of Spain, different experiments have been carried out in papaya cultivation to find a variety which gives fruits a weight between 600 and 1500 g, and that plants have a good behavior with respect to soil conditions, water, and climate. The characteristics of the cultivars used according to the companies that produce the seeds are described in Table 1 [6,13–16].

Table 1. Characteristics of the five cultivars of papaya, planted in this experiment, under greenhouse.

Variety (Seller) [13–16]	Fruit Weight (g)	Size FAO * [6]	Main Characteristics	Sweetness Total Soluble Solids (° Brix)
Intenzza (Semillas del Caribe)	1500–2200	I, J	Developed for medium size or Formosa type papaya market. Its epidermis is orange-yellow when it is ripe, and its interior is red.	10–13
Sweet Sense (Semillas del Caribe)	1200–1800	H, I	When it is ready to be consumed, on its ideal ripening state, its epidermis is yellow, and its interior is salmon. It is classified as "baby" type.	11–14
Vitale (Vitalplant Nursery)	>1000	G, H, I, J	It is a plant with medium vigor, very open.	Without information from the seller
Caballero (CapGenSeeds)	650–900	E, F, G	It is not a very big plant and it has few leaves. It is ideally grown under greenhouse. Its fruits are very sweet.	14–15
Alicia (CapGenSeeds)	750–1100	F, G	It is not a very high plant; therefore, it is ideal to grow under greenhouse. The internodes of the plant are very short. Alicia tolerates low temperatures. Fruit harvest can be carried out in an advance ripening stage.	Without information from the seller

* Food and Agriculture Organization of the United Nations (FAO).

2.6. Indices Maturity Stage for Harvesting

The fruit harvest was carried out every week, from 160 dat to 446 dat (from October 2017 to July 2018). The fruits were harvested in the maturity stages 2 and 3 described by Santamaria [7]. The maturity stage 2 corresponds with a visual aspect of green fruit but with a light-yellow coloring between 25%–33%. The maturity stage 3 corresponds with yellow coloring fruit between 34%–40%. From spring the harvest was only carried out at maturity stage 2. The harvest was carried out from one day to four days per week; it increased as temperatures were higher.

2.7. Data Collection and Statistical Analysis

The parameters assessed were: Yield, measured by kg·m^{-2}, fruit weight (kg), number of fruits per plant, total soluble solids (TSS) measured by ° Brix. Fruits that were at a maturity stage higher than 3, those with deformations, or those damaged fruits were discarded. The fruits which had to be analyzed to know the total solubles solids (° Brix), were weighted with a Classic ML6001E (Mettler Toledo, L'Hospitalet de Llobregat, Spain) precision scales, with a maximum capacity of 6200 g and ±0.1 g sensitivity. The result of TSS in fruits was obtained with the average ° Brix and the maximum ° Brix.

Every four weeks, the TSS of fruits was measured. From each of the treatments, a fruit was chosen at random. The data was obtained between weeks 10 and 25 in 2018. A digital Pal-1 (Atago Co., LTD., Tokio, Japan) refractometer that had a measuring range from 0–53 ° Brix and ±0.2 sensitiviy was used. The process was repeated three times per each fruit, and every time a different piece was used. The refractometer was calibrated with distilled water.

This fruit was peeled and cut lengthwise (weight higher than 15% of the total weight of harvested fruit). This piece of pulp was mashed with a kitchen press, and the juice extracted from the mashed pulp (8–10 g) was measured to know the ° Brix.

After the first measurement, the fruit chosen at random for each treatment was kept in a cooling chamber at 15 °C. The same process was repeated in the same way and three new measurements of TSS were obtained 3, 7, and 10 days after the first measuremet. The results analyzed were obtained from five harvests. The measurements were taken at room temperature from 19 °C in March to 32 °C in June.

Additionally, morphological data about the plant was gathered, specifically: Height from the peduncle of the first harvested fruit to soil, which was taken in week 40 in 2017. On this same date, the perimeter of the stem was measured, calculating the diameter of the same, and this data was taken when 10 cm from the soil. The number of nodes from the soil to the first fruit was measured in weeks 40 and 43 of 2017 and weeks 9, 10, 12, 14, 15, and 16 in 2018. The morphological data was taken using a measuring tape with a total length of 5 m and was graduated in mm.

The data was subjected to variance analysis (ANOVA), considering a significant data if $p \leq 0.05$. The average values were compared using the Fishers Least Significant Difference (LSD), using the computer software STATGRAPHICS® Centurion XVIII version 18.1.06 (64 bits) (Statpoint Technologies, Warrenton, United States of America, Inc. 1982–2018).

3. Results

3.1. Foliar Analysis

In October 2017 a foliar analysis was made and the parameters that were measured (N, P, K, Ca, Mg, Na, Fe, Mn, B, Cu, Zn, Mo), showed normal results in the petiole of the papaya leaf. The analysis was made in that tissue because the content of minerals is more stable than in the leaf blade. The sufficiency range of the nutrients found in the petiole of the papaya leaf are taken from Jones et al. (1991), according to the data shown by Osuna Enciso [17]. The results for each element analyzed were the following: N (1.26 %), P (0.21%), K (3.43%), Ca (1.09%), Mg (0.48%), Fe (28.5 ppm), Mn (23 ppm), B (29 ppm), Cu (5 ppm), and Zn (17 ppm). The range described by Osuna Enciso was: N (1%–2.5%), P (0.2%–0.4%), K (3.3%–5.5%), Ca (1%–3%), Mg (0.4%–1.2%), Fe (25–100 ppm), Mn (20–150 ppm), B (20–30 ppm), Cu (4–10 ppm), and Zn (15–40 ppm).

3.2. Crop Protection

In the experiment, there were problems with *Tetranichus urticae* attacks that were controlled with *Phytoseiulus persimilis* and *Amblyseiuscalifornicus* releases; *Stethorus punctillum* also appeared sporadically, which is a big predator of *Tetranichus* sp. Small attacks of *Aphis gossypii* were controlled with preventive *Lysiflebus testaceipes* and *Aphidius colemani* releases on cereal banker plants, which were infected with the specific aphid, *Rhopalosiphum padi*. In winter, small attacks of *Botrytis cinerea* appeared on the injuries in the stem, which caused the fall or removal of the petioles, and was controlled with Samurai®–Nutricrop paste (a product made from natural clays that isolates the internal tissues of the plant from the outside environment). At the end of winter, beginning of spring, *Oidium caricae* attacks appeared which were controlled by applying powdered sulphur which we alternated with products such as Ospo V®- Agrotecnología (a product made from vegetal extracts, flavonoids, alkaloids, phenols, macro and microelements, polysaccharides, and microorganism extracts) and Lareki greens®, Biofungitek, (a product made from potassium carbonate and vegetal extracts).

3.3. Total Yield

The harvest was carried out for 43 weeks. There were significant differences between treatments, T1 (Grafted Intenzza) was the treatment from which more yield was obtained, with 14.20 kg·m^{-2}. T2 (Sweet Sense) and T5 (Alicia) treatments form another statistical group that obtained 12.58 and 12.38 kg·m^{-2} respectively, the rest of the treatments were slightly lower in yield (Table 2). From week 4 of harvest, T1 was the treatment which gave more yield, and T3 treatment kept the harvest pace until week 25, the remaining treatments obtained always lower yields, although the significant increase of T4 and T5 from week 27 to 30 must be highlighted (Figure 3).

Table 2. Results obtained in papaya grown under greenhouse: Yield (kg·m^{-2}), Average fruit weight (AFW), number of harvested fruits, height from the soil to the first fruit, perimeter of the stem, number of nodes until the first fruit, Total soluble solids (TSS) (° Brix).

Treatments	Intenzza	Grafted Intenzza	Sweet Sense	Vitale	Caballero	Alicia	*p*-Value
	T0	T1	T2	T3	T4	T5	
Yield (kg·m^{-2})	9.59 ^{c}	14.20 ^{a}	12.58 ^{ab}	4.82 ^{d}	11.02 ^{bc}	12.38 ^{ab}	0.00
SIZE (FAO) AFW (kg)	*H* 1.279 ^{b}	*G* 1.063 ^{c}	*G* 0.982 ^{cd}	*H* 1.405 ^{a}	*G* 0.922 ^{d}	*G* 1.005 ^{c}	0.00
Number of harvested fruits per plant	24.90 ^{d}	42.43 ^{ab}	43.67 ^{a}	11.97 ^{e}	40.20 ^{bc}	39.65 ^{cd}	0.00
TSS (° Brix)	9.23 ^{c}	9.98 ^{a}	9.82 ^{ab}	10.00 ^{a}	9.34 ^{bc}	9.14 ^{c}	0.00
MAX TSS (° Brix)	9.72 ^{bc}	10.45 ^{a}	10.19 ^{ab}	10.36 ^{a}	9.72 ^{bc}	9.50 ^{c}	0.00
MIN TSS (° Brix)	8.76 ^{c}	9.51 ^{ab}	9.46 ^{ab}	9.59 ^{a}	9.01 ^{bc}	8.77 ^{c}	0.00
Increase of TSS (° Brix) 1st to 4th measurement Average values	10.1 ^{a}	8.6 ^{a}	10.3 ^{a}	9.2 ^{a}	9.1 ^{a}	9.0 ^{a}	0.99
Increase of TSS (° Brix) 1st to 4th measurement Maximum values	11.8 ^{a}	11.9 ^{a}	8.8 ^{a}	9.7 ^{a}	9.5 ^{a}	10.3 ^{a}	0.99
Increase of TSS (° Brix) 1st to 4th measurement Minimum values	8.1 ^{a}	8.7 ^{a}	11.1 ^{a}	7.2 ^{a}	8.6 ^{a}	8.3 ^{a}	0.99
Height from the soil to the first fruit (cm)	61.45 ^{b}	49.35 ^{c}	85.44 ^{a}	58.55 ^{b}	95.1 ^{a}	94.88 ^{a}	0.00
Perimeter of the stem (cm)	37.65 ^{c}	40.78 ^{b}	44.17 ^{ab}	36.68 ^{c}	46.57 ^{a}	46.53 ^{a}	0.00
Diameter of the stem	11.98 ^{a}	12.98 ^{b}	14.06 ^{bc}	11.68 ^{a}	14.82 ^{c}	14.81 ^{c}	0.00
Number of nodes until the first fruit	30.34 ^{e}	37.90 ^{d}	54.78 ^{c}	60.10 ^{b}	66.50 ^{a}	60.20 ^{b}	0.00

Different letters mean significant differences, at *p*-value < 0.05.

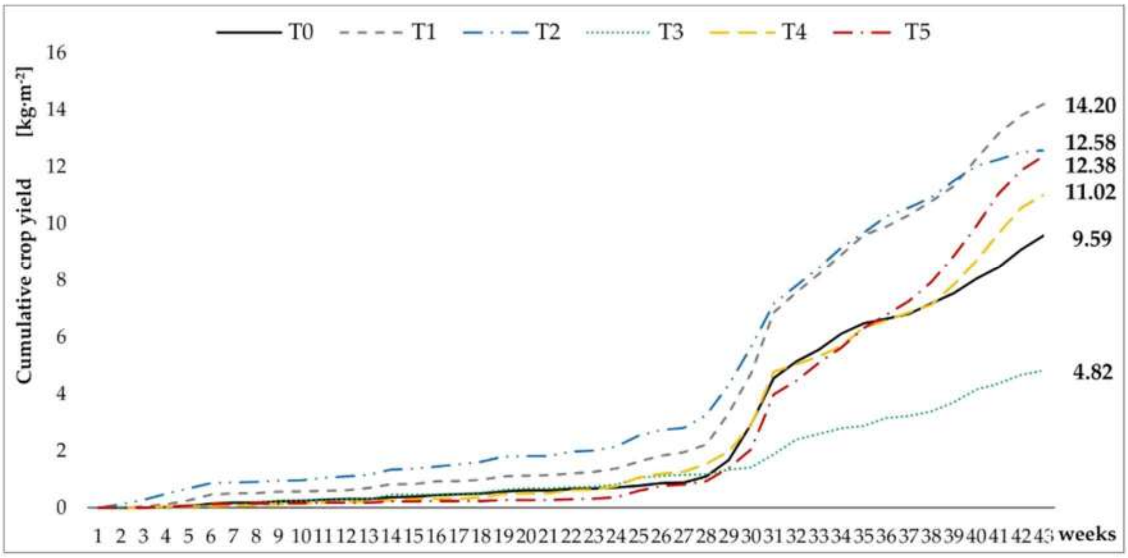

Figure 3. Cumulative crop yield of the five cultivars on 43 weeks in (kg·m^{-2}), T0 (■): Intenzza; T1 (■): Grafted Intenzza; T2 (■): Sweet sense; T3 (■): Vitale; T4 (■): Caballero; T5 (■): Alicia planted under greenhouse.

3.4. Average Fruit Weight (AFW)

Throughout the harvest, significant differences were observed between the fruits coming from the different treatments. The Vitale fruits had the highest weight, with a value of 1.405 kg, followed by T0 (Intenzza) fruits with 1.279 kg (Table 2), both values corresponded with size H (1104–1500 g) according to Codex 183–93, the rest of the fruits coming from the remaining treatments were classified as size G (801–1100 g) (Figure 4).

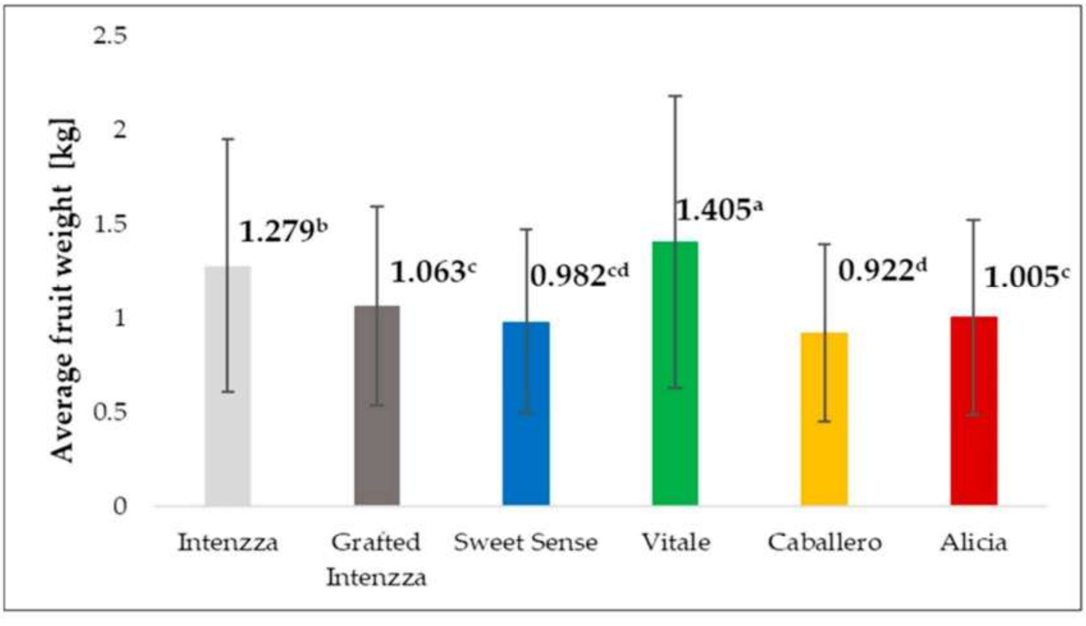

Figure 4. Average fruit weight of the five cultivars of papaya in (kg). T0 (■): Intenzza; T1 (■): Grafted Intenzza; T2 (■): Sweet sense; T3 (■): Vitale; T4 (■): Caballero; T5 (■): Alicia, planted under greenhouse. Different letters mean significant differences, at p-value < 0.05.

In Europe, the major papaya importers market papaya per units and not by weight (retail sale), therefore, the "average fruit weight" parameter has importance with respect to fruit marketing, distribution, and packaging. Fruit weights between 600 to 1000 g have an acceptable demand by European consumers and they can be sold in many countries.

3.5. Number of Fruits Per Plant

There were significant differences in this parameter for all the treatments (Table 2). Sweet Sense and Intenzza grafted on its own female rootstock were the plants with the highest number of fruits (Figure 5).

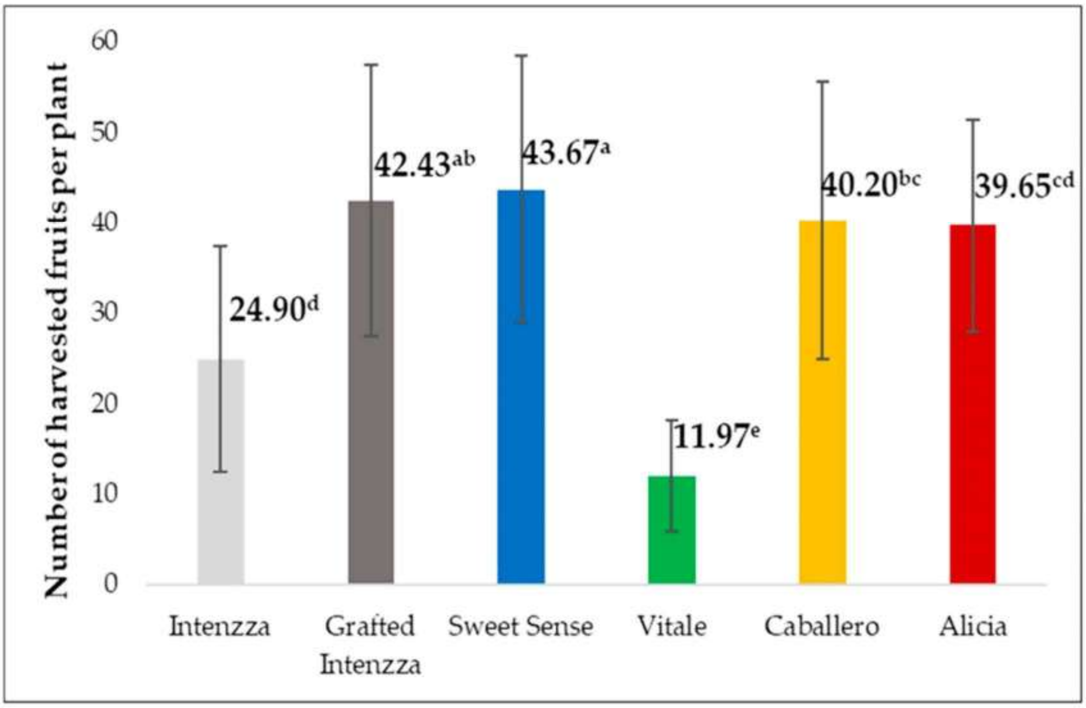

Figure 5. Harvested fruits per plant of the five cultivars of papaya cultivated under greenhouse. Different letters mean significant differences, at p-value < 0.05.

3.6. Total Soluble Solids

The analysis of total soluble solids was made for the ° Brix average, and for the maximum and minimum ° Brix in fruits (Figure 6). There were significant differences between treatments in the three measurements. T3 and T1 (Vitale and grafted Intenzza) form the group of fruits with the highest ° Brix, and the fruits coming from Alicia and Intenzza (T5 and T0) form the group of fruits with the lowest TSS. The same situation happened when the average of the maximum and minimum ° Brix was analyzed. The average minimum values obtained varied from 9.59 to 8.76 ° Brix. The absolute maximum values had values between 9.14 and 10.00 ° Brix.

An increase in the TSS can be observed in the measurement taken 10 days after the harvest (10 days after the first measurement (D + 10)). The value reached 10.33% if the absolute maximum values are considered (Table 2). All the measurements for this parameter taken after the harvest was carried out resulted in a value higher than the previous ones in the same fruit.

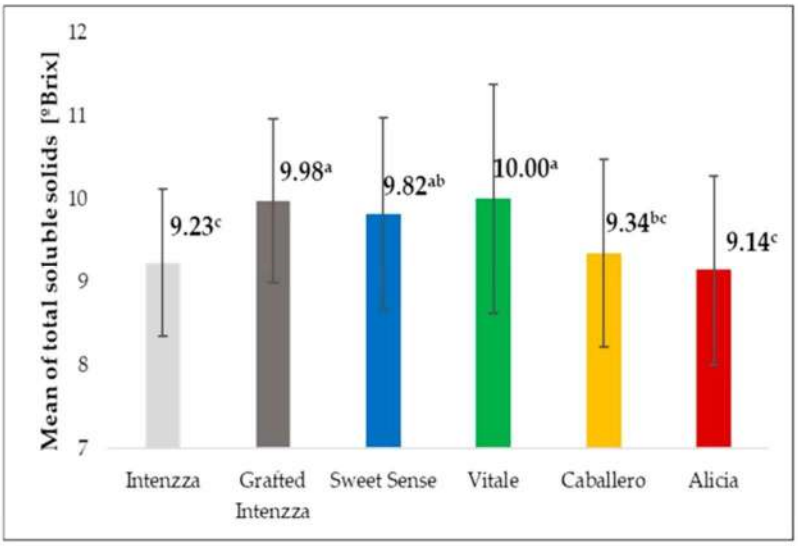

Figure 6. Average of the total soluble solids (TSS) measured of fruits of papaya cultivated under greenhouse. Different letters mean significant differences, at p-value < 0.05.

3.7. Height from the Soil and Node in which the First Flower Appears

There were significant differences between treatments, with respect to the height between the soil and where the first fruit was harvested, T4 and T5 (Caballero and Alicia) are the treatments where the first highest fruit was harvested, followed by T2 (Figure 7).

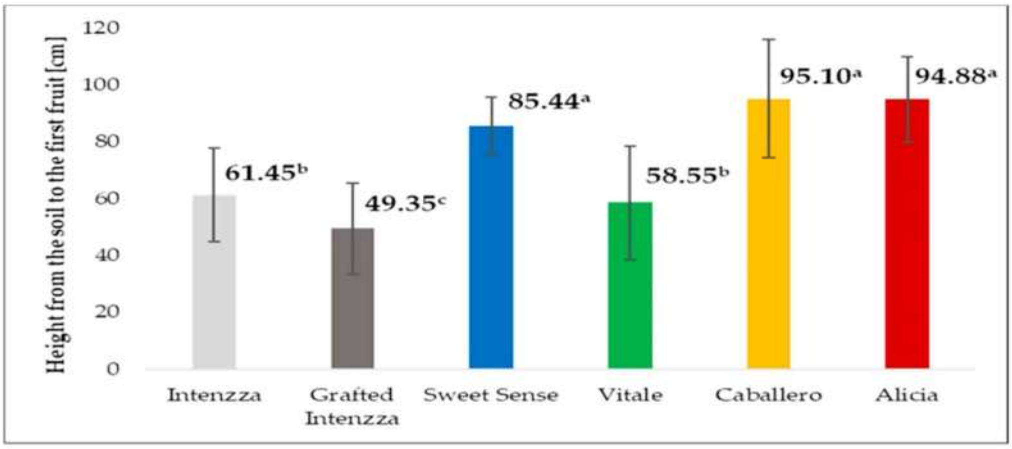

Figure 7. Height from the soil to the first fruit measured for five cultivars of papaya planted under greenhouse. Different letters mean significant differences, at p-value < 0.05.

With respect to the first node where the harvest was carried out, there were also significant differences and it also coincided with T4 (Caballero) in which the highest number of nodes appeared (Figure 8). The relation between both parameters gave the distance between nodes, which varied from 1.30 cm for Intenzza grafted onto its female rootstock to 2.02 cm of non-grafted Intenzza (T0).

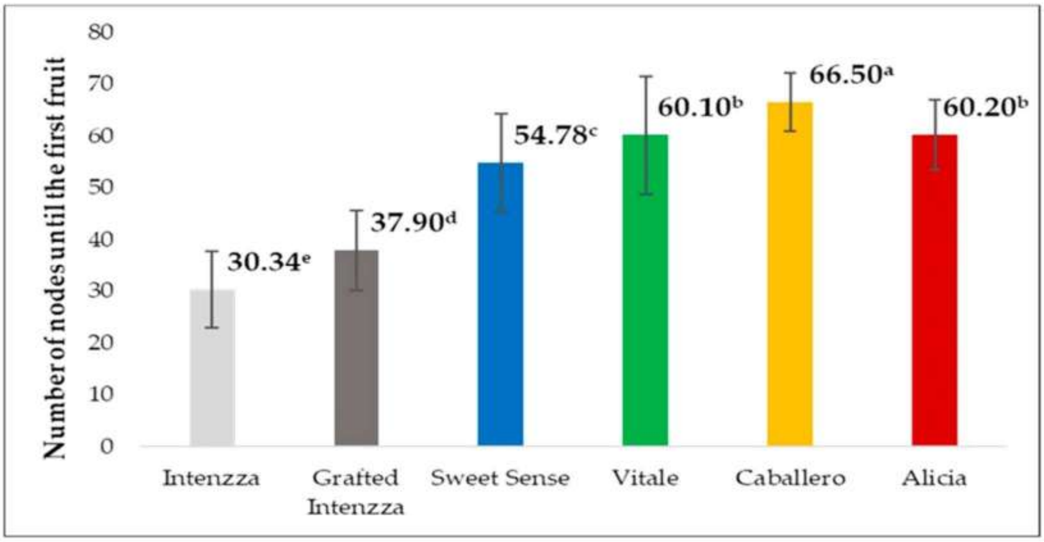

Figure 8. Number of nodes until the first fruit for the five cultivars of papaya planted under greenhouse. Different letters mean significant differences, at p-value < 0.05.

3.8. Perimeter of the Stem

There were significant differences between treatments (Table 2). T4 and T5 (Caballero and Alicia) had the highest longitudes of the perimeter, 46.57 and 46.53 cm respectively. The lowest longitude of perimeter was obtained with Vitale and Intenzza with 36.68 and 37.65 cm respectively (Figure 9). These perimeters gave a diameter of the stem between 11.68 and 14.82 cm for the thinnest stem (Vitale) and for the thickest (Caballero) respectively, as it can be appreciated there is a 3.14 cm gap.

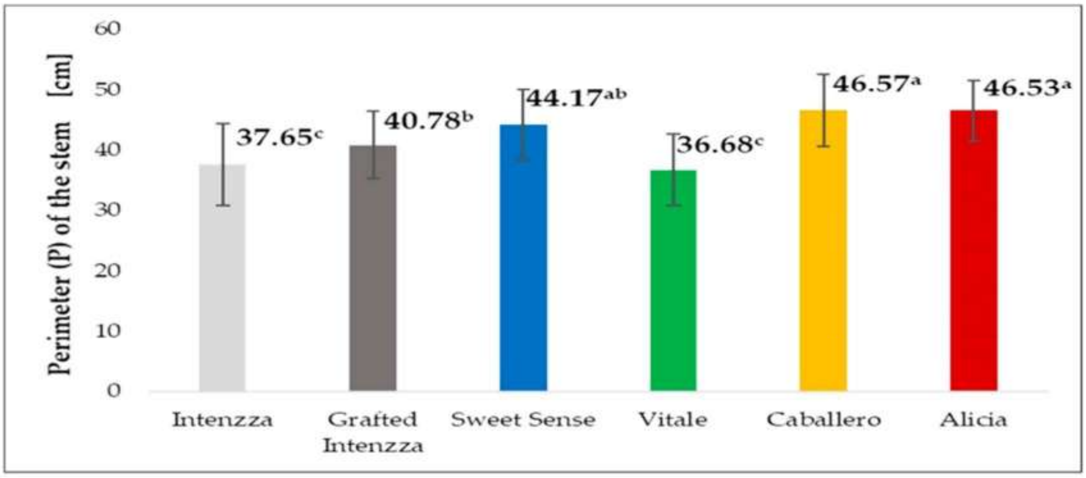

Figure 9. Perimeter (P) of the stem for the five cultivars of papaya planted under greenhouse. Different letters mean significant differences, at p-value < 0.05.

4. Discussion

Our yield results were higher than those obtained by Guzmán [18] which varied between 4–7 kg·m^{-2} and Jiménez [19] who obtained 8.9 kg·m^{-2}, both in Costa Rica and the last one in a three-year cycle. In Mexico, Escamilla et al. [20] conducted experiments to study the effects of organic, mineral, and foliar fertilization on the development and yield of *cv* Maradol papaya and obtained 2.8 kg·m^{-2}. In India, Singh et al. [21] conducted experiments to assess the effects of micronutrients on growth, yield, and quality of papaya, and reported yields between 6.5–9.3 kg·m^{-2}. In other experiments in India, Bhalerao et al. [22] obtained between 5.18–8.07 kg·m^{-2} in an experiment that assessed the effects of different micronutrients on yield and quality of papaya. In all the cases that have been compared, the plant cycles in field were longer than those of our experiment, which makes possible papaya cultivation in Southeast Spain in Europe, giving higher yields because the cycle was reduced until 30% compared with the rest of the plantation systems. In our treatments, an improvement can be appreciated when using hermaphrodite plant grafted onto female plant compared with non-grafted plants. The reason is that female and hermaphrodite plants are older than non-grafted plants, although they were planted the same day, the seed of grafted plants was sowed 35 days before, with the purpose that growing at the transplanting stage was similar.

With respect to fruit weight, the data obtained are consistent with the data obtained by Pérez [23], in an experiment conducted with 10 different varieties, although the production system was not the same. All the treatments gave fruits between 600 and 1200 g, a size demanded by the market which is accessible from Almería.

It can be observed in the different varieties, the significance of the genetic power on fruit size and weight. The weight obtained in the fruits coming from the different treatments has an acceptable demand in the European market, and they can be sold in many countries.

The number of fruits obtained in each of the varieties can be considered as high, hence its repercussion on yield for short cycle. Comparison with other varieties, as used in other experiments, would provide nothing to this parameter.

In soluble solids, our values were similar to those obtained by Pérez [23] for the Intenzza variety grown in the Canary Islands, although, in this case, two peaks of 12 ° Brix were observed. The values are also similar to the results obtained by Santamaría [24] in Costa Rica. The company that produces the Intenzza variety [14] claims that the ° Brix are between 10–13. In the case of Sweet Sense [15], the figures obtained are between 11 and 14 ° Brix.

The increase of ° Brix of the papaya after harvest have been reported by other authors, as Siriamornpun et al. [25] observed this phenomenon in papayas of different cultivars (KhakDam, Hawaii, and Holland), which were left to be ripened in 24 and 48 h at room temperature, compared with other group of green papayas. The ripe papaya they analyzed was fully yellow. They attribute the increase of TSS to the fact that fruit during the ripening process have more intense cellular respiration processes due to hydrolisis of starch to glucose and fructose by amylase action, described by Eskin et al. [26]. In our experiment, fruits were kept cool at 15 °C (except for when measurements were taken at room temperature). The data obtained in the experiment permitted the sale of papaya fruits in different European countries. Once again, the position of this parameter of hermaphrodite Intenzza grafted onto female Intenzza must be highlighted.

The results obtained with respect to the height of the first fruit, are consistent with those reported by Alonso et al. [27] for two varieties belonging to the germplasm bank located in the Scientific-Technological Unit (UCTB) in Jagüey Grande, Matanzas (Cuba) and those obtained by Pérez [23] for Intenzza and those obtained by Escamilla et al. [20] in Mexico for the Maradol variety.

This perimeter is slightly equal to the perimeter obtained by Alonso et al. [27] in Cuba, although the authors did not state when the measurement was taken with respect to transplanting. The diameters obtained according to the plant short cycle were enough to support the load of the fruits and the plant was neither bent nor had fallen over at any time.

If we analyze all the assessed parameters, we should consider grafting hermaphrodite plants onto female plants due to the benefit of early sex-identification plants, in addition to plants being transplanted with a higher development.

5. Conclusions

The most productive treatment corresponded with the hermaphrodite Intenzza variety grafted onto the female Intenzza rootstock. In all the treatments, the fruit weight reached the marked weight for our objective, which makes possible the selling of these fruits in European markets. Sweet Sense and hermaphrodite Intenzza grafted onto female Intenzza rootstock are the varieties which gave a higher number of fruits. When harvest was carried out, all the treatments had between 9–10 ° Brix, then the climacteric effect on the fruits was an increase by 10.33%, 10 days after the harvest and kept at 15 °C. Hermaphrodite Intenzza grafted on female Intenzza rootstock was the plant where the first fruit was harvested at the lowest distance from the soil, and its diameter of the stem was within the lowest thickness group. In all the treatments assessed, hermaphrodite Intenzza grafted onto female Intenzza obtained the best parameters to be an alternative to be considered with respect to other varieties.

Author Contributions: Conceptualization, F.C.-F. and A.N.-V.; methodology, F.C.-F. and L.J.B.-U.; investigation, M.N.H.; resources, F.C.-F. and A.N.-V.; writing—original draft preparation, M.N.H. and F.C.-F.; writing—review and editing, F.C.-F.and L.J.B.-U.; supervision, F.C.-F. and L.J.B.-U.; project administration, F.C.-F. and A.N.-V.; funding acquisition, F.C.-F. and L.J.B.-U.

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Conflicts of Interest: The authors declare no conflict of interest.

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Análisis del beneficio del cultivo de papaya bajo invernadero como alternativa a la horticultura intensiva tradicional en el sureste español.

(Artículo 3. Profit analysis of papaya crops under greenhouses as an alternative to traditional intensive horticulture in Southeast Spain)

ARTÍCULO 3

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Article

Profit Analysis of Papaya Crops under Greenhouses as an Alternative to Traditional Intensive Horticulture in Southeast Spain

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Abstract: The high-yield agricultural model in Almería is based on eight different crops. Having led fruit and vegetable exports in Spain for more than 50 years, a decrease in melon and watermelon growing areas in Almería caused a change in supply that affected the model's profit. Papaya cultivation could reactivate the profit of the agricultural model in Almería and also improve the available product range. The papaya crop needs greenhouse infrastructures high enough to contain the growth and size of the plants during a cycle crop, which is possible in most of the greenhouses of the Horticultural production model of Almería. The papaya harvests obtained in the region meet the quality requirements demanded by European markets. Furthermore, yields obtained are equal or higher than yields obtained by other producing countries. This crop improves profit compared with the profit obtained from the rotation of other horticultural crops that have been traditionally grown in the region.

Keywords: *Carica papaya*; alternative crop; transplant of sex-identified plants; productive structure for intensive crops

1. Introduction

In the last 50 years, the province of Almería, in southeast Spain, has experienced a large economic transformation. The development of innovative and intensive agriculture has generated significant economic growth in the region with a positive impact on the welfare of families who live there [1]. This growth happened even though the region did not follow a proposal in European rural development guidelines to adopt an economic diversification strategy [2]. The productive diversification strategy is valid and advisable for developing countries, although it cannot be extrapolated to cover the whole of an increasingly liberalized world [3]. The agricultural sector in Almería has invested in new greenhouse architectures and technology to improve climate management and hydric resources. Moreover, product specialization has generated a local production system incorporating cooperation mechanisms that share innovative experiences and specialist knowledge.

The product specialization in Almería, sometimes called a high-yield agricultural model, is based on eight crops grown under plastic greenhouses: tomato, pepper, cucumber, courgette, aubergine, green bean, melon, and watermelon. Currently, such model is found in a productive maturity stage after developing a powerful commercialization channel. Increasing competition with third world countries is met through the reduction of production costs—mainly reducing labor and transportation costs [4,5]. Other costs, derived from crop insurance and greenhouse structures, are increasingly common among fixed costs, of a financial nature, on agricultural farms [6,7].

Production costs can be very variable among different production systems, due to the great differences in the technological levels and equipments used in each case. There are differences between different agrosystems due to the technological level of greenhouse cultivation, the contributions of energy, and inputs that they require [8]. However, one of the main components of the costs is the amortization of the investment in the structure of the greenhouse, in the equipment of fertigation, and in the climatic control. Therefore, as described Testa et al. [9], in the Mediterranean basin most of the greenhouses are built with low cost and technology in comparison to the greenhouses of Northern Europe [10,11], having plastic coverings and few climate control systems [12,13]. Thanks to the mild winters and the high solar hours, the structures do not need more investments to ensure a very aceptable quality crop. Genetic improvements of vegetables contribute to producing fruits that have a longer post-harvest life [14,15].

The adaptation process of the agricultural sector in Almería is demonstrated by the reorganization of the area grown, as shown in Table 1.

Table 1. Evolution of the wintering area by type of crop (2009–2018) in hectares.

Year	Tomato	Sweet Pepper	Cucumber	Aubergine	Courgette	Green Bean	Melon	Watermelon	Total Area Green-House
2009	10,147	7505	4430	1868	4717	921	4447	5216	39,251
2010	9939	7475	4498	1824	5020	776	4039	5516	39,087
2011	9050	7300	4550	1924	5265	680	3539	4916	37,224
2012	9124	7388	4535	2190	5789	1170	3740	5665	39,601
2013	10,358	8461	4920	2006	6448	1321	4200	6400	44,114
2014	11,206	9378	4839	1908	7219	1387	2591	7100	45,628
2015	10,345	9326	4979	2447	7477	1439	2946	8378	47,337
2016	10,940	9491	5026	2300	7630	1340	2467	8590	47,784
2017	10,220	10,310	4980	2150	7970	1030	2220	8940	47,820
2018	10,380	10,181	5099	2209	7860	510	2290	9860	48,389
				Change (from 2009 to 2018)					
Abso-lute	233	2676	669	341	3143	−411	−2157	4644	9138
%	2.30	35.60	15.10	18.20	66.70	−44.60	−48.50	89.00	23.28

Source: Own elaboration made with data provided by the Provincial Delegation of the Regional Department of Agriculture of the Andalusian Regional Government in Almería (Spain).

Considering the data obtained from the previous table and the cartographic base of greenhouses in Almería [16], three important conclusions are obtained:

1. The soil occupancy rate from 2009 to 2018 varied from 1.38 to 1.59, which means that the area used for short cycles is greater than that used for long cycles. Soil occupancy is the rate between the addition of areas occupied by the different crops developed in a season by the soil area available for the greenhouse. When a farmer cultivates only a crop in the greenhouse along the season in a long cycle, this rate will be equal to 1. When the farmer cultivates two short cycles in the same greenhouse (one in autumn-winter and a second in spring-summer) this rate will be equal to 2. An increase in the soil occupancy rate shows an augmentation of the use of short cycles in the greenhouses. This is a dimensionless number.

2. In one decade, the area used for greenhouses has increased by 3123 hectares.

3. The area used for each crop has changed. There was a decrease of 2157 and 411 hectares for melon and green bean, respectively. Meanwhile, the area used for the other crops has grown, mainly watermelon (4644 ha), courgette (3143 ha), and pepper (2676 ha).

With respect to commercialization, farmers maintained revenues over many years, mainly due to the stability of the average prices of the vegetable commodities (see Figure 1 and Table 2) produced in Almería, all mentioned in Table 1. However, as production costs increased year after year, the margins fell for units of product sold.

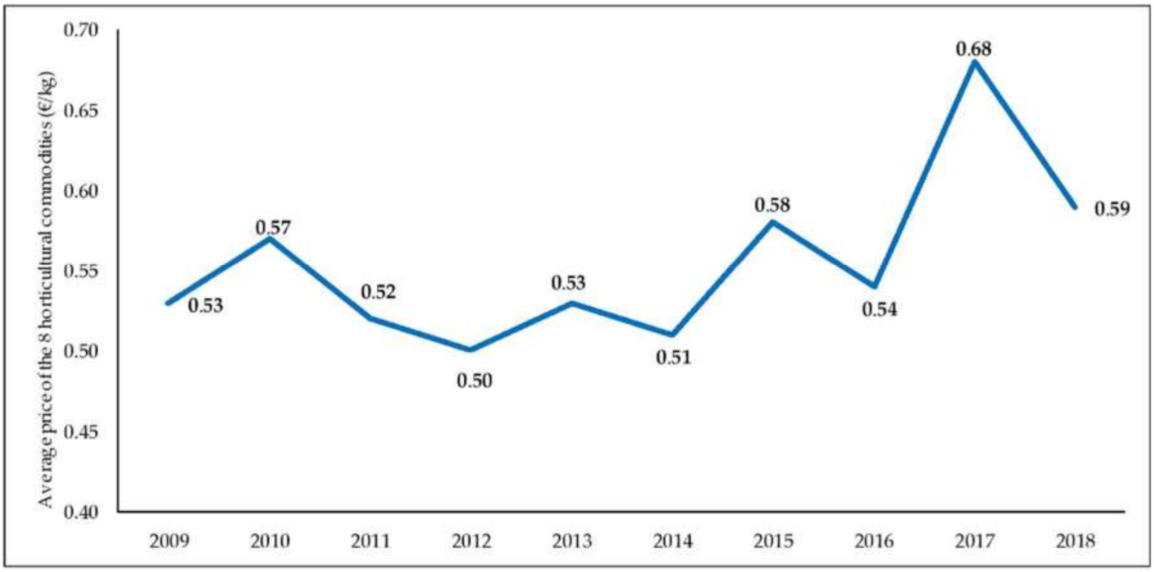

Figure 1. Evolution of the average price of the eight horticultural commodities grown under plastic greenhouses (tomato, pepper, cucumber, courgette, aubergine, green bean, melon, and watermelon) produced in the province of Almería (Spain) from 2009 to 2018, in €·kg^{-1} [17]. Source: Own elaboration made with data provided by the Provincial Delegation of the Regional Department of Agriculture of the Andalusian Regional Government in Almería (Spain) (2009 to 2018) [17].

The data of Figure 1 are obtained from Tables 1 and 2, calculating the weighted mean with the areas of each crop.

Table 2. Average price of the eight horticultural commodities grown under plastic greenhouses (watermelon, melon, courgette, cucumber, aubergine, tomato, pepper, and green bean) produced in the province of Almería (Spain) from 2009 to 2018, in €·kg^{-1} [17].

Crop	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Watermelon	0.242	0.249	0.332	0.250	0.263	0.278	0.372	0.318	0.327	0.407
Melon	0.336	0.398	0.376	0.395	0.381	0.367	0.451	0.470	0.448	0.535
Courgette	0.499	0.670	0.380	0.475	0.564	0.463	0.789	0.489	0.681	0.555
Cucumber	0.577	0.446	0.434	0.435	0.542	0.449	0.467	0.418	0.640	0.501
Aubergine	0.570	0.503	0.448	0.418	0.591	0.511	0.453	0.371	0.728	0.513
Tomato	0.560	0.646	0.511	0.571	0.525	0.538	0.559	0.527	0.714	0.621
Pepper	0.723	0.746	0.882	0.668	0.768	0.647	0.733	0.824	0.908	0.755
Green Bean	1.281	0.902	1.459	1.518	1.360	1.127	1.575	1.455	1.747	1.584
Average	0.599	0.570	0.603	0.591	0.624	0.548	0.675	0.609	0.774	0.684

Source: Own elaboration made with data provided by the Provincial Delegation of the Regional Department of Agriculture of the Andalusian Regional Government in Almería (Spain) (2009 to 2018) [17].

Two analyses can be made considering this price stability situation. On one hand, supply must decrease to meet a stable demand and, on the other hand, the product range that this model offers must increase to prevent loss of competitiveness within the sector.

Within this context, in order to expand the range of agricultural commodities offered by the province of Almería, we thought about working with an exotic species for the European continent such as papaya, obtaining production data and quality of the same as well as economic results of the sales and expenses incurred for production. The reasons for selecting the papaya crop in our study are twofold. First of all, in Europe, papaya consumption is growing due to its nutritional properties and high medicinal value [18,19]. Furthermore, the proximity of consumer markets to Southeast Spain allows fruits to be harvested at a more advanced stage of maturity compared to exporting countries from outside Europe, a timeline which improves the quality of the papaya.

Papaya (*Carica papaya* L) comes from southern Mexico and Nicaragua [20] and is a widely produced crop in the tropics. Until recently, the cultivation of this plant was carried out in tropical or subtropical regions. Nowadays, papaya is being cultivated in new regions using climatic protection techniques. In the province of Almería, some trials made on a very small scale by producers of the region have confirmed that this type of crop is well adapted to the agronomic conditions and production infrastructure found in southeast Spain. Additionally, there is an existing horticultural commercial network that provides a business infrastructure. The fruit were well accepted by the consumers. Additionally, in the economic situation of the province of Almería where there is a loss of competitiveness within the sector, we have observed that the papaya fruit is highly demanded by the European northern countries and that the average price is higher than the eight horticultural commodities cultivated under greenhouses.

In response to consumer demand we need to consider how product range can be expanded using the Protected Horticulture model from Almería. The trading sector has an agile commerce channel to sell the horticultural products, which has developed over more than 40 years, with an annual turnover of 3.5 million tonnes of fruit and vegetables for national and international markets. Within this framework and taking into account the special agro-environmental conditions and experience in the horticultural sector of Almería, the usual range of fruit and vegetables grown in this region could be extended, introducing a new crop such as papaya.

In the last decade, the demand for tropical fruits has grown at a constant and sustained rate. Papaya is the third most consumed tropical fruit, after mango and pineapple, and production reached 13,169,443 t in 2017 [21]. Although the increase in the papaya supply mostly derives from Indian production, this fruit has become a good source of revenue for many Asian and Latin American countries too.

In the last five-year period, over 50% of papaya production was distributed to the United States of America. In Europe, papaya consumption is consolidating due to the nutritional and high medicinal properties of the fruit [18,19]. The biggest importers of papaya in Europe are the United Kingdom, Holland, and Germany [22].

The Canary Islands (Spain is Europe's largest papaya producer with cultivation on 350 ha [23]. This cultivation area is expanding, meanwhile the area used for growing tomatoes is decreasing. Papaya is also grown in Continental Europe. In 2012, cultivation first began in the province of Almería on 6000 m^2. The production obtained was marketed locally as "papaya of Almería". Early on, studies took place to understand both the adaptation of this crop to the southeast Spain, greenhouse production system, and how different cultivation practices could improve yield.

The aim of this article is to present the advantages of incorporating a subtropical crop like papaya and increase the range of products offered by the Almería agricultural sector, which tends to concentrate the supply on only eight horticultural commodities. Papaya cultivation was selected for several reasons. First, there is an important European demand for this crop, and India is currently the first supplier. Another reason for this choice is that Papaya can be cultivated under greenhouses with the productive conditions of the Spanish southeast. For both reasons, a field study was carried out in Almería to assess the quality of a Papaya cultivation grown under a naturally ventilated greenhouse and to estimate the net profit before taxes that the papaya crop would generate, over a period of 2.5 years (30 months). A comparison is made with the most common horticultural crop combinations in South Eastern Spain, crops that have been grown in the province of Almería for four decades. Finally, from the point of view of the distribution, this crop has been incorporated into the offer of several suppliers in the region, even with scarce importance due to the reduced cultivated area now in the province.

2. Materials and Methods

An experiment was conducted to obtain the product. From this experiment, production and quality (agronomic) data were obtained alongside economic data concerning when papaya was put on the market. The greenhouse where it was planted has an area of 1800 m^2, and this area corresponds with the area of the greenhouse located in the experimental plot of the University of Almería.

2.1. Location of the Experiment

The experiment was conducted at the research station "Catedrático Eduardo Fernández", which belongs to the Foundation of the University of Almería-Anecoop. It is located in a place called "Los Goterones" in Almería, 36°51′ North latitude and 2°17′ West Longitude, at 90 m above sea level.

2.2. Greenhouse Infrastructure

The plants were transplanted in a "multi-tunnel" greenhouse with an area of 1800 m^2, a gutter height of 4.50 m, and a ridge height of 5.70 m. The covering was made from three layers of plastic film (low-density polyethylene, 200 microns thick). Due to the climatology of the region and the needs of the papaya plant to be within the above parameters, from June to September three side walls were opened and the East oriented side wall was closed; wind is warm in this orientation, so there is an excessive decrease in the relative humidity in the interior of the greenhouse. To avoid this decrease in relative humidity, white plastic mulch film was placed on the soil, in alternate lines, forming small reservoirs which were filled with water to produce evaporation (Figure 2). In winter, this mulch film was not filled with water and alternate lines were mulched with black plastic film because covering the whole soil surface decreases relative humidity.

Figure 2. Plastic mulching of part of the floor surface for the incorporation of humidity in the environment.

The soil used was enhanced to place its quantitative parameters of nutrients and organic matter within the range of fertile soils. The soil was protected with a sand covering, which is typical in this region, as described by Camacho and Fernández [24]. During the past 13 years, tomato, pepper, courgette, and cucumber were grown in this soil.

Irrigation was carried out through a localized irrigation system of high frequency (drip irrigation) using discharge drippers 3 $L{\cdot}h^{-1}$ with a density of 1.6 drippers/m^2.

2.3. Plant Material

The vegetal material used was Intenzza papaya seeds, belonging to the "Semillas del Caribe" company (Jalisco, Mexico) [25]. Out of the current varieties grown under greenhouse in Continental Europe, this specific variety was chosen because it is the leading variety. The vegetal material was prepared in the nursery to conduct the experiment in the plot described above.

The characteristics of the planted papaya were a sex-identified Intenzza Papaya with a rootball (pot) of 2 L and an approximate plant height of 60 cm. The sowing date was 10 October 2015 and the early sex-identification was made on 20 November 2015, 40 days after sowing (das).

The transplant to the final field was made on 23 March 2016. A total of 30 months (February 2016 to July 2018) is the period during which the analysis of the data of this experiment was made. The papaya cultivation in this trial started on March 2016 (transplanting date). Preparation of the soil was in February 2016 and during July of 2018, when the plants were taken off.

The distribution of plants was made in paired and staggered rows with a distance of 2.20 m (corridors) between paired rows, 1.00 m between lines and 2.00 m between plants. Under these distributions, there was a density of 2700 plants/ha. The total area of the experiment was 1650 m^2 used for growing, the rest of covered area was used as walkways.

2.4. Fertilization and Crop Protection

The soil had a clay loam texture with 0.45% of organic matter and pH and electrical conductivity (EC) values, in the saturation extract, of 7.80 and 4.65 $dS{\cdot}m^{-1}$ respectively.

The water used had an EC of 1.4 $dS{\cdot}m^{-1}$ and a pH of 7.13. Nutrients were applied by drip irrigation.

One week after transplanting, the addition of fertilizer began. Additionally, the EC of irrigation water increased by 0.5 $dS{\cdot}m^{-1}$ until it progressively reached 2 dS m^{-1}, the maximum amount of EC reached by addition of nutrients, for plants developed from the beginning to the end of the harvest (Figure 3).

Figure 3. Papaya plant under greenhouse with fruits close to harvest.

Crop pests and diseases were controlled with biological control with releases of beneficial insects, or natural pesticides. *Tetranichus urticae* were controlled with *Phytoseiulus persimilis* and *Amblyseius* *californicus* releases, in addition to the occasional appearance of *Stethorus punctillum*. The small aphids *Aphis gossypii* were controlled with preventive *Lysiphlebus testaceipes* and *Aphidius colemani* releases on cereal banker plants, which were infected by us with a specific aphid, *Rhopalosiphum padi*. In winter, *Botrytis cinerea* appeared in small areas injuring the stem, which caused the fall or removal of the lower petioles. It was controlled by applying Samurai®-Nutricrop paste (Almería, Spain) (a product made from natural clays that isolates the internal tissues of the plant from the outside environment) locally and on the injured stem. At the end of winter, *Oidium caricae* also appeared on small areas and it was controlled by applying Ospo V®-Agrotecnología sulphur (Orihuela, Spain) (a product made from vegetal extracts, flavonoids, alkaloids, phenols, macro and microelements, polysaccharides and microorganism extracts) and Larekigreens®, Biofungitek, (Derio, Spain) (a product made from potassium carbonate and vegetal extracts).

2.5. Harvest Time

The fruit harvest was carried out from October 2016 to the beginning of August 2017, and it began 193 days after transplanting (dat), first season. Then it began at the end of August 2017 until the middle of June 2018 (second season). Within the mentioned periods, the harvest was carried out every week in color stage 2 to 3 using the color stage values of Santamaría-Basulto et al. [26]. The maturity stage 2 corresponds with yellow coloring fruit between 25% and 33%. The maturity stage 3 corresponds with yellow coloring fruit between 33% and 40%. In the spring-summer weeks, the harvest was only carried out at maturity stage 2. The harvest was carried out one day per week in winter and four days per week in spring-summer.

The fruits were weighted with a BBA422-60LA BASIC (Mettler Toledo, L'Hospitalet de Llobregat, Spain) scale with a maximum capacity of 60 kg and ± 1 g sensitivity.

2.6. Comparison of Economic Data between the Papaya Cultivation and Crops currently Grown in the High-Yield Agricultural Intensive Model in Almería

The economic comparison was made under the principles of maximization of benefits by farmers. Hence, to evaluate the opportunity of the different crop alternatives, the net profit before taxes (NPbt) has been used for each possible crop combination [27–29]. NPbt was calculated as a difference between the total annual sales revenue (TAR) and the total costs (TC) incurred in each campaign.

$$\text{NPbt} = \text{TAR} - \text{TC}$$

With NPbt: Net Profit before taxes; TAR: Total Annual Revenue; TC: Total costs.

The structure of revenues and expenditure which was followed to conduct this research, was agreed by the "Experimental Plot of the Foundation University of Almería-Anecoop", where the experiment was conducted. Additionally, the structure obtained by Toresano and Camacho for Agroseguros, S.A.-Spain [30] was followed, data not published corresponding with the Provision of Services PS20120000000000184 of the Research Results Transfer Office (OTRI) of the University of Almería.

To make a comparison between the crops, five different agronomic alternatives were taken as a reference from the species with which the model works (four cucurbits, three solanaceous, and one leguminous plants). In this sense, a different crop was planted after each cycle, except for the case of long-cycle tomato. Therefore, the first four alternatives were formed by crops developed in short cycles, every six months (two harvest per year), and the fifth alternative began with a courgette crop, short cycle (6 months), and when it finished, two tomato harvests followed it, long cycle (12 months), until total period of 30 months was completed.

These alternative crops are usual in the intensive agriculture model in the Spanish southeast [8].

To make an economic comparison, the horticultural alternatives studied against the new papaya crop were:

Horticultural 1: watermelon (2016) + tomato (2016) + courgette (2017) + pepper (2017) + watermelon (2018).

Horticultural 2: tomato (2016) + cucumber (2016) + aubergine (2017) + green bean (2017) + melon (2018).

Horticultural 3: melon (2016) + pepper (2016) + watermelon (2017) + tomato (2017) + melon (2018).

Horticultural 4: courgette (2016) + aubergine (2016) + melon (2017) + pepper (2017) + watermelon (2018).

Horticultural 5: Courgette (2016) + tomato (2016–2017) + tomato (2017–2018).

The technical characteristics of the productive infrastructures, to obtain economic data with respect to investment cost and its corresponding depreciations, are as follows:

Papaya: Multitunnel greenhouse described above in Section 2.2.

Long-cycle horticultural crops: Almería type "raspa y amagado" greenhouse with 6.00 m ridge height, 5.00 m gutter height (amagado), and 4.70 m wall height [8].

Short cycle horticultural crops: Almería type "raspa y amagado" greenhouse, with 4.50 m ridge height, 3.50 m gutter height (amagado), and 3.00 m wall height. These are the dimensions of the "fashionable greenhouse" obtained by Valera et. al. [8]

The rest of infrastructures of production, climate control, and irrigation systems were the same in the different cases analyzed. The energy costs in the papaya cultivation and in the horticultural alternatives were the same in this study. The greenhouses were naturally ventilated without any heating system.

The amount of the total revenues from papaya cultivation was obtained from the real value in euros of the production which was sold during the corresponding field trial. In the case of horticultural alternatives (Horticultural 1 to Horticultural 5), the value of the total revenues was calculated by multiplying the average yield (kg/m^2) of each crop by the corresponding average campaign price (€/kg) (see Table 2 and Appendix A, Table A1) [17].

With respect to current expenditure, technical assessment was the same for the eight crops studied. Soil preparation was adjusted depending on the cycle length, 6, 12, or 30 months. The covering and structure depend on the type of greenhouse used and the size of the plastic covering, which also depends on the greenhouse size and the difference of labour costs to replace the greenhouse plastic which, in turn, and also depends on the structure and height of the greenhouse covering. For seeds and seedling production, the data were obtained according to the costs of each year.

In the case of water, fertilizers, phytosanitary products, labor costs, stakes, auxiliary insects, and management of crop residues, the guidelines marked individually for each crop and cycle by Toresano and Camacho [30] were followed. It is important to highlight the economic percentage weight that labor costs have within the current costs, once the work units were assessed (Table 3).

Table 3. Economic percentage weight of labor on current expenses of horticultural crops that occur in the southeast of Spain (Toresano and Camacho) [30].

Culture	Tomato	Sweet Pepper	Cucumber	Aubergine	Courgette	Green Bean	Melon	Watermelon
Percentage	52.66	47.32	45.40	52.07	86.44	42.00	22.33	21.19

3. Results and Discussion

Based on the obtained yield, the harvest of papaya (after assessing the yield parameters, average fruit weight, and soluble solids in °Brix) is appropriate to put papaya on the European market, since they have similar characteristics to those that are being imported to Europe from other continents.

3.1. *Total Yield of Papaya*

In the first season, 81 harvests were carried out between weeks 41 in 2016 and 31 in 2017. In the second season, 68 harvests were carried out between weeks 35 in 2017 and 25 in 2018. The total yield was 27.63 kg·m^{-2} (see Appendix A, Table A2).

The results obtained in this experiment of 276.3 t·ha^{-1}, are higher than those obtained in studies from Costa Rica by Guzmán Díaz [31], which varied between 40 and 70 t·ha^{-1}, and Jiménez Díaz [32], who obtained 89 t·ha^{-1} in a three-year cycle. In Mexico, Escamilla et al. [33] conducted an experiment to study yield of cultivarMaradol papaya and obtained 27.94 t·ha^{-1}. In India Singh et al. [34] reported yields between 65 and 93 t·ha^{-1}. In other experiments in India, Jeyakumar et al. [35], reported yields between 139.3 and 184.9 t·ha^{-1}. and Bhalerao et al. [36] obtained between 51.83 and 80.76 t·ha^{-1}. Migliaccio et al. [37] carried out an experiment in Florida (USA) and obtained yields between 152 and 193 t·ha^{-1}.

The difference in total production of papaya produced in Almería with respect to total production for other countries mentioned, is due to the production system. In effect, in Almería the papaya is cultivated under greenhouses while in the rest of the countries, this is an open field cultivation.

3.2. Average Fruit Weight (AFW) of Papaya

The fruits harvested in the second season weighed more than those obtained in the first season.

These data are consistent with those obtained by Pérez Hernández [23], in an experiment conducted with 10 different varieties, where the fruit harvested in the second season weighed more than those obtained in the first season.

The weight obtained in the fruits has an acceptable demand in the European market. The weight of the Intenzza fruit in this experiment had the size G (801–1100 g) and H (1101–1500 g), described in the International FAO (Food and Agriculture Organization of the United Nations) Standards for papaya cultivation [38].

3.3. Number of Fruits per Plant

The number of fruits per plant in the second season was lower. There is a relationship between fruit size and number of fruits per plant.

3.4. Total Soluble Solids

The analysis of total soluble solids was made for the °Brix average and for the maximum °Brix in fruits. The values obtained throughout the harvest time varied between 10.00 and 10.30 °Brix.

These values were similar to those obtained by Pérez Hernández [23] for the Intenzza variety grown in the Canary Islands. The values are also similar to the results obtained by Santamaría et al. [39] in Costa Rica. The data obtained in the experiment permitted the sale of papaya fruits in different European countries.

3.5. Comparative of Results: Horticultural Alternatives Versus Papaya Cultivation

After the analysis of the structure of revenues and costs of the main combinations of horticultural crops in the southeast of Spain, a comparison of the economic yields was made with those obtained by papaya cultivation as described above (see Tables A2–A7 in the Supplementary Material, Appendix A). In the case of papaya cultivation, the real costs and revenues were taken into account, whereas in the case of the different horticultural alternatives, the production data and prices used were published by official bodies [17,40]. Furthermore, the detail of horticultural costs, attributable to each alternative, comes from the cost analysis updated by Toresano and Camacho for Agroseguros, S.A.-Spain [30]. The results of the comparison of papaya crop with five crops that are usually cultivated in the Province of Almería are detailed and represented in Tables A2–A7 (see the Supplementary Material, Appendix A). The data of Table 4 are obtained from Tables A2–A7 and represent a resume of the comparison for the five crops.

Table 4. Structure of revenues and costs per hectare of five horticultural alternative crops versus papaya cultivation, analyzed from February 2016 to July 2018.

Comparison. Feb 2016 to July 2018	Horticultural Alternative 1	Horticultural Alternative 2	Horticultural Alternative 3	Horticultural Alternative 4	Horticultural Alternative 5	Papaya Cultivation
Total annual revenues (€)	193,805	203,845	188,498	158,765	281,560	248,013
Total variable cost (€)	177,390	191,244	179,599	175,953	194,971	135,618
Technical assessment (€)	772	772	772	772	772	772
Soil preparation (€)	19,458	19,458	19,458	19,458	11,575	3839
Covering and structure (€)	11,846	11,846	11,846	11,846	11,846	12,297
Seeds and seedling production (€)	17,983	22,588	25,630	18,741	14,689	13,500
Growing and development until 1st inflorescence (€)	41,947	35,401	34,958	43,591	32,898	33,131
Flowering periods until 1st harvesting season (€)	25,779	33,679	25,862	18,771	31,380	37,570
From the 1st harvesting season until the end of the cultivation (€)	59,605	67,499	61,073	62,772	91,811	34,510
Total fixed costs (€)	49,052	49,052	49,052	49,052	53,693	54,859
Soil maintenance (€)	5140	5140	5140	5140	5140	5125
Covering and structure (€)	10,287	10,287	10,287	10,287	10,287	10,257
Energy and fixed supplies (€)	4063	4063	4063	4063	4063	4051
Insurance, management, and financial services (€)	8947	8947	8947	8947	8947	8920
Equipment and irrigation system (€)	20,615	20,615	20,615	20,615	25,256	26,506
Total cost (€)	226,443	240,296	228,651	225,005	248,664	190,477
Net profit before taxes (€)	−32,638	−36,451	−40,153	−66,240	32,896	57,535

Source: Own elaboration from a field trial (papaya), Toresano and Camacho [30] and Annual Report of the Regional Department of Agriculture, Rural Development and Fisheries [17].

Table 4 shows the profit and loss account of each of the alternatives that are compared, that is, the five horticultural combinations with papaya cultivation. In the case of papaya, the revenues that were calculated in the experiment were those received by the sale of this fruit. The data are obtained from Table A2 (see Supplementary Material, Appendix A). All the papaya fruits coming from the Experimental Plot of the Foundation University of Almería-Anecoop were put on the market through a company operating in the region, which is a specialist in introducing new fruits to European markets. This company grew 10 papaya hectares on its own plots of land and on other plots belonging to its associates. In all the cases, the comparisons were made for the same period, from February 2016 to July 2018.

The data of total annual revenues for each cultivation in this table are provided in the Supplementary Material—Tables A2–A7 in Appendix A. To have a global visualization of the comparison between the five horticultural alternatives and papaya crop, the total annual revenues, the total costs, and the net profit (before taxes) are represented in Figure 4 for each case. The data were obtained from Table 4. Figure 4 shows the comparison between papaya cultivation in southeast Spain with the different proposed horticultural alternatives. In this figure, four out of the five combinations of horticultural crops generate losses within the period analyzed (February 2016 to July 2018) and only the combination called "Horticultural 5" gives profits.

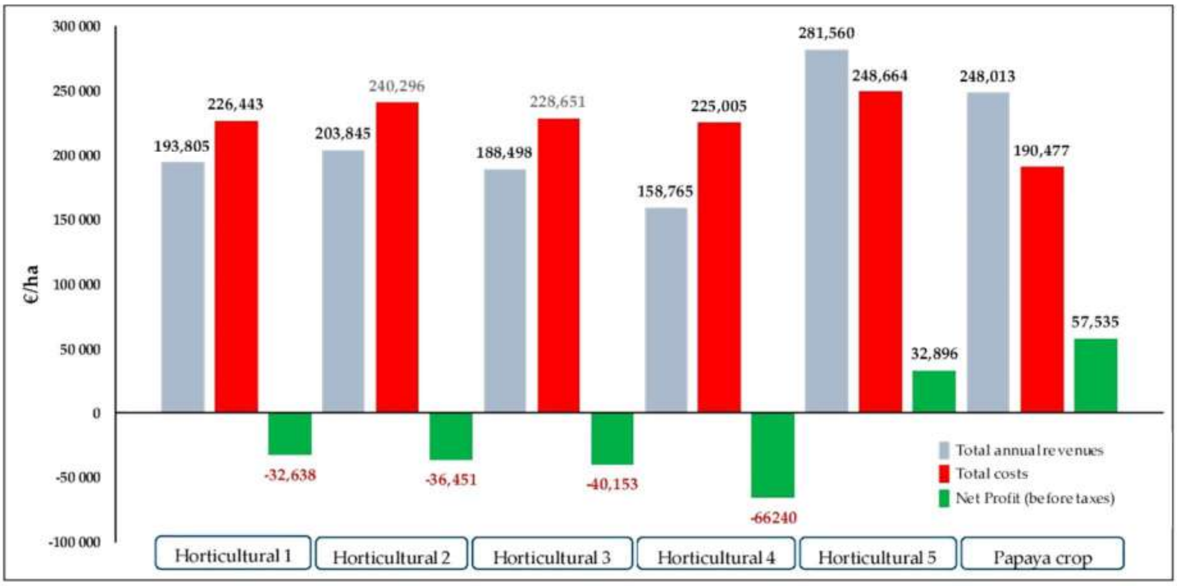

Figure 4. Comparison between the economic results (€/ha) of the proposed horticultural alternatives and the cultivation of the papaya in a 30-month cycle (2016–2018). Total annual revenues ( ); Total costs ( ); Net Profit (before taxes) ( ). Own elaboration.

The question that needs to be asked is how can this horticultural production model be maintained, especially in the "Horticultural 1 to Horticultural 4" combinations? As certain studies had anticipated [41], the answer must be sought in the structure of the revenue statements of each farm and not from a business logic, profit maximization, but in a way to subsist in a mature sector. In this sense, there are two accounting entries that are not assessed in terms of opportunity costs by the owners of the farming business. These are labor costs and annual depreciation costs:

1. There are some studies that place labor costs between 25% and 40% of the annual costs of a farming business under greenhouses [42,43]. In this sense, the field study that was carried out by Valera et al. [8] showed that the owner of the farming business, together with their staff, is another worker. Therefore, when there are losses, as described in the combinations "Horticultural 1 to Horticultural 4", the owner renounces his remuneration as owner of the means of production because they tend to reduce staff numbers and, together with their family, take roles which, during favorable economic conditions, would be filled with employed workers.

2. The annual depreciation cost of the greenhouse structure, the irrigation system and pools, represents the main part of the fixed costs of the farming business. According to Calatrava and Villa [44], the fixed costs of a greenhouse used for horticulture varies from 1 to 1.5 €/m^2. This result is in accordance with our calculations per hectare and cycle (see "Total fixed costs (€)", in Tables A2–A7, in Supplementary Material, Appendix A). In this case, the depreciation cost can reach 50% of the total fixed costs, from 4000 to 5000 Euros per hectare and cycle. In the case of producers with lower indebtedness and that have already paid for the farming business, they could have these amounts available because they would not be obliged to depreciate yearly. Considering the average area of the farming business in Almería, 23,508 m^2 [45], the depreciation costs of the greenhouse structures, irrigation systems and pools, would be higher than the costs stated in this article. Furthermore, the level of subsidies that the Almería intensive horticulture receives is low in relation to its size [8] and as has already happened in other productive sectors of the province. In the foreseeable future the subsidies should be reduced [46].

3. Finally, we calculated the accumulated net profit before taxes for each comparison of the horticultural alternatives and papaya crop during the period of 30 months (February 2016 to July 2018), time used for the trial with the papaya crop. Figure 5 represents the visualization of the accumulated monthly Net Profit before taxes (NPbt) for the most profitable crop (Horticultural 5 and the papaya cultivation, see Tables A2 and A7) during the period of the trial (30 months). In both cases, there was a positive net profit. Monthly, the calculated NPbt in each alternative is added the NPbt of the last month and cumulated, until the end of the period. The "Horticultural 5" contains a cycle of courgette cultivation and two cycles of tomato cultivation. Analyzing Figure 5, it can be highlighted that the farmers which choose the papaya cultivation should be conscious that they must have enough liquidity to maintain their business for 11 months (March 2017, in Figure 5). At this moment, the NPbt is positive. In the case of Horticultural 5, after 3 months (May 2016), the farmer can recover part of his investment, althought the cumulative NPbt is still negative. Most of the time, farmers prefer horticultural crops with short cycle, of 6 months, for which they begin to receive revenues for the sale of their products and to improve the cumulative NPbt, 40–45 days after sowing.

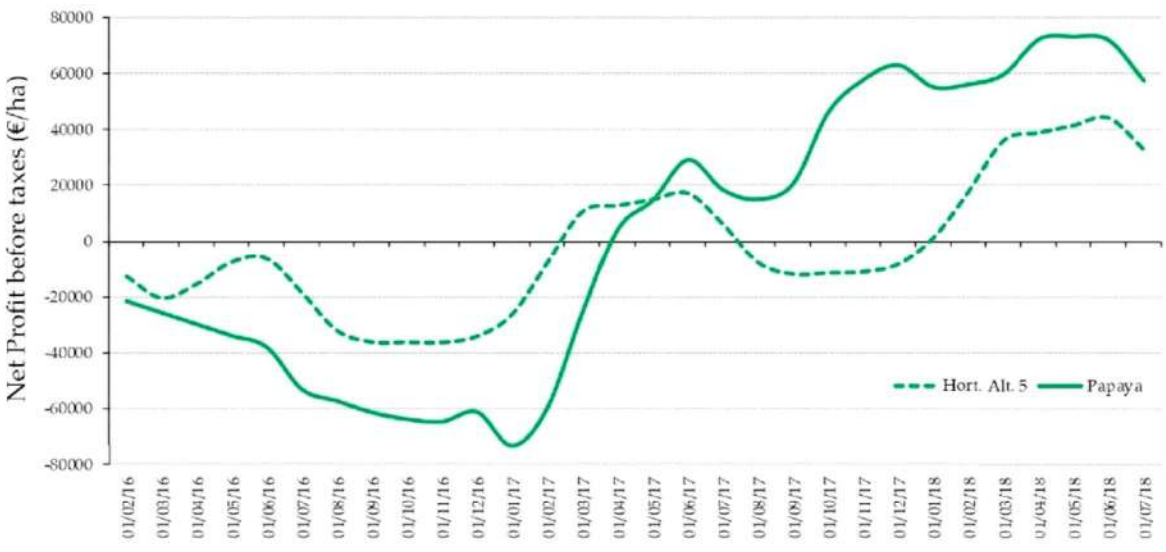

Figure 5. Monthly evolution of the accumulated Net Profit before taxes (NPbt) for Horticultural alternative 5 (---) versus papaya cultivation (—) (€/ha) during the trial period (February 2016 to July 2018). Own elaboration [17,30].

4. Conclusions

After analyzing the development of the areas and production of the main horticultural crops in southeast Spain, as well as the evolution of the average prices from 2009 to 2018, there are evident signs that the horticultural production model in Almería is at a mature stage. In addition to this, there is also an assessment of the alternative of papaya crops grown under greenhouses. After making a comparison of papaya crop with five crops that are usually cultivated in the Province of Almería, it can be observed that only one horticultural alternative gives positive results, from February 2016 to July 2018. For each one of those crops, the cultural system is very particular, and this is the reason why the comparison must be taken in the context of the province of Almería. For the cultivation of papaya, there was only one plantation (from February 2016 to July 2018, 30 months), and in the alternative five, three crops were planted (one cycle of courgette and two cycles of tomato), thus, to achieve a planting period similar to the papaya crop.

A detailed analysis of the profit and loss account for each of the horticultural alternatives allows a relationship to be drawn between the good results of the season with high sale prices, compared with the average of previous seasons in 2017, the year with best economic result for the horticultural production model in Almería. In 2017, an average price of 0.68 €·kg^{-1} was registered compared with the range from 0.50 to 0.59 €·kg^{-1} that was registered in the period 2009–2018. The producers of long-cycle tomatoes are the only ones who achieve reduction in their variable costs (in the phases from the "seed to the seedling in nursery" and the phase from "flowering to first harvesting season"), making the harvest period more continuous and, therefore, obtaining revenues from the sales of the horticultural commodities.

With the results of this work, it is demonstrated that papaya can be one of the crops for the Province of Almería to extend the range of products offered to the Northern European market. The papaya cultivation under greenhouses in this region is feasible, with higher yield obtained than in other countries, with local mature commercial channels which have the how-know to sell exotic commodities complying with the European marketing standards. The cultivation of this fruit under greenhouses in Almería can be a rentable and commercial activity for farmers.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Area, production, and price of horticultural crops in years 2016–2018.

Crop	2016			2017			2018		
	Area (ha)	Production (t)	Price (€·kg^{-1})	Area (ha)	Production (t)	Price (€·kg^{-1})	Area (ha)	Production (t)	Price (€·kg^{-1})
Watermelon	8590	532,288	0.318	8940	558,223	0.327	9860	512,742	0.407
Melon	2467	96,417	0.470	2220	93,527	0.448	2290	91,656	0.535
Courgette	7630	434,195	0.489	7970	448,975	0.681	7860	456,045	0.555
Cucumber	5026	438,870	0.418	4980	422,214	0.640	5099	443,604	0.501
Aubergine	2300	184,161	0.371	2,150	168,046	0.728	2,209	181,130	0.513
Tomato	10,940	1,107,706	0.527	10,220	1,008,867	0.714	10,380	996,254	0.621
Sweet pepper	9491	665,922	0.824	10,310	694,402	0.908	10,181	732,989	0.755
Green bean	1340	26,453	1.455	1030	21,001	1.747	510	10,224	1.584

Own elaboration made with data provided by Andalusian Regional Government (Almería, Spain) [17,30].

Table A2. Revenues and expenses per hectare imputed to the papaya cultivation in a 30-month cycle (2016–2018).

Papaya Cultivation	Papaya	Papaya	Papaya	Papaya	Papaya	Total
	February 2016 to July 2016	August 2016 to January 2017	February 2017 to July 2017	August 2017 to January 2018	February 2018 to July 2018	February 2016 to July 2018
Total annual revenues (€)	-	16,874	130,268	67,523	33,347	248,013
Yield (kg·ha^{-1})	-	12,532	127,809	85,727	50,213	276,282
Average price (€·kg^{-1})		1.326	1.013	0.784	0.665	0.893
Total variable cost (€)	42,022	26,162	27,645	19,889	19,900	135,618
Technical assessment (€)	152	152	155	155	158	772
Soil preparation (€)	3839	-	-	-	-	3839
Covering and structure (€)	2443	2443	2444	2480	2487	12,297
Seeds and seedling production (€)	13,500	-	-	-	-	13,500
Growing and development until 1st inflorescence (€)	22,087	11,044	-	-	-	33,131
Flowering periods until 1st harvesting season (€)	-	12,523	25,047	-	-	37,570
From the 1st harvesting season until the end of the cultivation (€)	-	-	-	17,255	17,255	34,510
Total fixed costs (€)	10,912	10,912	10,996	10,912	11,127	54,859
Soil maintenance (€)	1014	1014	1029	1014	1053	5125
Covering and structure (€)	2030	2030	2060	2030	2108	10,257
Energy and fixed supplies (€)	802	802	814	802	832	4051
Insurance, management, and financial services (€)	1765	1765	1792	1765	1833	8920
Equipment and irrigation system (€)	5301	5301	5301	5301	5301	26,506
Total cost (€)	52,934	37,074	38,641	30,801	31,027	190,477
Net profit before taxes (€)	−52,934	−20,201	91,627	36,722	2320	57,535

Own elaboration.

Table A3. Revenues and expenses per hectare imputed to the cultivation of the horticultural alternative 1 in a 30-month cycle (2016–2018).

Horticultural Alternative 1	Watermelon	Tomato	Courgette	Sweet Pepper	Watermelon	Total
	February 2016 to July 2016	August 2016 to January 2017	February 2017 to July 2017	August 2017 to January 2018	February 2018 to July 2018	February 2016 to July 2018
Total annual revenues (€)	19,716	53,385	38,340	61,199	21,164	193,805
Yield (kg·ha^{-1})	62,000	101,300	56,300	67,400	52,000	
Average price (€·kg^{-1})	0.318	0.527	0.681	0.908	0.407	
Total variable cost (€)	18,532	52,092	36,406	51,117	19,243	177,390
Technical assessment (€)	152	152	155	155	158	772
Soil preparation (€)	3839	3839	3897	3897	3986	19,458
Covering and structure (€)	2337	2337	2372	2372	2427	11,846
Seeds and seedling production (€)	1993	5639	1277	7005	2070	17,983
Growing and development until 1st inflorescence (€)	3173	7385	14,942	13,151	3295	41,947
Flowering periods until 1st harvesting season (€)	-	15,573	-	10,206	-	25,779
From the 1st harvesting season until the end of the cultivation (€)	7037	17,166	13,763	14,332	7307	59,605
Total fixed costs (€)	9678	9678	9823	9823	10,049	49,052
Soil maintenance (€)	1014	1014	1029	1029	1053	5140
Covering and structure (€)	2030	2030	2060	2060	2108	10,287
Energy and fixed supplies (€)	802	802	814	814	832	4063
Insurance, management, and financial services (€)	1765	1765	1792	1792	1833	8947
Equipment and irrigation system (€)	4067	4067	4128	4128	4223	20,615
Total cost (€)	28,211	61,770	46,230	60,940	29,292	226,443
Net profit before taxes (€)	−8495	−8385	−7889	259	−8128	−32,638

Own elaboration made with revenue data provided by Andalusian Regional Government [17,30].

Table A4. Revenues and expenses per hectare imputed to the cultivation of the horticultural alternative 2 in a 30-month cycle (2016–2018).

Horticultural Alternative 2	Tomato	Cucumber	Aubergine	Green Bean	Melon	Total
	February 2016 to July 2016	August 2016 to January 2017	February 2017 to July 2017	August 2017 to January 2018	February 2018 to July 2018	February 2016 to July 2018
Total annual revenues (€)	53,385	36,491	56,930	35,639	21,400	203,845
Yield (kg·ha^{-1})	101,300	87,300	78,200	20,400	40,000	
Average price (€·kg^{-1})	0.527	0.418	0.728	1.747	0.535	
Total variable cost (€)	52,092	42,301	41,681	25,851	29,318	191,244
Technical assessment (€)	152	152	155	155	158	772
Soil preparation (€)	3839	3839	3897	3897	3986	19,458
Covering and structure (€)	2337	2337	2372	2372	2427	11,846
Seeds and seedling production (€)	5639	6901	2984	1470	5594	22,588
Growing and development until 1st inflorescence (€)	7385	8472	6907	6889	5748	35,401
Flowering periods until 1st harvesting season (€)	15,573	7063	8694	2349	-	33,679
From the 1st harvesting season until the end of the cultivation (€)	17,166	13,536	16,673	8720	11,404	67,499
Total fixed costs (€)	9678	9678	9823	9823	10,049	49,052
Soil maintenance (€)	1014	1014	1029	1029	1053	5140
Covering and structure (€)	2030	2030	2060	2060	2108	10,287
Energy and fixed supplies (€)	802	802	814	814	832	4063
Insurance, management, and financial services (€)	1765	1765	1792	1792	1833	8947
Equipment and irrigation system (€)	4067	4067	4128	4128	4223	20,615
Total cost (€)	61,770	51,980	51,505	35,674	39,367	240,296
Net profit before taxes (€)	−8385	−15,488	5425	−36	−17,967	−36,451

Own elaboration made with revenue data provided by Andalusian Regional Government [17,30].

Table A5. Revenues and expenses per hectare imputed to the cultivation of the horticultural alternative 3 in a 30-month cycle (2016–2018).

Horticultural Alternative 3	Melon	Sweet Pepper	Watermelon	Tomato	Melon	Total
	February 2016 to July 2016	August 2016 to January 2017	February 2017 to July 2017	August 2017 to January 2018	February 2018 to July 2018	February 2016 to July 2018
Total annual revenues (€)	18,377	57,845	20,405	70,472	21,400	188,498
Yield (kg·ha^{-1})	39,100	70,200	62,400	98,700	40,000	
Average price (€·kg^{-1})	0.470	0.824	0.327	0.714	0.535	
Total variable cost (€)	28,235	50,361	18,810	52,873	29,318	179,599
Technical assessment (€)	152	152	155	155	158	772
Soil preparation (€)	3839	3839	3897	3897	3986	19,458
Covering and structure (€)	2337	2337	2372	2372	2427	11,846
Seeds and seedling production (€)	5388	6901	2023	5723	5594	25,630
Growing and development until 1st inflorescence (€)	5536	12,957	3221	7496	5748	34,958
Flowering periods until 1st harvesting season (€)	-	10,055	-	15,807	-	25,862
From the 1st harvesting season until the end of the cultivation (€)	10,983	14,120	7143	17,424	11,404	61,073
Total fixed costs (€)	9678	9678	9823	9823	10,049	49,052
Soil maintenance (€)	1014	1014	1029	1029	1053	5140
Covering and structure (€)	2030	2030	2060	2060	2108	10,287
Energy and fixed supplies (€)	802	802	814	814	832	4063
Insurance, management, and financial services (€)	1765	1765	1792	1792	1833	8947
Equipment and irrigation system (€)	4067	4067	4128	4128	4223	20,615
Total cost (€)	37,914	60,040	28,634	62,697	39,367	228,651
Net profit before taxes (€)	−19,537	−2195	−8229	7775	−17,967	−40,153

Own elaboration made with revenue data provided by Andalusian Regional Government [17,30].

Table A6. Revenues and expenses per hectare imputed to the cultivation of the horticultural alternative 4 in a 30-month cycle (2016–2018).

Horticultural Alternative 4	Courgette	Aubergine	Melon	Sweet Peper	Watermelon	Total
	February 2016 to July 2016	August 2016 to January 2017	February 2017 to July 2017	August 2017 to January 2018	February 2018 to July 2018	February 2016 to July 2018
Total annual revenues (€)	27,824	29,717	18,861	61,199	21,164	158,765
Yield (kg·ha^{-1})	56,900	80,100	42,100	67,400	52,000	
Average price (€·kg^{-1})	0.489	0.371	0.448	0.908	0.407	
Total variable cost (€)	35,868	41,065	28,659	51,117	19,243	175,953
Technical assessment (€)	152	152	155	155	158	772
Soil preparation (€)	3839	3839	3897	3897	3986	19,458
Covering and structure (€)	2337	2337	2372	2372	2427	11,846
Seeds and seedling production (€)	1258	2940	5469	7005	2070	18,741
Growing and development until 1st inflorescence (€)	14,722	6805	5619	13,151	3295	43,591
Flowering periods until 1st harvesting season (€)	-	8565	-	10,206	-	18,771
From the 1st harvesting season until the end of the cultivation (€)	13,560	16,427	11,148	14,332	7307	62,772
Total fixed costs (€)	9678	9678	9823	9823	10,049	49,052
Soil maintenance (€)	1014	1014	1029	1029	1053	5140
Covering and structure (€)	2030	2030	2060	2060	2108	10,287
Energy and fixed supplies (€)	802	802	814	814	832	4063
Insurance, management, and financial services (€)	1765	1765	1792	1792	1833	8947
Equipment and irrigation system (€)	4067	4067	4128	4128	4223	20,615
Total cost (€)	45,546	50,744	38,482	60,940	29,292	225,005
Net profit before taxes (€)	−17,722	−21,026	−19,622	259	−8128	−66,240

Own elaboration made with revenue data provided by Andalusian Regional Government [17,30].

Table A7. Revenues and expenses per hectare imputed to the cultivation of the horticultural alternative 5 in a 30-month cycle (2016–2018).

Horticultural Alternative 5	Courgette	Tomato	Tomato	Tomato	Tomato	Total
	February 2016 to July 2016	August 2016 to January 2017	February 2017 to July 2017	August 2017 to January 2018	February 2018 to July 2018	February 2016 to July 2018
Total annual revenues (€)	27,824	48,895	73,343	52,599	78,899	281,560
Yield (kg·ha^{-1})	56,900	78,800	118,200	78,800	118,200	
Average price (€·kg^{-1})	0.489	0.621	0.621	0.668	0.668	
Total variable cost (€)	35,868	45,977	30,156	46,755	36,214	194,971
Technical assessment (€)	152	152	155	155	158	772
Soil preparation (€)	3839	3839	-	3897	-	11,575
Covering and structure (€)	2337	2337	2372	2372	2427	11,846
Seeds and seedling production (€)	1258	5638	-	5723	2070	14,689
Growing and development until 1st inflorescence (€)	14,722	7385	-	7496	3295	32,898
Flowering periods until 1st harvesting season (€)	-	15,573	-	15,807	-	31,380
From the 1st harvesting season until the end of the cultivation (€)	13,560	11,052	27,629	11,306	28,265	91,811
Total fixed costs (€)	10,662	10,662	10,746	10,746	10,877	53,693
Soil maintenance (€)	1014	1014	1029	1029	1053	5140
Covering and structure (€)	2030	2030	2060	2060	2108	10,287
Energy and fixed supplies (€)	802	802	814	814	832	4063
Insurance, management, and financial services (€)	1765	1765	1792	1792	1833	8947
Equipment and irrigation system (€)	5051	5051	5051	5051	5051	25,256
Total cost (€)	46,530	56,639	40,902	57,501	47,092	248,664
Net profit before taxes (€)	−18,706	−7743	32,441	−4902	31,807	32,896

Own elaboration made with revenue data provided by the Andalusian Regional Government [17,30].

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Efecto sobre la temperatura de una cubierta ligera de agrotextil que envuelve la fruta de Carica papaya en un invernadero mediterráneo de ventilación pasiva.

(Artículo 4. Effect on temperature of lightweight plant cover enveloping papaya fruit (*Carica papaya* L.) in a naturally ventilated Mediterranean greenhouse)

ARTÍCULO 4

Autores: **M.N. Honoré, L.J. Belmonte-Ureña, F.D. Molina-Aiz, F. Camacho-Ferre**

Effect on temperature of lightweight plant cover enveloping papaya fruit (*Carica papaya* L.) fruit in a naturally ventilated Mediterranean greenhouse

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Effect on temperature of lightweight plant cover enveloping papaya fruit (*Carica papaya* L.) in a naturally ventilated Mediterranean greenhouse

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Abstract

In recent years, the traditional horticultural crops in greenhouse on the Mediterranean coast as tomato have lost profitability. In this situation, a possible alternative is the production of tropical crops like *Carica papaya*. The plant growth in continental Europe presents the handicap of the low winter temperatures. When air temperature falls below 12-14 °C for several hours at night, papaya production can be affected. The objective of the present study was to analyse the effect of wrapping fruits with polypropylene lightweight nonwoven curtain on the daily thermal oscillations and the production, in a naturally ventilated multispan greenhouse (1800 m²) in Almeria (Spain). White lightweight cover was placed around the fruit column, leaving the leaves out of the cover. The covers were used from December 11th, 2017 to April 19th, 2018 and placed around 30 trees in 111.11 m². Alternate rows with plant cover and without it were placed in the greenhouse. Temperature and humidity sensors were laid next to the unwrapped fruits at 1.5 m above the ground, in each row. At the same height, in plants with a plant cover, two sensors were placed close to the fruits, one inside the light white cover and one outside. As a result of the use of the plant cover, the minimum and mean temperature of the air inside of the thermal cover increased respectively 1 and 0.7°C. The augmentation temperature seems to induce an early production. The diurnal temperature range was reduced, and the reduction values were in the range of 0.4-1.2°C. No statistically significant increase in the yield (during the period using the plant cover) was observed in the wrapping plants, although production was 4.3 kg·m^{-2} for protected plants and 3.5 kg·m^{-2} without protection.

Keywords: papaya, winter, protected cropping, thermal cover, growing degree days, yield, early production

INTRODUCTION

Papaya *(Carica papaya* L.*)* is the third most consumed tropical fruit in Europe and the third most cultivated in the world, after mango and pineapple. India with 5.940.000 t, Brazil with 1.057.101 t, Mexico with 961.768 t are the first worldwide producers of this fruit (FAO, 2019). The five top main importers of papaya in Europe are Holland with 5482 t, Spain with 2335 t, Germany with 2251 t, Portugal with 1030 t and Belgium with 622 t. The first EU suppliers in 2018 were Brazil with 38.286 t, Ghana with 1057 t, Thailand with 878 t, Jamaica with 538 t, Mexico with 283 t, Costa Rica with 130 t and Dominican Republic with 129 t (EC, 2019).

The climate of the south of Spain allows the cultivation of papaya under greenhouse. The first preliminary trials of papaya cultivars were carried out in the Canary Islands, to determine the yield of the 'Intenzza' papaya cultivar, among others (Lobo Rodrigo and Pérez Hernández, 2012). In Almería, some farmers have set their interest in this tropical crop, being an alternative to horticultural crops under greenhouse, because the demand in Europe for fresh tropical fruits is growing. In the province of Almería, more than 100 hectares of papaya are cultivated. Nevertheless, Papaya is susceptible to low temperatures. And the low Winter temperatures represent a handicap for production. Nakasone and Paull (1998) describe that optimum temperature for growth is between 21 and 33°C and say that if the temperature falls below 12-14°C for several hours at night, growth and production are severely affected. In Almeria, the coldest months (with medium temperature below 12°C) are those from November to March. Cold temperatures can cause chilling injuries to the fruit and so the commercial quality of the fruit is poor.

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Chilling injury occurs at temperatures that are too low for normal growth but are above freezing. When plants grown at relatively warmer temperature (25–35 °C) are exposed to colder temperatures (10–15 °C), chilling injury occurs (Taiz *et al.*, 2015). In Almería, this situation may occur frequently during the winter and the spring when the temperature inside the greenhouse can rise above 20°C and fall during the night under 10°C. For this reason, the farmers usually install some material, like aluminized screens or double plastic under the cultivation, to minimize the thermal shock. The aim of this study is to observe the effect of wrapping *Carica papaya* fruits with a light cover in the trunk, on the yield and the daily thermal oscillations in a commercial greenhouse.

MATERIAL AND METHODS

Experimental equipments, soil, fertigation

This experiment was conducted from December 11th, 2017 to April 19th, 2018 in a multispan greenhouse of 1800 m^2 (Fig. 1) at the Experimental Station UAL-ANECOOP "Catedrático Eduardo Fernandez" in the province of Almería on the Mediterranean coast in south-eastern Spain (Longitude: 2°170 W, Latitude: 36°510 N and altitude: 90 m above mean sea level). The ridges of the greenhouse were East-West oriented, and the crops rows were aligned north to south.

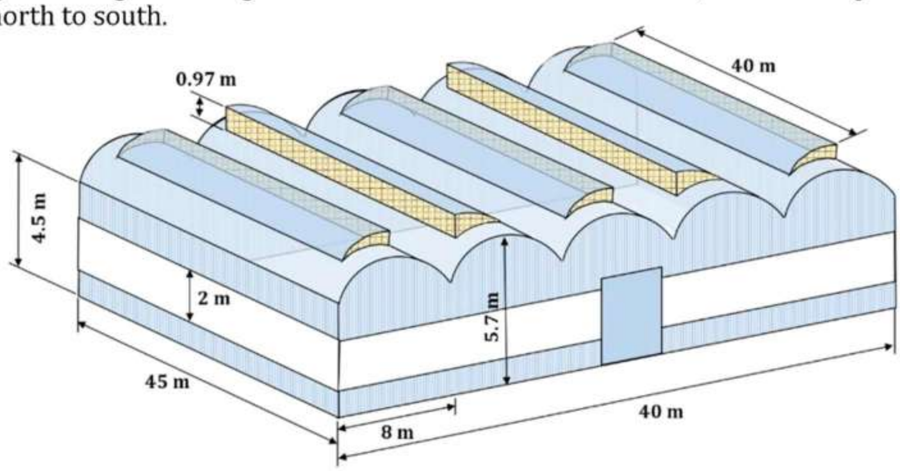

Figure 1. Outline of the experimental greenhouse of the study with papaya cultivation.

The covering of the greenhouse is made of a three-layer thermal plastic of 200 microns thick, low density polyethylene film (LDPE). The greenhouse had roof vents in each span powered by motors and a pinion-rack system, whose opening was controlled by temperature and wind sensors. In fall-winter, the East oriented continuous side vents were closed. There were opened in spring-summer, in May of 2018. The cultivation was carried out in a ground composed of a mixture of sand and soil. Sand is used to cover the soil after adding 10 $kg{\cdot}m^{-2}$ of manure. This is a common technique in greenhouses of Almeria (Valera et al., 2016). The previous crops in this soil were tomato, pepper, zucchini and cucumber for thirteen years.

Plant irrigation was done through a drip irrigation system. Each plant row had two lines of droppers with a diameter of 16 mm, made of a low-density polyethylene. The drippers were integrated in the line, with discharge of 3 $L{\cdot}h^{-1}$ and the distance between them was 37 cm. Tensiometers were used for the irrigation control, initiating irrigation with 20 cbar and stopping at 10 cbar (during Spring-Summer), being the values in Autumn-Winter 35 to 18 cbar respectively. The fertilizer used, UNIQUA TROP® by MEGASA, was made ad hoc for the cultivation, and had the following characteristics. NPK+Ca+Mg: 2.9–1.3–5.7 (2.2–0.5).

Nutrition was initiated by raising the electrical conductivity (EC) of irrigation water 0.5 $dS{\cdot}m^{-1}$, ending in the winter with 2.5 $dS{\cdot}m^{-1}$ above the EC of irrigation water. The EC of the irrigation water was 4.65 $dS{\cdot}m^{-1}$ in the saturation extract. A mix of microelements were added to UNIQUA TROP®. The microelements had the following proportions: Iron (Fe) 7.5%, Manganese (Mn) 2.5%, Copper (Cu) 0.15%, Zinc (Zn) 0.1%, Boron (B) 1.25%, and Molybdenum (Mo) 0.25%. The dosage of the mixing with the water was 20 $g{\cdot}m^{-3}$.

Experimental design and plant material

North and south plots are both separated by a central corridor of 90 m^2. The experiment was carried out in the south side, in an area of 229.63 m^2. All the south area of the greenhouse was planted with the cultivar of papaya called 'Intenzza' , but with different experiments. The seeds of 'Intenzza' are commercialized by "Semillas del Caribe". The fruit of 'Intenzza' papaya had a weight between 1.50 and 2.20 kg. It was developed for the market of medium papayas or type Formosa. His skin is yellow orange when ripe, with a red flesh (Semillas del Caribe, 2015). The plant was early sex - identified when it was in a cotyledon state, 40 days after sowing (DAS) in the Vitalplant nursery. The sex was previously determined with the technique of the molecular markers "random amplification of Polymorphic DNA" (RAPD) as described (Chaves-Bedoya et al., 2009). The transplant was made the 5th of April of 2017, with one plant per pot, with a plant height of 60 cm, and a root ball of 2 L.

The distribution of the plants was made in paired and staggered rows with 2.20 m between paired rows, 1.10 m between lines and 2.00 m between plants. The plant density was 2700 plants/ha. Each side of the greenhouse had 26 rows of plants, but the experiment was carried out in the south from the 10th to the 17th row (Fig. 2).

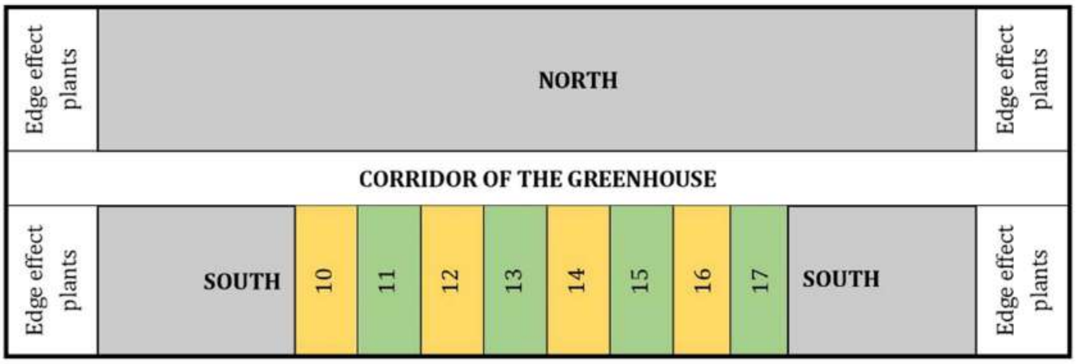

Figure 2. Location of the plants within the greenhouse (229.63 m^2). Crop lines with a lightweight cover wrapping each papaya trunk (□) and lines without the cover (□).

a) b)

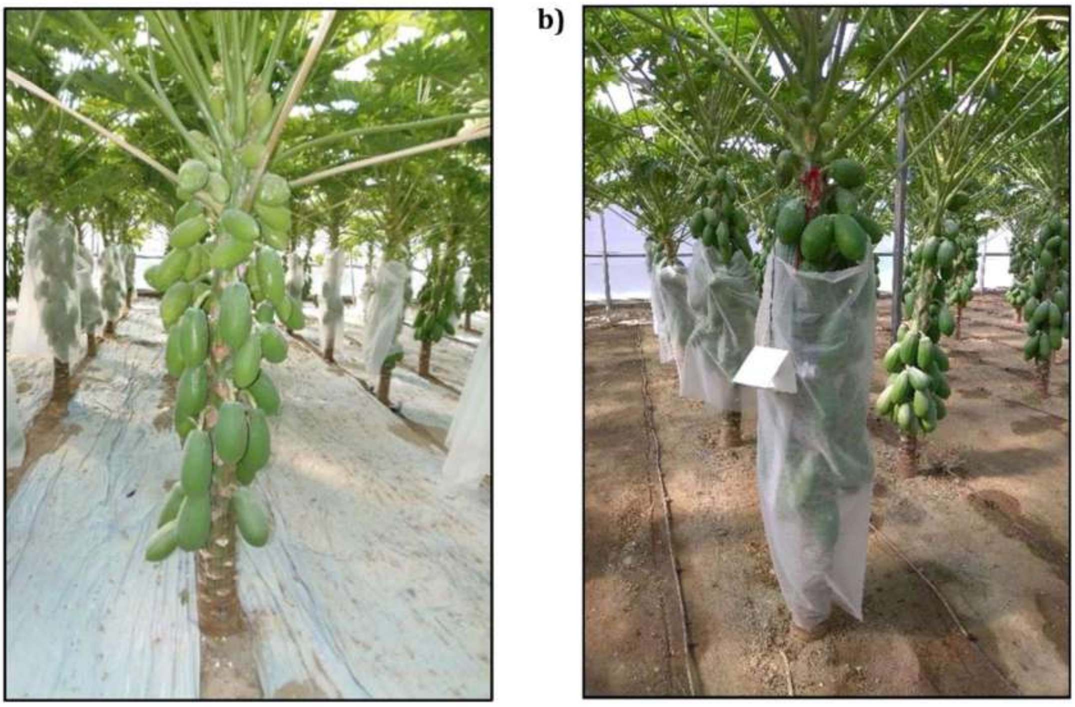

Figure 3. Vision of the 14-15-16th rows of the papaya trees with the thermal cover in the experimental trial, 288 DAS (a) and detail of sensors Hobo Pro v2 installed inside and outside the thermal cover with a radiation shield (b).

For each treatment, there were:

- Treatment TC (with thermal cover): 30 hermaphrodite plants of the 'Intenzza' cultivar. The area for this treatment was 111.11 m^2.
- Treatment N (plants naked): 32 hermaphrodite plants of the 'Intenzza' cultivar. The area for this treatment was 118.52 m^2.

Table 1. Location and surfaces of the plants covered (TC) or not (N) by the thermal lightweight.

Treatment	Row Index	Nb. of plants	Surface (m^2/row)
Thermal cover (TC)	10	8	29.63
Without protection (N)	11	8	29.63
Thermal cover (TC)	12	6	22.22
Without protection (N)	13	8	29.63
Thermal cover (TC)	14	8	29.63
Without protection (N)	15	8	29.63
Thermal cover (TC)	16	8	29.63
Without protection (N)	17	8	29.63

The temperature and humidity were measured close to the fruit with a weatherproof data logger HOBO Pro v2 U23-001 (Onset Computer Corporation, Bourne, USA), with built-in temperature and relative humidity sensors, with accuracies of ±0.21°C (from 0° to 50°C) and ±2.5% (from 10% to 90% RH). In each row of uncovered trees, one sensor was placed in the 5th tree of the row at 1.5 m above the ground. In the row of trees with the thermal plant cover, two sensors were placed at 1.5 m above the ground. One of them was placed inside the thermal blanket, and the other one was placed outside, protected with an open radiation shield. Data was recorded every minute.

Harvesting seasons

During this experiment, the fruit harvesting was carried out with the maturity stage of 2 and 3 as described (Santamaria et al., 2009). The maturity stage 2 corresponds with a visual aspect of green fruit but with a light-yellow coloring between 25-33%. The maturity stage 3 corresponds with yellow coloring fruit between 34-40 %, with one or more orange-colored stripes in skin. (See Figure 4).

Figure 4. Visual aspect of '*Intenzza*' papaya fruit picked at the maturity stage of 3 during this experiment in the greenhouse.

The harvest was carried out one day per week in winter at the maturity stage of 3 and until two days per week at the beginning of March (just before Spring); at this moment the harvest was only carried out at maturity stage 2. In each harvest, the number of fruits for each treatment, and their weight were noted. The fruits weighted during the harvesting of each row and so for each treatment (TC and N) were differentiated by placing an identification plate in the plastic harvesting crates. To weigh the fruits in the field, a Mettler

Toledo BBA422- 60LA BASIC (L'Hospitalet de Llobregat, Spain) scale was used, with a maximum capacity of 60 kg and a repeatability of 1 g.

Statistical analysis

For the assessment of the yield, the data were analysed for each treatment with the weight of all the harvested fruits. The different parameters measured for each treatment of the papaya cultivation were statistically treated with the software STATGRAPHICS® Centurion XVIII version 18.1.06 (64 bits) (Statpoint Technologies, Warrenton, United States of America, Inc. 1982–2018), using an analysis of variance (considered significant if p-value ≤ 0.05), by contrasting the average values using Fischer's Minimum significant difference (LSD) test. The analysis to verify that the different median of the two treatments for each parameter analysed have a similar variance was carried out using the test of Kruskal-Wallis, not observing statistically significant differences in any case (Statgraphics, 2017).

RESULTS AND DISCUSSION

Effect of wrapping *Carica papaya* L. fruits with a light cover in the trunk on the yield

The total production of treatment with thermal cover (TC) was compared with the treatment without it (N). After 379 DAS, the production of (TC) was slightly higher than (N), being 4.3 kg.m^{-2} and 3.5 kg.m^{-2} respectively, although there were no statistically significant differences between them (Fig. 5).

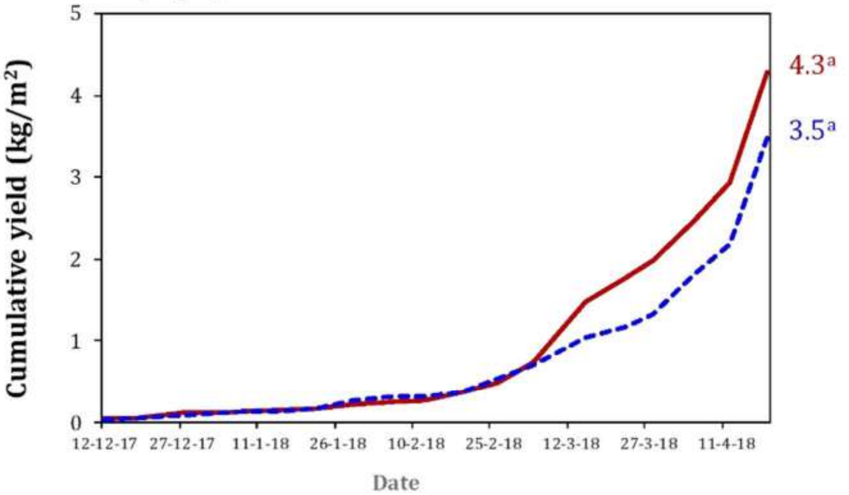

Figure 5. Evolution of yield of papaya trees protected with the lightweight cover (—) and without protection (---).

Comparing the yield of the cultivar 'Intenzza' to the yield obtained in the Canary Islands in the South essay of the "Instituto Canario de Investigaciones Agrarias" (I.C.I.A.), after 373 DAS, the yield was 5.1 kg.m-2 for a density of 2222 plants·ha-1 (Santos Coello et al., 2015). This value is not so far from our result, considering the same time of the cultivation. From week 10/2018 (March, 5rd), the production of (TC) increases more rapidly than for (N). The fruits in (TC) are early and advance their maturation before (N). But there is no significant difference between (TC) or (N) treatment for the average weight fruit. (1.01 kg ± 0.21 and 1.0 kg ± 0.14). And there is no significant difference either for the number of fruits harvested per tree (4.60 kg ± 1.19 and 4.19 kg ± 0.99). It could be explained by the fact that before placing the cover on the trunks, the fructification was made under the same environmental conditions for both treatments. The data analysed during this trial are only a part of the global yield of the cultivation. The final yield was 12.25 kg·m^{-2} (week 29/2018). There is no significant difference (12.25 kg ± 1.19 and 14.20 kg ± 0.99) with the yield of the same cultivar planted in the North of the greenhouse (Honoré et al. 2019). The blanket causes an effect on the temperature inside and by the way, the growing degree-days (GDD) of the (TC) treatment needed for fruits ripeness are higher. The fruits (TC) ripe early. The light effect of the thermal blanket on the yield could be explained by the fact that the increase of the temperature helps to the ripeness of the fruits (Table 2). The higher GDD induces the precocity in the harvest, but there is no effect on the yield. Placing a thermal cover over the fruits could be a cheap method to induce the precocity and quality of the fruit in the autumn papaya cycle. It would be interesting to test the effect of the cover on the earliness with more trees or also to conduct a new trial with thermal blanket in the province of Almería, in an experimental unit of largest area, with several cultivars, in a year or a 2-year commercial crop cycle to verify that the placement of the thermal blanket has really a positive impact on the quality of the fruit. Since it has been observed that during the winter, low temperature is a production limiting factor in the South of Spain. Cabrera et al. (2019) describe this phenomenon of the GDD in the Canary Islands. They comment that the total soluble solids are higher on fruits which received higher GDD.

Effect of lightweight plant cover on air temperature and humidity

The use of the lightweight cover to protect the papaya fruit shows a positive effect on temperatures, increasing minimum values in the night and maintaining maximum temperatures in the midday (Fig. 6).

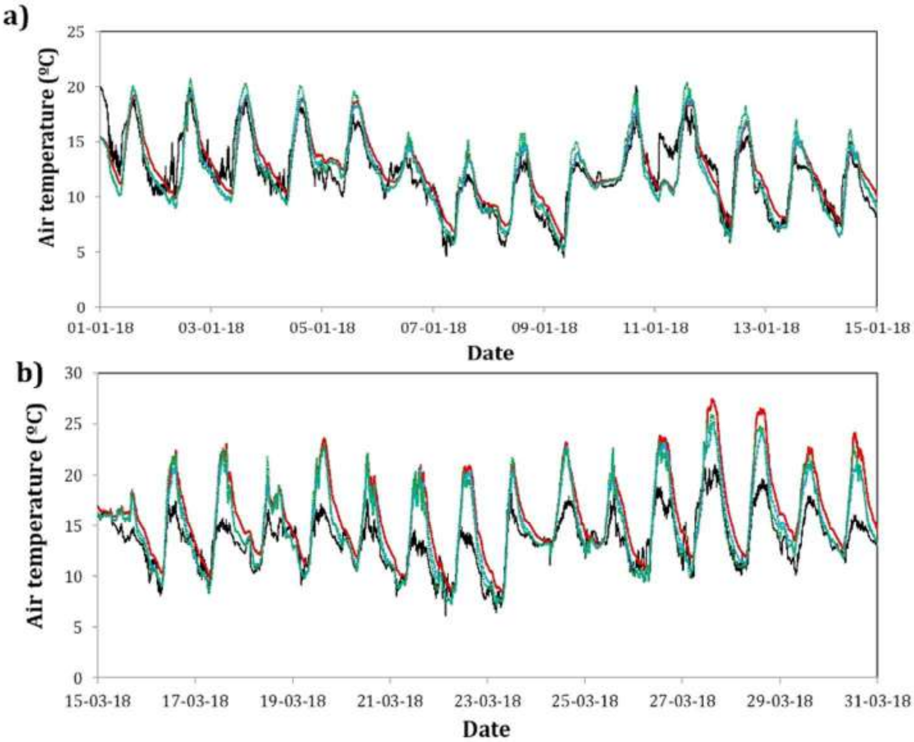

Figure 6. Evolution of temperatures of outside air (--) and inside the multispan greenhouse in the plant lines with lightweight cover inside the protection (—) and outside the protection (- - -) and in the plant lines without cover (····). First fortnight of January (a) and second fortnight of March (b).

Analysing minimum daily temperatures (Table 2), we can observe an augmentation statistically significant of 1 °C between the temperature inside the protection cover compare to the trees without protection. There is no significant difference in the temperature measured by sensors outside the blanket (T_{OTC}) and the sensors of the uncovered trees (T_N) for the 5 months analysed. Differences in the mean temperatures between (T_{ITC}) temperature inside of the protection and (T_N) temperature of the uncovered tree, were statistically significant, ranging from 0.5°C in December to 1.2°C in April (Table 2), and with an average value of 0.7°C.

Table 2. Mean and minimum daily air temperatures T (°C) measured inside of the experimental greenhouses at 1.5 m height in the plant lines with lightweight cover, inside of the protection (T_{ITC}) and outside of the protection (T_{OTC}) and in the plant lines without cover (T_N).

Month	Mean temperature			Minimum daily temperature		
	T_{ITC}	T_{OTC}	T_N	T_{ITC}	T_{OTC}	T_N
December 2017	13.3 c	12.9 b	12.8 a	9.5 a	8.5 a	8.5 a
January 2018	13.2 c	12.8 b	12.7 a	9.7 b	8.1 a	8.7 ab
February 2018	13.8 b	13.2 a	13.2 a	9.6 b	8.4 a	8.5 ab
March 2018	16.6 b	15.7 a	15.7 a	12.3 b	11.1 a	11.3 a
April 2018	18.2 c	17.2 b	17.0 a	12.9 a	11.8 a	12.0 a

[a] Different letters mean significant differences, at p-value < 0.05.

We can observe in Fig. 7 that, during all the period using the thermal cover, minimum temperatures were below the limit of 12-14°C reported by Nakasone and Paull (1998), affecting negatively the papaya growth and production. The use of the permeable protection around the papaya trunk allowed to increase minimum temperatures in the night without increasing the maximum temperatures in the day (Fig. 6). Therefore, the diurnal temperature range was reduced, and the reduction values were in the range of 0.4-1.2°C.

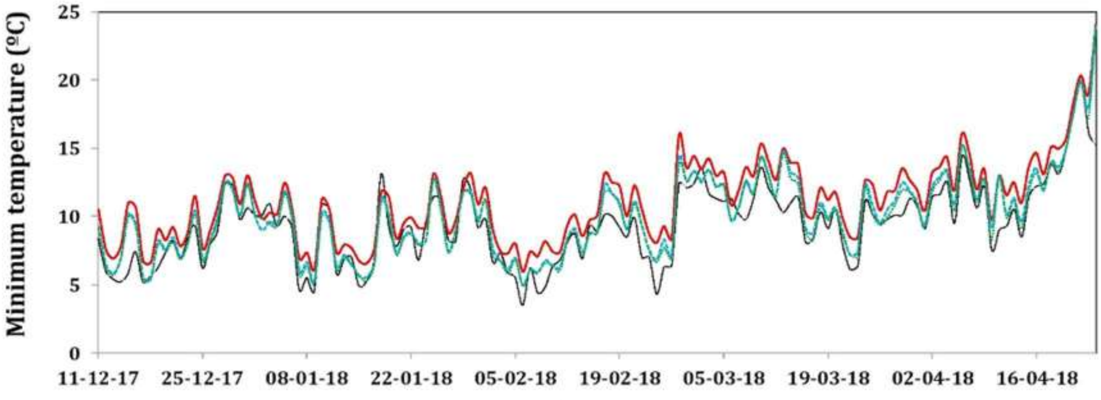

Figure 7. Evolution of daily minimum temperatures of outside air (--) and inside the multispan greenhouse in the plant lines with lightweight cover inside the protection (—) and outside the protection (- - -) and in the plant lines without cover (····).

The use of the permeable protection did not affect negatively to the humidity around the papaya fruit. Relative humidity values were statistically lower in the area around the papaya trunks of the (TC) treatment (Table 3). This fact is quite interesting for the crop protection because higher humidity may influence the growth of fungi causing plant diseases.

Table 3. Mean and maximum relative humidity of air RH (°C) measured inside the experimental greenhouses at 1.5 m height in the plant lines with lightweight cover inside the protection (RH_{ITC}) and outside the protection (RH_{OTC}) and in the plant lines without cover (RH_N).

Month	Mean relative humidity			Maximum relative humidity		
	RH_{ITC}	RH_{OTC}	RH_N	RH_{ITC}	RH_{OTC}	RH_N
December 2017	77.2 a	77.8 a	78.0 a	94.8 b	93.5 a	93.7 a
January 2018	75.6 a	76.2 b	76.7 c	93.9 b	92.2 a	93.4 b
February 2018	71.0 a	72.2 b	72.6 c	93.2 a	93.6 a	93.6 a
March 2018	68.3 a	71.1 b	71.6 b	93.2 a	93.6 a	93.6 a
April 2018	62.7 a	65.8 b	65.9 b	87.6 a	89.6 b	89.2 b

[a] Different letters mean significant differences, at p-value < 0.05.

CONCLUSIONES

From the analysis of results of the present work, the next conclusions can be drawn:
- Air temperatures were increased (with statistical significance) in the area around the papaya trunk wrapped with the cover, around 1 and 0.7 °C for minimum and mean temperature respectively. The augmentation temperature seems to induce an early production.
- Although without a statistical significance, the yield of *Carica papaya* L. cv 'Intenzza' trees, wrapped with the lightweight cover is higher than those which were uncovered, with respectively 4.3 kg·m^{-2} and 3.5 kg·m^{-2} in each case.

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En el presente trabajo se presentan los datos obtenidos en los ensayos realizados en el cultivo de papaya en tres invernaderos de tipo multitúnel, con ventilación natural situados en el Sureste de España. El primer ensayo se desarrolló en un ciclo largo durante dos campañas agrícolas (2016-2017 y 2017-2018) en el que se analizó el comportamiento de plantas hermafroditas sexadas de forma precoz mediante marcadores moleculares, una parte de ellas injertadas sobre su propio pie femenino, frente a plantas trasplantadas de modo tradicional (tres plántulas no sexadas), todas ellas del cultivar \`Intenzza´. Para las plantas sin injertar se compararon dos tamaños de plantas al momento del trasplante, plántulas en cepellón de 133 $cm^3$ y plántulas en cepellón de 2000 $cm^3$. Además, se plantó el cultivar \`Sweet Sense´ sexado de forma precoz.

En un segundo ensayo, durante esas dos mismas campañas, se cultivaron plantas de papaya sexadas precozmente del cultivar \`Intenzza´ con el objetivo de realizar un análisis de su rentabilidad económica y determinar de su viabilidad como alternativa a los cultivos intensivos tradicionales bajo invernadero que se realizan en la provincia de Almería.

En un tercer ensayo se realizó un ciclo corto (campaña 2017-2018) con el objetivo de comparar la producción de cinco cultivares de papaya sexados de modo precoz (\`Intenzza´, \`Sweet Sense´, \`Vitale´, \`Caballero´ y \`Alicia´) y uno además injertado (\`Intenzza´). En este tercer cultivo también se ensayó el uso de agrotextiles colocados alrededor de las piñas de frutos como medida de protección de los frutos frente a las bajas temperaturas durante el periodo invernal.

En el primer ensayo, las plantas sexadas de forma precoz obtuvieron una producción estadísticamente superior a las trasplantadas de forma tradicional, incluso cuando se injertaron sobre su propio pie. Los rendimientos obtenidos en el ensayo (262,8 a 325,2 $t·ha^{-1}$), fueron superiores a los referenciados en diferentes continentes. Para el cultivar \`Intenzza´, el injerto de plantas hermafroditas sobre plantas femeninas obtuvo los mejores rendimientos (321,2 $t·ha^{-1}$), con valores similares a los del cultivar \`Sweet Sense´ para plantas sexadas sin injertar (325,2 $t·ha^{-1}$). El peso medio de los frutos fue superior en la segunda campaña (0,92-1,16 kg) a los de la primera (0,71-0,91 kg). Sin embargo, el número de frutos por planta fue mayor en la primera campaña (43,57-87,13) que en la segunda (37,95-56,45), siendo en ambos casos el cultivar \`Sweet Sense´ el que obtuvo los mayores valores (con significación estadística). El injerto no influyó significativamente en el contenido de sólidos solubles de los frutos. Las plantas trasplantadas con mayor tamaño (cepellón de 2000 cm^3) emitieron los primeros frutos en nudos más cercanos al suelo y entraron en producción de forma precoz.

El análisis económico realizado en el segundo ensayo demostró su viabilidad como alternativa dentro del modelo agrícola almeriense. El beneficio tras los 30 meses de cultivo en ciclo largo fue de +57.535 $€·ha^{-1}$. Sin embargo, el agricultor interesado en producir papaya deberá de tener suficiente liquidez en los primeros once meses de cultivo, tras los cuales se observó una recuperación de parte de la inversión con los ingresos obtenidos por la venta de la papaya.

En el ciclo corto de producción, el cultivar \`Intenzza´ injertado fue el más productivo con 142,0 $t·ha^{-1}$, produciendo los frutos con el contenido en solidos solubles totales más alto. El injerto de \`Intenzza´ tenía los entrenudos más cortos que la planta de \`Intenzza´ franca. Además, la altura del primer fruto para los árboles injertados fue menor que para los árboles francos.

La colocación de agrotextiles alrededor de los frutos al inicio del invierno, permitió un aumento estadísticamente significativo de las temperaturas mínimas y medias de 1 y 0,7°C, respectivamente. La protección indujo precocidad de la producción sin aumentar el rendimiento final.