Universidad de Concepción
Dirección de Postgrado
Facultad de Agronomía
Programa de Magíster en Ciencias Agronómicas

Evaluación de nuevas técnicas para mejorar la eficiencia en el uso de la luz en huertos de avellano europeo (*Corylus avellana* L.)

Tesis para optar al grado de Magíster en Ciencias Agronómicas con Mención en Producción y Protección vegetal

IGNACIO ELIECER URRA URRA
CHILLÁN-CHILE
2022

Profesor Guía: Richard Bastías Ibarra
Dpto. de Producción Vegetal
Facultad de Agronomía
Universidad de Concepción

Esta tesis ha sido realizada en el Departamento de Producción Vegetal de la Facultad de Agronomía, Universidad de Concepción.

Profesor Guía

_____
Dr. Richard Bastías Ibarra
Facultad de Ciencias Biológicas
Universidad de Concepción

Comisión Evaluadora:

_____
Dr. Ernesto Moya Elizondo
Facultad de Ciencias Biológicas
Universidad de Concepción

_____
Dr. Jorge Campos Parra
Facultad de Ciencias Biológicas
Universidad de Concepción

Director de Programa

_____
Dra. Marisol Vargas Concha
Facultad de Ciencias Biológicas
Universidad de Concepción

AGRADECIMIENTOS

TABLA DE CONTENIDOS

INDICE DE FIGURAS Y TABLAS

LA PODA DE VERANO Y UNA PELÍCULA PARTICULADA INCREMENTAN EL RENDIMIENTO Y EL DESEMPEÑO FOTOSINTÉTICO EN AVELLANO EUROPEO

SUMMER PRUNING AND PARTICLE FILM INCREASE YIELD AND PHOTOSYNTHETIC PERFORMANCE IN HAZELNUT

RESUMEN

Los huertos de avellano europeo están continuamente expuestos a condiciones de luz solar baja o excesiva, sin embargo, no hay suficiente conocimiento sobre sus efectos en el rendimiento y la respuesta fisiológica de la planta. Esta investigación evaluó el efecto de la exposición del dosel a la luz mediante la poda y la protección del dosel a la luz mediante una película particulada a base de caolinita, sobre el rendimiento (peso del fruto, nuez y de la semilla) y la respuesta fisiológica de la hoja (intercambio gaseoso y fluorescencia de clorofila) en avellano europeo. Avellanos 'Tonda di Gifoni' fueron sometidos a podas de invierno del eje central (*WCA*), y del eje central más 2 ramas laterales (*WCA+2L*). Se aplicó además la poda de verano del eje central más 2 ramas laterales (*SCA+2L*), y combinada con aspersión de partículas de caolinita (*SCA+2L+K*). Árboles sin podar se incluyeron como control. *WCA*, *WCA+2L*, *SCA+2L* y *SCA+2L+K* aumentaron en más del 120% la transmisión de luz desde la parte superior hasta la mitad de la zona del dosel. *SCA+2L+K* aumentó, en la zona media del dosel, la tasa de fotosíntesis neta (A_n), el rendimiento, el peso de la nuez y el peso del grano en un 100%, 90%, 4% y 5%, respectivamente. El tratamiento *SCA+2L+K* mostró una relación significativa entre rendimiento y la transmisión de luz (R^2 aj= 0.68*) y entre A_n y la transmisión de luz (R^2 aj= 0.58**). Los resultados sugieren que la poda de verano combinada con la película

particulada aumenta el rendimiento y el desempeño fotosintético en avellano europeo.

Summary

Hazelnut orchards are continuously exposed to low and excess sunlight conditions, but there is not enough knowledge about their effects on yield and plant physiological responses. This research evaluated the effect of light-canopy exposition by pruning and light-canopy protection by kaolin-based particle film on yield (fruit, nut, and kernel weight) and leaf physiological (gas exchange and chlorophyll fluorescence) responses in hazelnut. 'Tonda di Gifoni' hazelnut trees were subjected to winter pruning of the central axis (*WCA*), and of the central axis plus 2 lateral branches (*WCA+2L*). Summer pruning was applied to the central axis plus 2 lateral branches (*SCA+2L*), and combined with kaolin particle spraying (*SCA+2L+K*). Unpruned trees were included as a control. *WCA*, *WCA+2L*, *SCA+2L*, and *SCA+2L+K* increased more than 120% the light transmission from the top to the middle of the canopy zone. *SCA+2L+K* increased, at the middle zone canopy level, the net photosynthetic rate (A_n), yield, nut weight, and kernel weight by 100%, 90%, 4%, and 5%, respectively. *SCA+2L+K* treatment showed a significant relationship between yield and light transmission (R^2 aj= 0.68*) and between A_n and light transmission (R2 aj= 0.58**). Results suggest that summer pruning combined with particle film increase yield and photosynthetic performance in hazelnut.

CAPÍTULO 1

INTRODUCCION GENERAL

El manejo de la luz solar en avellano europeo (*Corylus Avellana* L.) es una práctica clave, pero que presenta una dualidad. Debido al hábito de crecimiento de esta especie, la transmisión de luz al interior del dosel resulta ser insuficiente, lo que trae como consecuencia una baja tasa de asimilación de CO_2, pobre desarrollo floral, disminución del rendimiento y menor calidad de fruta (Hampson et al., 1996; Farinelli et al., 2005; Pannico et al., 2017). Por otra parte, un exceso de luz solar incidente en las hojas de esta especie provoca una disminución de la capacidad de fotosíntesis, al reducir la conductancia estomática y promover inhibición del proceso de transporte de energía a nivel del PS-II (Luciani et al., 2020).

En los árboles frutales, es deseable maximizar la intercepción de la luz solar junto con una distribución apropiada dentro del dosel de la planta (Lauri et al., 2009; Cherbiy-Hoffmann et al., 2012). Esto permite la máxima eficiencia del uso de la radiación solar en los procesos de la fotosíntesis, desarrollo de yemas florales, crecimiento y la calidad de los frutos (Cherbiy-Hoffmann et al., 2012). La poda es una práctica usada habitualmente para mejorar la transmisión de luz solar al interior del dosel de los árboles frutales, logrando una producción estable en cantidad y calidad de frutos (Pescie et al., 2011). En avellano europeo la poda se realiza durante el invierno y se orienta a la eliminación de brotes excesivamente vigorosos como "chupones" y madera vieja, enferma o dañada (Cristofori et al., 2009; Silvestri et al., 2021). En esta especie la práctica de poda permitió incrementar el rendimiento de la planta al cabo de 3 a 5 años de producción y como consecuencia de una mayor formación de brotes mixtos con una alta cantidad de yemas fértiles (Lauri et al., 2009, Roversi et al., 2009).

Por otra parte, la poda puede generar daños en las hojas, brotes y frutos por sobre exposición de estos a una alta intensidad de luz solar (Racsko and Schrader, 2012; Yu et al., 2014). En avellano europeo se ha demostrado que las altas temperaturas y la alta luz solar incidente, a menudo inducen el cierre estomático, reduciendo la transpiración que es la principal vía de disipación de calor de las hojas. Al incrementar la temperatura del follaje se disminuye la fotosíntesis neta (Luciani et al., 2020). En manzano (*Malus domestica* Borkh.) se ha reportado que estas condiciones de estrés por exceso de luz y altas temperaturas pueden producir una inhibición de la fotosíntesis a nivel del PS-II o activación de radicales libres que originan daño foto oxidativo en hojas o frutos por su sobre exposición al sol (Olivares-Soto y Bastías, 2021). El uso de partículas reflectantes como la caolinita ha sido efectivo para mitigar el nivel excesivo de temperatura y radiación solar en cultivos como el pomelo (*Citrus paradisi* L.) (Jifon y Syvertsen, 2003), vid (*Vitis vinífera* L.) (Dinis et al., 2018), nogal (*Juglans regia* L.) (Gharaghani et al., 2018), olivo (*Olea europea* L.) (Brito et al., 2021) y avellano europeo (Luciani et al., 2020). La aplicación de esta partícula en frutos, forma una película protectora de color blanco en la superficie de la epidermis permitiendo reducir la absorción de luz, y particularmente de la radiación UV-B, la que es reflejada desde la superficie (Glenn et al., 2002; Sharma et al., 2015). La aplicación de caolinita ha presentado buenos resultados en cuanto a protección de cultivos frutales ante el estrés de verano. Por ejemplo, en vid, disminuyó la temperatura de la hoja aminorando la limitación estomática y, por ende, incrementando los niveles de intercambio gaseoso de la hoja (Dinis et al., 2018). En nogal, redujo el daño por sol en frutos y hojas e incrementó la conductancia estomática, asimilación neta de CO_2, y el tamaño y calidad de la fruta producida (Gharaghani et al., 2018). Por otra parte, en mandarino (*Citrus unshiu* Marc.) se determinó que el uso de caolinita fue efectivo en el control de daño por golpe de sol sin alterar la calidad organoléptica de la fruta (Chabbal et al., 2014). En avellano europeo, el uso de caolinita redujo la temperatura de la

hoja, mejorando la fotosíntesis neta (Luciani et al., 2020). Este estudio propone que la práctica de poda combinada con el uso de caolinita mejora el potencial fotosintético y productivo del avellano europeo.

HIPOTESIS

La práctica de poda combinada con el uso de caolinita mejora el potencial fotosintético y productivo del avellano europeo.

OBJETIVO GENERAL

Evaluar el efecto de la poda combinada con el uso de caolinita sobre parámetros de rendimiento fotosintético y productivo en avellano europeo.

OBJETIVOS ESPECIFICOS

- Evaluar el efecto de diferentes tratamientos de poda de invierno y verano combinada con caolinita sobre la transmisión de luz fotosintética al interior del dosel de los árboles.
- Cuantificar el efecto de los tratamientos sobre variables de intercambio gaseoso y fluorescencia de clorofila de la hoja.
- Determinar el efecto de los tratamientos sobre los componentes de rendimiento del árbol a nivel de frutos y de desarrollo floral.
- Relacionar variables de intercambio gaseoso y de rendimiento con la transmisión de luz al interior del dosel.

- **LITERATURA CITADA**

1. Brito, C., A. Gonçalves, E. Silva, S. Martins, L. Pinto, L. Rocha, M. Arrobas, M. A. Rodrigues, J. Moutinho-Pereira and C. M. Correia. 2021. Kaolin foliar spray improves olive tree performance and yield under sustained deficit irrigation. Sci. Hortic. 277: 109795. https://doi.org/10.1016/j.scienta.2020.109795.

2. Chabbal, M., A. Piccoli, G. Martínez, M. Avanza, S. Mazza y V. Rodríguez. 2014. Aplicaciones de caolín para el control de golpe de sol en mandarino 'Okitsu'. Cultivos. Tropicales. 35 (1): 50-56

3. Cherbiy-Hoffmann, U., P. Searles, A. Hall and M. Rousseaux. 2012. Influence of light environment on yield determinants and components in large olive hedgerows following mechanical pruning in the subtropics of the southern Hemisphere. Sci. Hortic. 137: 36-42. https://doi.org/10.1016/j.scienta.2012.01.019.

4. Cristofori, V., C. Cammilli, F. Valentini and C. Bignami. 2009. Effect of different pruning methods on growth, yield and quality of the hazelnut cultivar 'Tonda Gentile Romana'. Acta Hortic. 845: 315-322. https://doi.org/10.17660/ActaHortic.2009.845.48.

5. Dinis, L. T., A. C. Malheiro, A. Luzio, H. Fraga, H. Ferreira, I. Gonçalves and J. Moutinho-Pereira. 2018. Improvement of grapevine physiology and yield under summer stress by kaolin-foliar application: Water relations, photosynthesis and oxidative damage. Photosynthetica, 56(2): 641-651. https://doi.org/10.1007/s11099-017-0714-3.

6. Farinelli, D., M. Boco and A. Tombesi. 2005. Influence of canopy density on fruit growth and flower formation. Acta Hortic. 686: 247-252. 10.17660/ActaHortic.2005.686.33

7. Gharaghani, A., A. M. Javarzari and K. Vahdati. 2018. Kaolin particle film alleviates adverse effects of light and heat stresses and improves nut and kernel quality in Persian walnut. Sci. Hortic. 239: 35-40. https://doi.org/10.1016/j.scienta.2018.05.024.

8. Glenn, M., E. Prado, A. Erez, J. McFerson and G. Puterka. 2002. A reflective processed-Kaolin particle film affects fruit temperature, radiation reflection, and solar injury in Apple. J. Amer. Soc. Hort. Sci. 127(2): 188-193. https://doi.org/10.21273/JASHS.127.2.188.

9. Hampson, C., A. Azarenko and J. Potter. 1996. Photosynthetic rate, flowering, and yield component alteration in Hazelnut in response to different light environments. J. Amer. Soc. Hort. Sci. 121(6): 1103–1111. https://doi.org/10.21273/JASHS.121.6.1103.

10. Jifon, J. L. and J. P. Syvertsen. 2003. Kaolin Particle Film Applications Can Increase Photosynthesis and Water Use Efficiency of Ruby Red' Grapefruit Leaves. J. Am. Soc. Hortic. Sci. 128(1): 107-112. https://doi.org/10.21273/JASHS.128.1.0107.

11. Lauri, P., E. Costes, J. Regnard, L. Brun, S. Simon, P. Monney and H. Sinoquet. 2009. Does knowledge on fruit tree architecture and its implications for orchard management improve horticultural sustainability? An overview of recent advances in the apple. Acta Hortic. 817: 243-250. 10.17660/ActaHortic.2009.817.25.

12. Luciani, E., A. Palliotti, T. Frioni, S. Tombesi, F. Villa, C. Zadra and D. Farinelli. 2020. Kaolin treatments on Tonda Giffoni hazelnut (Corylus avellana L.) for the control of heat stress damages. *Sci. Hortic. 263*: 109097. https://doi.org/10.1016/j.scienta.2019.109097

13. Olivares-Soto, H. and R. M. Bastías. 2018. Photosynthetic efficiency of apples under protected shade nets. Chil. J. Agr. Res. 78(1): 126-138. http://dx.doi.org/10.4067/S0718-58392018000100126.

14. Pannico, A., C. Cirillo, M. Giaccone, P. Scognamiglio, R. Romano, N. Caporaso and B. Basile. 2017. Fruit position within the canopy affects kernel lipid composition of hazelnuts. J. Sci. Food Agr. 97(14): 4790-4799. https://doi.org/10.1002/jsfa.8348.

15. Pescie, M., M. Borda, P. Fedyszak y C. López. 2011. Efecto del momento y tipo de poda sobre el rendimiento y calidad del fruto en arándano altos del sur (Vaccinium corymbosum) var. O´Neal en la provincia de Buenos Aires. RIA. 37(3): 268-274. http://hdl.handle.net/20.500.12123/6426.

16. Racsko, J. and L.E. Schrader. 2012. Sunburn of apple fruit: Historical background, recent advances and future perspectives. Crit. Rev. Plant Sci. 31(6): 455-504. https://doi.org/10.1080/07352689.2012.696453.

17. Roversi, A., G. Malvicini, G. Mozzone and T. Dilmacunal. 2009. A simple summer pruning trial on hazelnut. Acta Hortic. 845: 367-372. https://doi.org/10.17660/ActaHortic.2009.845.57.

18. Sharma, R., S. Reddy, and S. Datta. 2015. Particle films and their applications in horticultural crops. Appl. Clay Sci. 116: 54-68. https://doi.org/10.1016/j.clay.2015.08.009.

19. Silvestri, C., L. Bacchetta, A. Bellincontro and V. Cristofori. 2021. Advances in cultivar choice, hazelnut orchard management, and nut storage to

enhance product quality and safety: an overview. J. Sci. Food Agric. 101(1): 27-43. https://doi.org/10.1002/jsfa.10557.

20. Yu, D. J., J. I. Lee, S. W. Chung, J. Y. Hwang, S. K. Yun and H. J. Lee. 2014. Photosynthetic acclimatisation of leaves in response to a shade-to-sun transition following summer pruning in peach (Prunus persica cv. Changhoweonhwangdo) trees. J. Hortic. Sci. Biotech. 89(3): 279-286. https://doi.org/10.1080/14620316.2014.11513080.

CAPÍTULO 2

Summer pruning and particle film increase yield and photosynthetic performance in hazelnut

Ignacio Urra[1], Richard M. Bastías[1]*, Ernesto A. Moya-Elizondo[1], Jorge Campos[2]

1. Departamento de Producción Vegetal, Facultad de Agronomía, Universidad de Concepción, Av. Vicente Méndez 595, Chillán, Chile.
2. Departamento de Producción Animal, Facultad de Agronomía, Universidad de Concepción, Av. Vicente Méndez 595, Chillán, Chile.
* Correspondence: ribastias@udec.cl

Abstract

Hazelnut orchards are continuously exposed to low and excess sunlight conditions, but there is not enough knowledge about their effects on yield and plant physiological responses. This research evaluated the effect of light-canopy exposition by pruning and light-canopy protection by kaolin-based particle film on yield (fruit, nut, and kernel weight) and leaf physiological (gas exchange and chlorophyll fluorescence) responses in hazelnut. 'Tonda di Gifoni' hazelnut trees were subjected to winter pruning of the central axis (*WCA*), and of the central axis plus 2 lateral branches (*WCA+2L*). Summer pruning was applied to the central axis plus 2 lateral branches (*SCA+2L*), and combined with kaolin particle spraying (*SCA+2L+K*). Unpruned trees were included as a control. *WCA*, *WCA+2L*, *SCA+2L*, and *SCA+2L+K* increased more than 120% the light transmission from the top to the middle of the canopy zone. *SCA+2L+K* increased, at the middle zone canopy level, the net photosynthetic rate (A_n), yield, nut weight, and kernel weight by 100%, 90%, 4%, and 5%, respectively. *SCA+2L+K* treatment showed a significant relationship between yield and light transmission (R^2 aj= 0.68*) and between A_n and light transmission (R2 aj= 0.58**). Results suggest that summer pruning combined with particle film increase yield and photosynthetic performance in hazelnut.

Keywords: *Corylus avellana* L.; sunlight management, leaf gas exchange, sustainable production, climate change.

1. Introduction

Effective sunlight management is of outmost importance in European hazelnut (*Corylus Avellana* L.). Due to the growth habit of this species, light transmission tends to be limited to canopies, resulting in low CO_2 assimilation rate, poor floral development, decreased yield and reduced fruit quality [1-3]. Furthermore, an excess of incident radiation on the leaves causes a decrease in photosynthetic capacity by reducing stomatal conductance and leading to PS-II inhibition [4].

To maximize sunlight interception and distribution within the canopy is desirable in tree fruit crops [5,6], because it allows maximum efficiency of solar radiation in photosynthesis, flower bud development, and fruit growth and quality [6]. Pruning is a commonly used practice to enhance yield and fruit quality by improving sunlight transmission into the canopy [7]. In hazelnut, pruning is done during winter in order to remove excessively vigorous shoots, such as suckers, as well as old, dead, and damaged wood [8,9]. In fact, there is evidence that pruning resulted in increased yield after 3 to 5 years of production due to a greater formation of mixed shoots with a high number of fertile buds [5,10].

Overexposure to intense sunlight can damage leaves, shoots and fruit [11,12]. In hazelnut, high temperatures and high incident radiation often induce stomatal closure, reducing transpiration, which is the main route of heat dissipation from leaves, increasing foliage temperature, and decreasing net photosynthesis [4]. In apples (*Malus domestica* Borkh.), it has been reported that stress conditions due to excess light and high temperatures can produce inhibition of photosystem II or activation of free radicals, causing photo-oxidative damage in leaves or fruits induced by sun overexposure [13]. In this sense, the use of reflective particles such as kaolin has been suggested as a strategy to reduce the negative effects derived from excessive heat and solar radiation in crops such as grapefruit (*Citrus paradisi* L.) [14], grape (*Vitis vinífera* L.) [15], walnut (*Juglans*

regia L.) [16], olive (*Olea europea* L.) [17], and European hazelnut [4]. Kaolin particles form a white protective film on the surface of the epidermis, reducing light absorption and particularly UV-B radiation, which is reflected out the surface [18,19]. The application of kaolin has proven effective in protecting fruit crops from heat stress in the summer. For example, it decreased leaf temperature in grapes, reducing stomatal limitation and, therefore, increasing leaf gas exchange levels [15]. In walnut, it reduced sun damage on fruits and leaves and increased stomatal conductance, net CO_2 assimilation, and fruit size, while it also improved fruit quality [16]. Furthermore, there is evidence that the foliar spray of kaolin reduced sun damage in mandarin, without altering the organoleptic quality of the fruit [20]. In European hazelnut, the use of kaolin reduced leaf temperature, improving net photosynthesis [4]. This study proposes that pruning combined with the use of kaolin improves the photosynthetic and productive potential of European hazelnut. Accordingly, the objective of this work was to evaluate the effect of pruning and kaolin application on light transmission, leaf physiological (gas exchange, chlorophyll fluorescence) and fruit yield components (yield, nut, and kernel weight) parameters.

2. Materials and Methods

2.1. Plant material

The study was conducted during the 2019-20 and 2020-21 seasons in a 4-year-old commercial orchard of European hazelnut cv. 'Tonda di Giffoni', located in Pinto, Ñuble Region, Chile (36°39'21" S 71°59'29" W). Minimum, mean and maximum air temperatures reach 3, 14, and 28 °C, respectively, with a maximum solar radiation level of 980 W m^{-2} in the summer. In terms of relative humidity, minimum, mean and maximum values reach 48%, 72%, and 96%, respectively (Agromet, 2022). Spacing was 3 m apart between trees and 5 m apart between rows, with a north-south orientation. The trees were trained as a single-axis system, which consists of a single trunk from which 4-5 branches are born,

inserted at a height of 80-90 cm from ground level. Irrigation was provided by two drip lines per plant; emitters were spaced 0.5 m apart and with a flow rate of 3 L per hour. Pruning, nutrition, and phytosanitary management were conducted according to standard procedures for a young European hazelnut orchard.

2.2. Treatments and experimental design

Two trials consisting of different pruning treatments were conducted (winter and summer). Winter pruning was conducted on August 24, 2019, and included: i) a control treatment without winter pruning (*WC*); ii) winter pruning of the central axis (*WCA*); and iii) winter pruning of the central axis plus 2 lateral branches (*WCA+2L*). Summer pruning was conducted on January 14, 2020, and included: i) a control treatment without summer pruning (*SC*); ii) summer pruning of the central axis plus 2 lateral branches (*SCA+2L*); and iii) summer pruning of the central axis plus 2 lateral branches, and kaolin application (*SCA+2L+K*). Kaolin (Screen duo ®) (Crop Microclimate Management, North Carolina, USA) was applied at 1.25 %, using an SR 200 motorized sprayer (STILH, Dieburg, Germany). The experiment was established in a completely randomized block design with 4 replicates and 2 plants per treatment as the experimental unit.

2.3. Light Transmission Measurements

Light transmission measurements were made the last week of January 2020, using an AccuPAR LP-80 ceptometer (Decagon Devices, Pullman, USA). The measurements were made on sunny days at three time points throughout the day: i) 2-3 hours before solar noon; ii) at solar noon; and iii) 2-3 hours after solar noon [21]. The amount of photosynthetically active photon flux (*PPFD*, µmol m^{-2} s^{-1}) was estimated in the top (1.6 m above ground level), middle (1.1 m above ground level) and bottom (0.6 m above ground level) canopy zones, using the methodology proposed by Hampson et al. [1] and Pannico et al. [3] (Figure 1). The amount of *PPFD* was determined by measuring from the center of one row to the center of the next row and at a distance of 0.4 m between each

measurement point, for a total of 13 points in each level [22] (Figure 1), using an SQ-100X-SS quantum sensor (Apogee Instruments, Logan, Utah, United States) located in full sun and at a height of 1.2 m. With the information obtained, the *PPFD* transmitted to each point of the plant (*LT*, %) was calculated according to the following relationship:

$$LT = (PPFD\ below/PPFD\ above) \times 100.$$

where *PPFD below* is the photosynthetically active photon flux density measured below the canopy and *PPFD above* is the photosynthetically active photon flux density measured above the canopy.

2.4. Leaf gas exchange and chlorophyll fluorescence

The influence of the treatments on the incidence of photosynthetically active photons (*PPFD*, μmol m^{-2} s^{-1}), net CO_2 assimilation (A_n, μmol CO_2 m^{-2} s^{-1}), stomatal conductance (g_s, μmol m^{-2} s^{-1}), transpiration rate (*E*, μmol H_2O m^{-2} s^{-1}), and leaf intercellular CO_2 concentration (C_i, μmol mol^{-1}) was determined using a TARGAS-1 infrared gas analyzer (PP Systems, Massachusetts, USA). Measurements were made the first week of February 2020, on a sunny day at noon, and on healthy mature leaves from one-year-old shoots located in the central point (0.0) of the top, middle, and bottom canopy zones (Figure 1). Simultaneously, maximum (F_m) and minimum (F_0) leaf chlorophyll fluorescence measurements were made in the same zones used for gas exchange determinations using an OS-30p portable fluorometer (Opti-Sciences, Hudson, USA), after dark-adaptation of the leaf for 30 min [23]. Maximum photochemical efficiency of PSII (F_v/F_m) was determined by the relationship $F_v/F_m = (F_m-F_0)/F_m$ proposed by Maxwell and Johnson [24], which reflects the photochemical efficiency of PSII.
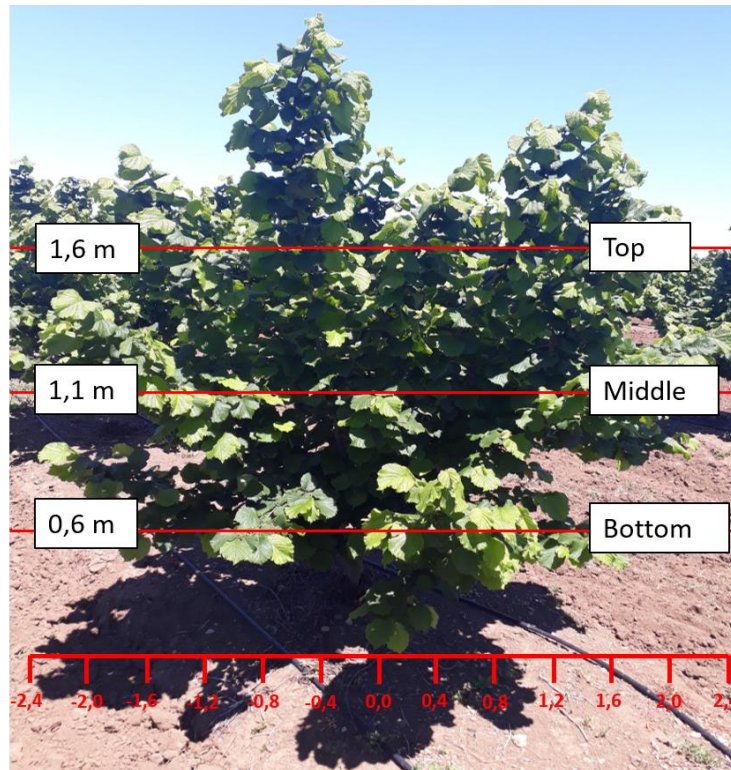
Figure 1. Vertical and horizontal division of the canopy of European hazelnut. Source: Own elaboration.

2.5 Fruit yield components

Harvest was conducted in the first week of March 2021. Fruits were manually harvested from the top, middle, and bottom canopy zones [2] (Figure 1), while yield (kg) was determined using a digital scale, model PCE-PM 6 T (PCE Instruments, Alicante, Spain). Subsequently, a sample of 20 fruits was randomly selected per canopy zone (Figure 1), and both nut (g) and kernel (g) were weighed using a digital desktop scale, model A6702231 (Veto, Santiago, Chile). Kernel yield was calculated as the relationship between kernel weight and fruit weight with the shell.

2.6. Additional information

During the flowering stage, the total number of catkins and glomeruli from two complete branches per plant was estimated for the, top, middle and bottom canopy zones (Figure 1) according to the methodology described by Tombesi and Farinelli [25]. The number of 1-year shoots per branch was determined, while shoot length (cm) was measured in order to evaluate the effect of pruning on vegetative growth.

Additionally, the incidence of species of genera *Botrytis*, *Fusarium*, *Alternaria*, *Cladosporium*, *Penicilium*, *Trichothecium*, and other saprophytic fungi was evaluated in order to determine the possible influence of the different treatments on disease incidence, and their possible relationship with yield. Samples of 5 catkins per each canopy zone were taken for each treatment (Figure 1) and moistened with distilled water at a temperature of 20 °C for 7 days to induce mycelial growth, then the fungi were identified by optical microscope (BA310E Motic, Hong Kong, China).

2.7 Statistical analysis

Data of light transmission were subjected to a non-parametric Friedman test at a significance level of 95%. For determinations of gas exchange, chlorophyll fluorescence, yield and fruit quality, data were subjected to an analysis of variance at the same significance level, and a Tukey's mean comparison test. In order to comply with the variance analysis assumptions, the 'fruit filling' variable was transformed using the 'normal scores' formula; the floral return variables were transformed to their natural logarithm; and the variables corresponding to the percentage of incidence of pathogens were transformed with the equation y = √ (x + 0.5), where x = percentage value. Finally, a quadratic regression analysis was performed using the $ax^2 + bx + c$ model to determine the relationships between i) net photosynthetic rate (A_n) and stomatal conductance (g_s), ii) instantaneous carboxylation efficiency (A_n/C_i) and stomatal conductance (g_s), iii)

net photosynthetic rate (A_n) and light transmission (%), and iv) yield and light transmission (%) at a significance level of 95%. Data were analyzed using the statistical software INFOSTAT [26].

3. Results

3.1 Light transmission

In the top canopy zone (Figure 2A) and in central part of the tree (vertical division), light transmission increased by 232% and 226% in the *WCA* and *WCA+2L* treatments, respectively, with respect to *WC*, showing a significant effect ($p<0.001$). In the midpoint of the tree, *WCA* increased light transmission significantly ($p=0.042$) by 85% compared to *WC*. A similar pattern, although to a lesser extent, was observed in the middle canopy zone (Figure 2B). In the central part of the tree, a significant increase ($p=0.031$) in light transmission (66%) was observed in *WCA+2L*, whereas significant increases ($p=0.0018$) of 247% and 463% were also observed in the mid-point of the tree in *WCA* and *WCA+2L*, respectively. Finally, the pruning treatments did not significantly affect light transmission in the lower part of the tree (Figure 2C) ($p>0,05$).
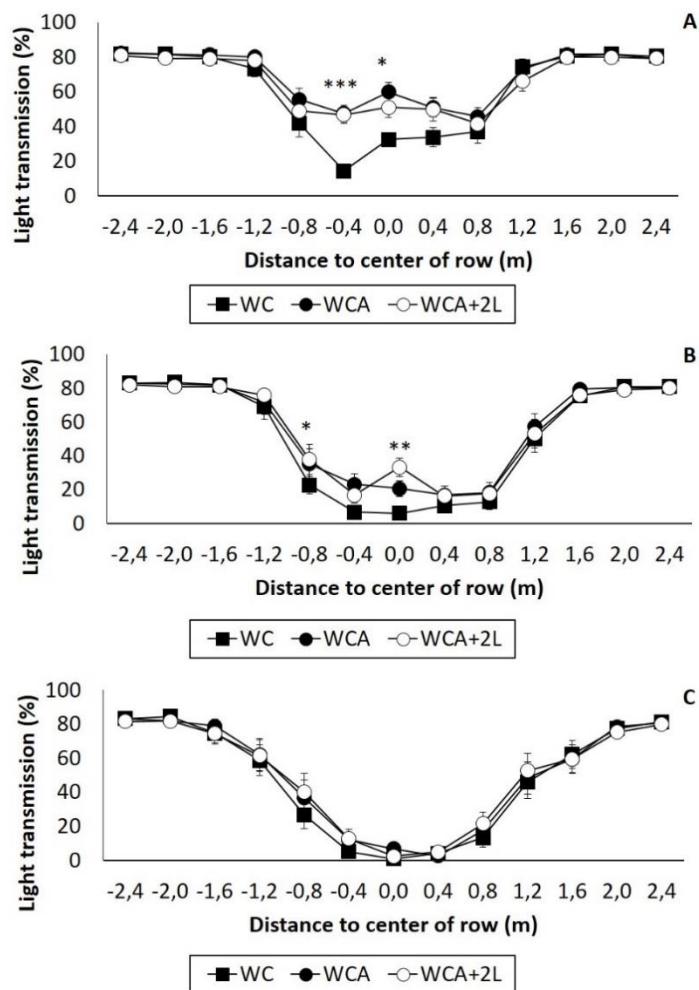
Figure 2. Light transmission pattern of photosynthetically active photon flux (PPFD) measured in top (A), middle (B), and bottom (C) canopy zones of European hazelnut for the control treatments without winter pruning (*WC*), winter pruning of the central axis (*WCA*) and winter pruning of the central axis plus 2 lateral branches (*WCA+2L*). Asterisks indicate level of significance according to Friedman test (*: $p \leq 0.05$, **: $p \leq 0.01$, ***: $p \leq 0.001$, ns: not significant). Bars in the same point indicate standard error for n= 12. Source: Own elaboration.

In the top canopy zone (Figure 3A) and in the central part of the tree (vertical division), *SCA+2L* and *SCA+2L+K* significantly increased (p=0.002) light transmission by 137% and 123% % compared to *SC*, respectively. In the mid-

point of the tree, *SCA+2L+K* showed a significant effect by increasing the amount of light transmitted by 63% (p=0.02) (Figure 3A). This was also observed in the middle canopy zone (Figure 3B) since *SCA+2L* resulted in a significant increase (p=0.007) of 190% in light transmission in the central part of the tree. On the other hand, *SCA+2L* and *SCA+2L+K* in the mid-point of the tree increased light transmission significantly (p=0.002) by 474% and 378%, respectively (Figure 3B). In the bottom canopy zone, the treatments did not significantly affect light transmission (p>0.05) (Figure 3C).
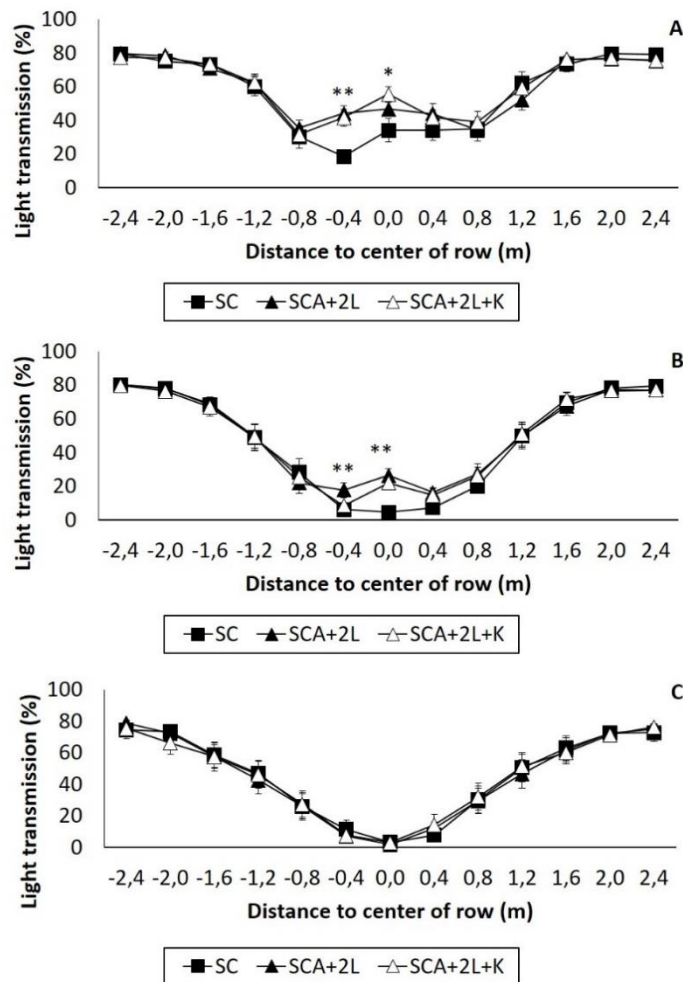
Figure 3. Light transmission pattern of photosynthetically active photon flux (PPFD) measured in top (A), middle (B), and bottom (C) canopy zones of European hazelnut for

the control treatments without summer pruning (*SC*), summer pruning of the central axis plus 2 lateral branches (*SCA+2L*), and summer pruning of the central axis plus 2 lateral branches and kaolin application (*SCA+2L+K*). Asterisks indicate level of significance according to Friedman test (*: $p \leq 0.05$, **: $p \leq 0.01$, ***: $p \leq 0.001$, ns: not significant). Bars in the same point indicate standard error for n= 12. Source: Own elaboration.

3.2. Gas exchange and chlorophyll fluorescence

WCA and *WCA+2L* had no significant effect on PPFD, A_n, g_s, and E compared to *WC* (p>0.05) (Figure 4) and did not significantly affect the F_v/F_m ratio (p>0.05) (Figure 6A).

In the middle canopy zone, *SCA+2L+K* resulted in a 13% increase (p=0.0458) in PPFD compared to the control treatment without pruning (Figure 5A). In addition, A_n was significantly higher (p=0.011) in *SCA+2L* and *SCA+2L+K*, with increases of 117% and 100%, respectively, compared to *SC* (Figure 5B). In addition, g_s and E were not significantly affected by the summer pruning treatments (p>0.05) (Figure 5). Finally, no treatment significantly affected F_v/F_m in the different canopy zones (p>0.05) (Figure 6B).
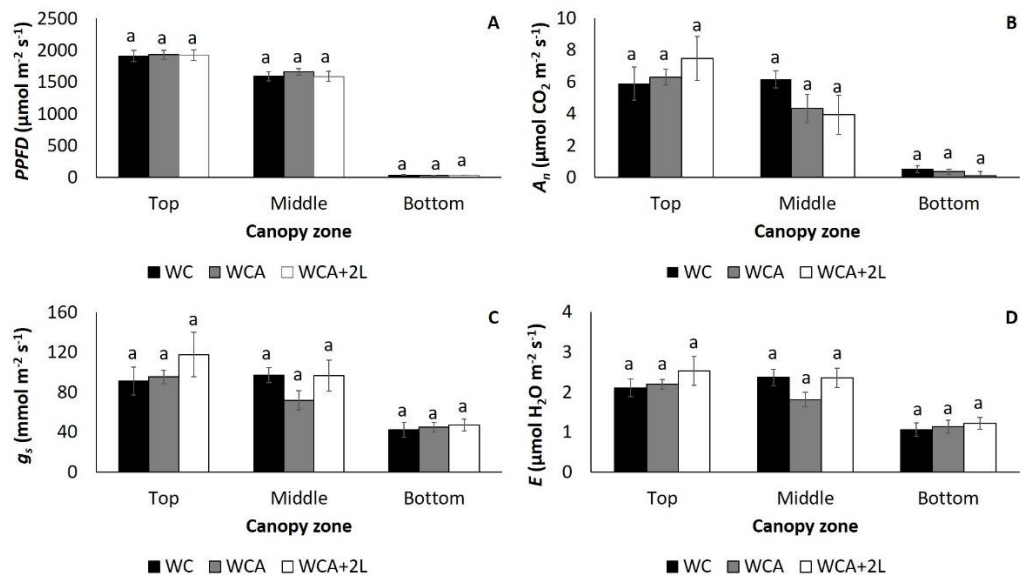
Figure 4. Photosynthetically active photon flux, *PPFD* (A), net photosynthetic rate, A_n (B), stomatal conductance, g_s (C) and transpiration rate, *E* (D) of leaves from the top, middle and bottom canopy zones of European hazelnut for the control treatments without winter pruning (*WC*), winter pruning of the central axis (*WCA*) and winter pruning of the central axis plus 2 lateral branches (*WCA+2L*). Different letters indicate significant differences according to Tukey's test (p≤0.05). Bars in the same point indicate standard error for n= 4. Source: Own elaboration.
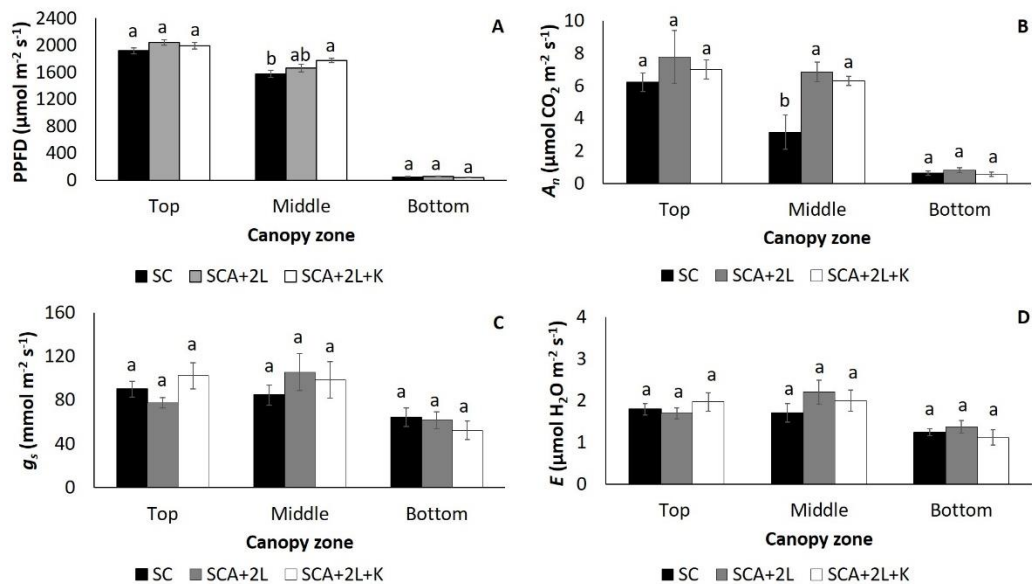
Figure 5. Photosynthetically active photon flux, *PPFD* (A), net photosynthetic rate, A_n (B), stomatal conductance, g_s (C) and transpiration rate, *E* (D) of leaves from the top, middle and bottom canopy zones of European hazelnut for the control treatments without summer pruning (*SC*), summer pruning of the central axis plus 2 lateral branches (*SCA+2L*), and summer pruning of the central axis plus 2 lateral branches and kaolin application (*SCA+2L+K*). Different letters indicate significant differences according to Tukey's test (p≤0.05). Bars in the same point indicate standard error for n= 4. Source: Own elaboration.
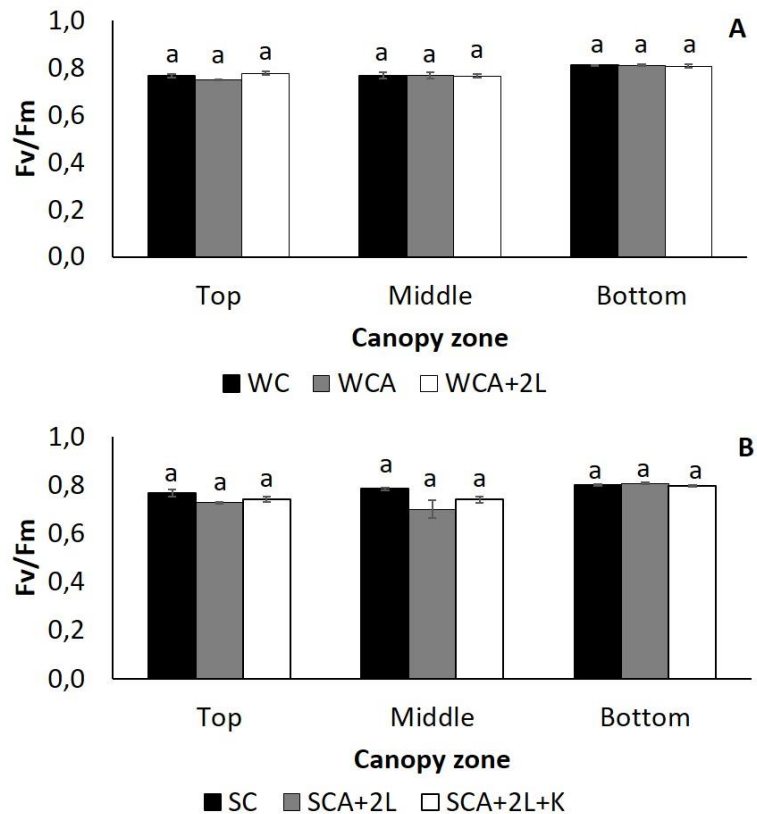
Figure 6. Photochemical efficiency of PS-II (F_v/F_m) measured in leaves of the top, middle and bottom canopy zones of European hazelnut for the control treatments without winter pruning (*WC*), winter pruning of the central axis (*WCA*), winter pruning of the central axis plus 2 lateral branches (*WCA+2L*) (A); control treatments without summer pruning (SC), summer pruning of the central axis plus 2 lateral branches (*SCA+2L*) and summer pruning of the axis central plus 2 lateral branches and kaolin application (*SCA+2L+K*) (B). Different letters indicate significant differences according to Tukey's test (p≤0.05). Bars in the same point indicate standard error for n= 4. Source: Own elaboration.

3.3. Fruit yield components

Winter pruning did not significantly (p>0.05) affect yield in any of the canopy zones Table 1). *WCA* resulted in a significant increase (p=0.015) of 5% in nut weight in the bottom canopy zone (Table 1). In both winter pruning treatments,

kernel weight increased significantly (p=0.002), recording a 5% increase in the lower part of the plant. For *WCA+2L,* the same parament recorded an increase of 4% (p=0.012) in the top canopy zone. In the bottom canopy zone, *WCA+2L* increased kernel yield by 3% compared to *WC* (p=0.02) (Table 1).

Regarding summer pruning, yield had a significant increase (p=0.022) of 90% in the middle canopy zone for *SCA+2L+K* compared to *SC* (Table 2). The same treatment recorded significant increases of 4% (p=0.013) and 5% (p<0.001) in nut and kernel weight, respectively. Finally, *SCA+2L+K* increased kernel yield by 2% in the bottom (p=0.019) and top (p=0.05) canopy zones (Table 2).

3.4. Vegetative growth, floral return, and incidence of fungal pathogens

In the top canopy zone, *WCA+2L* showed a significant increase (p=0.015) of 59% in the number of shoots with respect to the control without pruning (*WC)*, decreasing (p=0.038) total shoot length by 45% (Table 3). In the middle canopy zone, the same treatment increased mean shoot length by 61% compared to *WC* (p=0.047) (Table 3). *SCA+2L* and *SCA+2L+K* had no significant effect (p>0.05) on the number, total length, and mean length of one-year shoots in any of the canopy zones (Table 4).

Table 1. Influence of the control treatments without winter pruning (*WC*), winter pruning of the central axis (*WCA*) and winter pruning of the central axis plus 2 lateral branches (*WCA+2L*) on yield, nut weight, kernel weight and kernel yield for the top, middle and bottom canopy zones of European hazelnut. Different letters indicate significant differences between treatments according to Tukey's test (*: p≤0.05, **: p≤0.01, ***: p≤0.001, ns: not significant). Source: Own elaboration.

Parameter	Treatments	Canopy Zone		
		Bottom	Middle	Top
Yield (g plant^{-1})	WC	242.25 ± 81.1	733.50 ± 162.3	1443.00 ± 228.0
	WCA	240.25 ± 55.4	716.00 ± 110.6	1206.75 ± 191.7
	WCA+2L	244.00 ± 48.0	778.25 ± 65.4	1501.25 ± 243.7
	p value	0.99 ^{ns}	0.931 ^{ns}	0.627 ^{ns}
Nut weight (g)	WC	3.10 ± 0.03 b	3.32 0 ± 0.04	3.33 ± 0.03
	WCA	3.26 ± 0.04 a	3.31 ± 0.03	3.40 ± 0.03
	WCA+2L	3.19 ± 0.03 ab	3.30 ± 0.04	3.43 ± 0.03
	p value	0.015 *	0.748 ^{ns}	0.073 ^{ns}
Kernel weight (g)	WC	1.47 ± 0.02 b	1.56 ± 0.02	1.58 ± 0.02 b
	WCA	1.55 ± 0.02 a	1.56 ± 0.02	1.59 ± 0.02 b
	WCA+2L	1.55 ± 0.02 a	1.56 ± 0.02	1.64 ± 0.02 a
	p value	0.002 **	0.876 ^{ns}	0.012 *
Kernel yield (%)	WC	47.32 ± 0.4 b	47.07 ± 0.3	47.49 ± 0.3 ab
	WCA	47.67 ± 0.3 ab	47.15 ± 0.2	46.64 ± 0.3 b
	WCA+2L	48.65 ± 0.3 a	47.16 ± 0.3	47.88 ± 0.3 a
	p value	0.020 *	0.837 ^{ns}	0.008 **

Table 2. Influence of the control treatments without summer pruning (SC), summer pruning of the central axis plus 2 lateral branches (SCA+2L) and summer pruning of the central axis plus 2 lateral branches and kaolin application (SCA+2L+K) on yield, nut weight, kernel weight and kernel yield for the top, middle and bottom canopy zones of

European hazelnut. Different letters indicate significant differences between treatments according to Tukey's test (*: $p \leq 0.05$, **: $p \leq 0.01$, ***: $p \leq 0.001$, ns: not significant). Source: Own elaboration.

Parameter	Treatments	Canopy Zone		
		Bottom	Middle	Top
Yield (g plant^{-1})	SC	172.50 ± 73.5	460.00 ± 55.4 b	1238.00 ± 138.0
	SCA+2L	263.50 ± 33.0	734.50 ± 94.7 ab	1384.75 ± 224.2
	SCA+2L+K	315.50 ± 62.9	876.25 ± 100.8 a	1529.25 ± 192.4
	p value	0.273 ^{ns}	0.022 *	0.570 ^{ns}
Nut weight (g)	SC	3.21 ± 0.03	3.28 ± 0.03 b	3.39 ± 0.03
	SCA+2L	3.18 ± 0.03	3.34 ± 0.03 ab	3.40 ± 0.03
	SCA+2L+K	3.20 ± 0.03	3.40 ± 0.03 a	3.41 ± 0.03
	p value	0.992 ^{ns}	0.008 **	0.839 ^{ns}
Kernel weight (g)	SC	1.50 ± 0.02	1.54 ± 0.02 b	1.59 ± 0.02
	SCA+2L	1.50 ± 0.01	1.58 ± 0.01 ab	1.60 ± 0.01
	SCA+2L+K	1.54 ± 0.02	1.62 ± 0.01 a	1.63 ± 0.02
	p value	0.167 ^{ns}	0.0003 ***	0.167 ^{ns}
Kernel yield (%)	SC	47.30 ± 0.4 ab	46.90 ± 0.3	46.87 ± 0.3 b
	SCA+2L	47.18 ± 0.3 b	47.29 ± 0.3	47.20 ± 0.3 ab
	SCA+2L+K	48.29 ± 0.3 a	47.82 ± 0.3	47.77 ± 0.3 a
	p value	0.019 *	0.063 ^{ns}	0.050 *

Table 3. Influence of the control treatments without winter pruning (*WC*), winter pruning of the central axis (*WCA*) and winter pruning of the central axis plus 2 lateral branches (*WCA+2L*) on the number, total length, and mean length of one-year shoots (cm) for the top, middle and bottom canopy zone of European hazelnut. Different letters indicate significant differences between treatments according to Tukey's test (*: $p \leq 0.05$, **: $p \leq 0.01$, ***: $p \leq 0.001$, ns: not significant). Source: Own elaboration.

Parameter	Treatments	Canopy Zone		
		Bottom	Middle	Top
Number of shoots	WC	56.63 ± 9.5	79.63 ± 13.7	29.13 ± 4.5 a
	WCA	39.38 ± 5.2	71.00 ± 13.0	22.38 ± 4.5 ab
	WCA+2L	57.63 ± 6.4	41.63 ± 6.6	12.00 ± 1.7 b
	p value	0.160 ns	0.073 ns	0.015 *
Total shoot length (cm)	WC	177.63 ± 35.4	398.50 ± 60.0	498.00 ± 53.8 a
	WCA	102.25 ± 20.2	387.00 ± 50.9	372.38 ± 72.5 ab
	WCA+2L	163.88 ± 22.8	325.75 ± 36.8	274.63 ± 40.4 b
	p value	0.134 ns	0.554 ns	0.038 *
Mean shoot length (cm)	WC	3.13 ± 0.3	5.37 ± 0.7 b	18.66 ± 2.1
	WCA	2.49 ± 0.2	6.28 ± 0.9 ab	17.65 ± 1.8
	WCA+2L	2.82 ± 0.2	8.65 ± 1.0 a	23.21 ± 2.0
	p value	0.196 ns	0.047 *	0.123 ns

Table 4. Influence of the control treatments without summer pruning (*SC*), summer pruning of the central axis plus two lateral branches (*SCA+2L*) and summer pruning of the central axis plus 2 lateral branches and kaolin (*SCA+2L+K*) on the number, total length, and mean length of one-year shoots (cm) for the top, middle and bottom canopy

zones of European hazelnut. Different letters indicate significant differences between treatments according to Tukey's test (*: p≤0.05, **: p≤0.01, ***: p≤0.001, ns: not significant). Source: Own elaboration.

Parameter	Treatments	Canopy Zone		
		Bottom	Middle	Top
Number of shoots	SC	43.63 ± 8.5	72.38 ± 19.7	15.17 ± 3.1
	SCA+2L	41.38 ± 9.7	54.75 ± 11.2	18.00 ± 3.9
	SCA+2L+K	43.43 ± 6.6	38.38 ± 6.7	14.25 ± 3.3
	p value	0.978 ^{ns}	0.234 ^{ns}	0.727 ^{ns}
Total shoot length (cm)	SC	173.25 ± 44.2	343.13 ± 39.6	315.50 ± 50.7
	SCA+2L	138.13 ± 38.0	326.00 ± 34.8	353.88 ± 56.6
	SCA+2L+K	151.14 ± 28.4	303.88 ± 52.1	277.88 ± 42.2
	p value	0.800 ^{ns}	0.811 ^{ns}	0.572 ^{ns}
Mean shoot length (cm)	SC	3.77 ± 0.5	8.49 ± 2.6	23.83 ± 2.7
	SCA+2L	3.26 ± 0.2	7.46 ± 1.3	21.46 ± 1.9
	SCA+2L+K	3.37 ± 0.2	9.44 ± 1.8	22.38 ± 2.2
	p value	0.579 ^{ns}	0.777 ^{ns}	0.763 ^{ns}

Both *WCA* and *WCA+2L* as well as *SCA+2L* and *SCA+2L+K* did not significantly affect (p>0.05) floral return in terms of number and density of catkins and glomeruli (Tables 5 and 6).

Despite the high diversity of pathogens observed in male flowers (Figure 7), associated with genera such as *Botrytis*, *Fusarium*, *Alternaria*, *Cladosporium*, *Penicilium*, and *Trichothecium*, neither winter (Figure 7A) nor summer (Figure 7B)

pruning affected the incidence of these fungi, except for species of *Fusarium*, which recorded a 9% increase in incidence in *WCA* (p=0.0125) (Figure 7A). However, it is important to note that the pruning treatments did not significantly affect pathogen incidence in any of the three assessed canopy zones (data not shown).

Table 5. Influence of the control treatments without winter pruning (*WC*), winter pruning of the central axis (*WCA*) and winter pruning of the central axis plus 2 lateral branches (*WCA+2L*) on the number and density of male (catkins) and female (glomeruli) flowers for the bottom, middle and top canopy zones of European hazelnut. Different letters indicate significant differences between treatments according to Tukey's test (*: p≤0.05, **: p≤0.01, ***: p≤0.001, ns: not significant). Source: Own elaboration.

Parameter	Treatments	Canopy Zone		
		Bottom	Middle	Top
Number of catkins	WC	4.50 ± 1.6	16.63 ± 5.0	26.38 ± 7.1
	WCA	3.75 ± 1.0	14.38 ± 4.1	17.50 ± 7.5
	WCA+2L	9.00 ± 3.2	12.25 ± 5.1	19.88 ± 10.5
	p value	0.564 ^{ns}	0.809 ^{ns}	0.533 ^{ns}
Number of glomeruli	WC	22.50 ± 4.2	58.00 ± 14.8	65.13 ± 9.1
	WCA	12.25 ± 2.8	43.88 ± 8.3	53.63 ± 12.0
	WCA+2L	21.38 ± 4.9	38.13 ± 4.6	40.50 ± 9.2
	p value	0.514 ^{ns}	0.670 ^{ns}	0.178 ^{ns}
Catkins density (n° cm^{-1})	WC	0.022 ± 0.007	0.038 ± 0.011	0.051 ± 0.014
	WCA	0.056 ± 0.022	0.039 ± 0.013	0.035 ± 0.012
	WCA+2L	0.054 ± 0.017	0.037 ± 0.014	0.087 ± 0.026

Parameter	Treatments			
	p value	0.345 [ns]	0.631 [ns]	0.565 [ns]
Glomeruli density (n° cm^{-1})	WC	0.21 ± 0.08	0.21 ± 0.07	0.14 ± 0.03
	WCA	0.13 ± 0.03	0.13 ± 0.03	0.16 ± 0.03
	WCA+2L	0.13 ± 0.03	0.13 ± 0.02	0.16 ± 0.03
	p value	0.960 [ns]	0.905 [ns]	0.955 [ns]

Table 6. Influence of the control treatments without summer pruning (*SC*)), summer pruning of the central axis plus two lateral branches (*SCA+2L*), and summer pruning of the central axis plus 2 lateral branches and kaolin application (*SCA+2L+K*) on the number and density of male (catkins) and female (glomeruli) flowers for the bottom, middle and upper canopy of European hazelnut. Different letters indicate significant differences between treatments according to Tukey's test (*: $p \leq 0.05$, **: $p \leq 0.01$, ***: $p \leq 0.001$, ns: not significant). Source: Own elaboration.

Parameter	Treatments	Canopy Zone		
		Bottom	**Middle**	**Top**
Number of catkins	SC	9.43 ± 4.0	18.63 ± 4.4	20.88 ± 9.2
	SCA+2L	5.00 ± 0.8	14.00 ± 5.5	15.88 ± 5.4
	SCA+2L+K	4.63 ± 1.7	11.38 ± 2.4	20.88 ± 9.6
	p value	0.295 [ns]	0,483 [ns]	0.778 [ns]
Number of glomeruli	SC	19.88 ± 5.4	41.88 ± 8.3	52.63 ± 11.9
	SCA+2L	21.00 ± 3.2	40.88 ± 6.7	51.75 ± 10.1
	SCA+2L+K	22.75 ± 5.5	39.25 ± 6.7	38.38 ± 7.7
	p value	0.840 [ns]	0.973 [ns]	0.467 [ns]
Catkins density (n° cm^{-1})	SC	0.052 ± 0.013	0.055 ± 0.015	0.081 ± 0.036

	SCA+2L	0.048 ± 0.010	0.037 ± 0.011	0.040 ± 0.011
	SCA+2L+K	0.042 ± 0.017	0.037 ± 0.005	0.057 ± 0.024
	p value	0.363 ns	0.450 ns	0.724 ns
	SC	0.27 ± 0.12	0.13 ± 0.03	0.22 ± 0.06
	SCA+2L	0.26 ± 0.08	0.13 ± 0.02	0.21 ± 0.07
Glomeruli density (n° cm^{-1})	SCA+2L+K	0.19 ± 0.05	0.14 ± 0.02	0.14 ± 0.03
	p value	0.797 ns	0.868 ns	0.897 ns
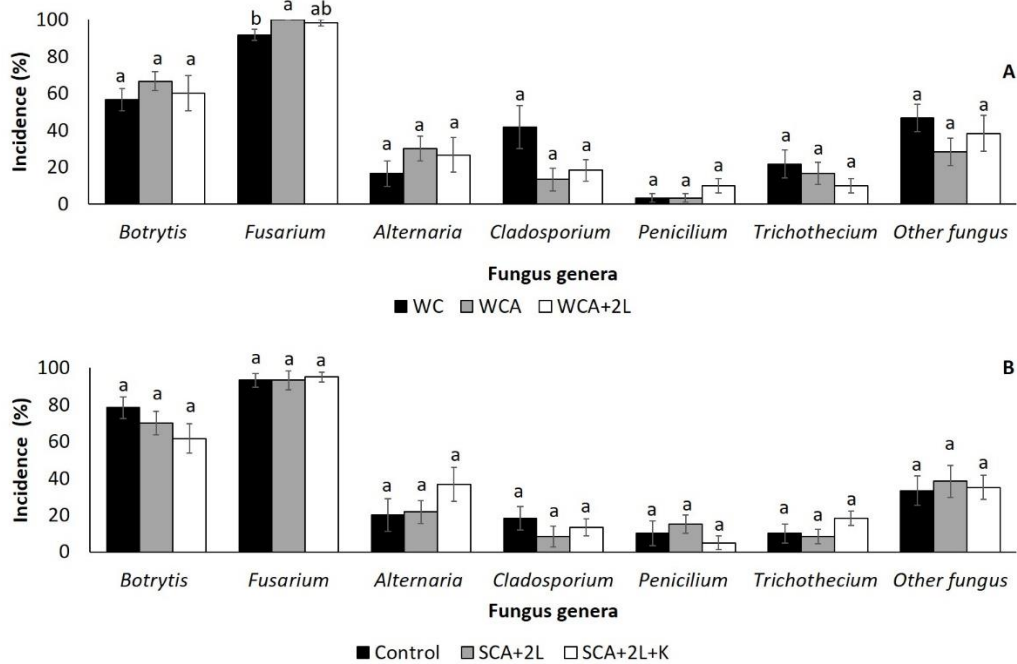
Figure 7. Influence of the control treatments without winter pruning (*WC*), winter pruning of the central axis (*WCA*), winter pruning of the central axis plus 2 lateral branches (*WCA+2L*) (A); and control treatments without summer pruning (*SC*), summer pruning of the central axis plus 2 lateral branches (*SCA+2L*) and summer pruning of the central axis plus 2 lateral branches and kaolin application (*SCA+2L+K*) (B) on the incidence (%) of different fungal pathogenic agents in male flowers (catkins) of European hazelnut.

Different letters indicate significant differences according to Tukey's test (p≤0.05). Bars in the same point indicate standard error for n=12.

3.5. Regression analysis

WCA+2L, *SCA+2L* and *SCA+2L+K* showed a statistically significant relationship between A_n and g_s (p=0.0001; 0.039 and 0.0144, respectively) (Table 7). However, no significant relationship was found in *SC* for these variables (p>0.05). For all the pruning treatments, the variation in A_n was explained in at least 40% by the effect of the variation in g_s (Table 7). All the treatments showed a negative polynomial curve, except for *SC* (Table 7; Figure 8). In addition, a statistically significant relationship was found between A_n/C_i and g_s for *WCA+2L* and *SCA+2L+K* (p=0.0004 and 0.0417, respectively), but not for *SC* or *SCA+2L* (p>0.05) (Table 7). However, *WCA+2L* had a positive polynomial curve pattern (β_2=0.00000029). In addition, *WCA+2L* recorded the highest R^2 values (0.78 and 0.83), i.e., about 80% of the variation in A_n and A_n/C_i was explained by the variation in g_s (Table 7; Figure 8).

A significant relationship was found between yield and light transmission for *SCA+2L* and *SCA+2L+K* (p=0.0023 and 0.0025, respectively), being yield variation mostly explained (68%) by the effect of the variation in the transmitted light (Table 8; Figure 9). No statistically significant relationship was observed between *yield* and light transmission for *SC* and *WCA+2L* (p>0.05) (Table 8). A statistically significant relationship between A_n and light transmission was found in *SC*, *SCA+2L* and *SCA+2L+K* (p=0.0086 and 0.0078, respectively), while light transmission explained 41%, 57% and 58% of A_n variations, respectively. Conversely, the *WCA+2L* treatment did not present a significant relationship (p>0.05) (Table 8). In both cases, the curves corresponding to *SCA+2L* and *SCA+2L+K* presented a negative polynomial pattern (Table 8; Figure 9). It is important to note that *SCA+2L+K* showed β2 values higher than those observed with *SCA+2L* in all the relationships studied (Tables 7 and 8).

Table 7. Regression coefficients for the relationship between net photosynthetic rate (A_n) and stomatal conductance (g_s), and between instantaneous carboxylation efficiency (A_n/C_i) and stomatal conductance (g_s) affected by the control treatments without summer pruning, winter pruning of the central axis plus 2 lateral branches (*WCA+2L*), summer pruning of the central axis plus 2 lateral branches (*SCA+2L*) and summer pruning of the central axis plus 2 lateral branches and kaolin application (*SCA+2L+K*). Asterisks indicate level of significance (*: $p \leq 0.05$, **: $p \leq 0.01$, ***: $p \leq 0.001$, ns: not significant). Source: Own elaboration.

Regression coefficients	Pruning treatments			
	SC	*WCA+2L*	*SCA+2L*	*SCA+2L+K*
	A_n			
β_0	-4.37 [ns]	-3.73 [ns]	-18.28 [ns]	6.84 [ns]
β_1	0.10 [ns]	0.09 [ns]	0.47 [ns]	0.22 [ns]
β_2	0.000001 [ns]	-0.000064 [ns]	-0.002 [ns]	-0.00087 [ns]
R^2 Aj	0.35 [ns]	0.83 ***	0.40 *	0.52 *
	A_n/C_i			
β_0	-0.03 [ns]	-0.01 [ns]	-0.11 [ns]	-0.03 [ns]
β_1	0.0006 [ns]	0.00024 [ns]	0.0029 [ns]	0.00097 [ns]
β_2	-0.0000016 [ns]	0.00000029 [ns]	-0000013 [ns]	-0.0000043 [ns]
R^2 Aj	0.25 [ns]	0.78 **	0.23 [ns]	0.40 *

Table 8. Regression coefficients for the relationship between *yield* and light transmission, and between net photosynthetic rate (A_n) and light transmission affected by the control treatments without summer pruning (*SC*), winter pruning of the central axis plus 2 branches (*WCA+2L*), summer pruning of the central axis plus 2 lateral branches

(*SCA+2L*) and summer pruning of the central axis plus 2 lateral branches and kaolin application (*SCA+2L+K*). Asterisks indicate level of significance (*: $p \leq 0.05$, **: $p \leq 0.01$, ***: $p \leq 0.001$, ns: not significant). Source: Own elaboration.

Regression coefficients	Pruning treatments			
	SC	WCA+2L	SCA+2L	SCA+2L+K
Yield				
β_0	3135.23 [ns]	-2219.75 [ns]	-28415.75 *	-8109.13 [ns]
β_1	-141.52 [ns]	56.63 [ns]	971.89 *	252.68 [ns]
β_2	1.77 [ns]	-0.09 [ns]	-7.93 *	-1.58 [ns]
R^2 Aj	0.29 [ns]	0.28 [ns]	0.68 **	0.68 *
A_n				
β_0	-46.36 [ns]	-10.42 [ns]	-205.1 *	-162.00 **
β_1	1.53 [ns]	0.22 [ns]	7.07 *	5.69 **
β_2	-0.01 [ns]	0.00029 [ns]	-0.06 *	-0.05 *
R^2 Aj	0.41 *	0.20 [ns]	0.57 **	0.58 **
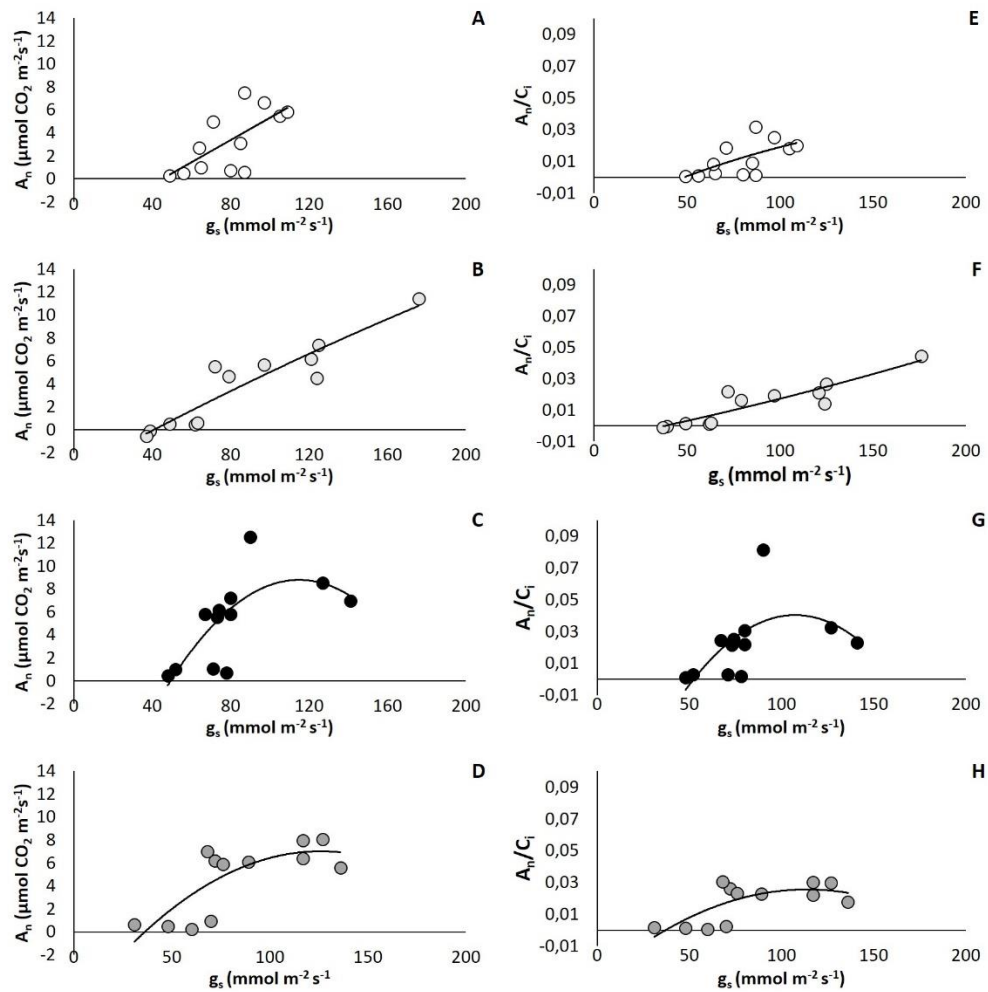
Figure 8. Relationship between net photosynthetic rate (A_n) and stomatal conductance (g_s) (A, B, C, D), and between instantaneous carboxylation efficiency (A_n/C_i) and stomatal conductance (g_s) (E, F, G , H) affected by the control treatments without summer pruning (*SC*) (A, E), winter pruning of the central axis plus 2 lateral branches (*WCA+2L*) (B, F), summer pruning of the central axis plus 2 lateral branches (*SCA+2L*) (C, G) and summer pruning of the central axis plus 2 lateral branches and kaolin application (*SCA+2L+K*) (D, H). Source: Own elaboration.
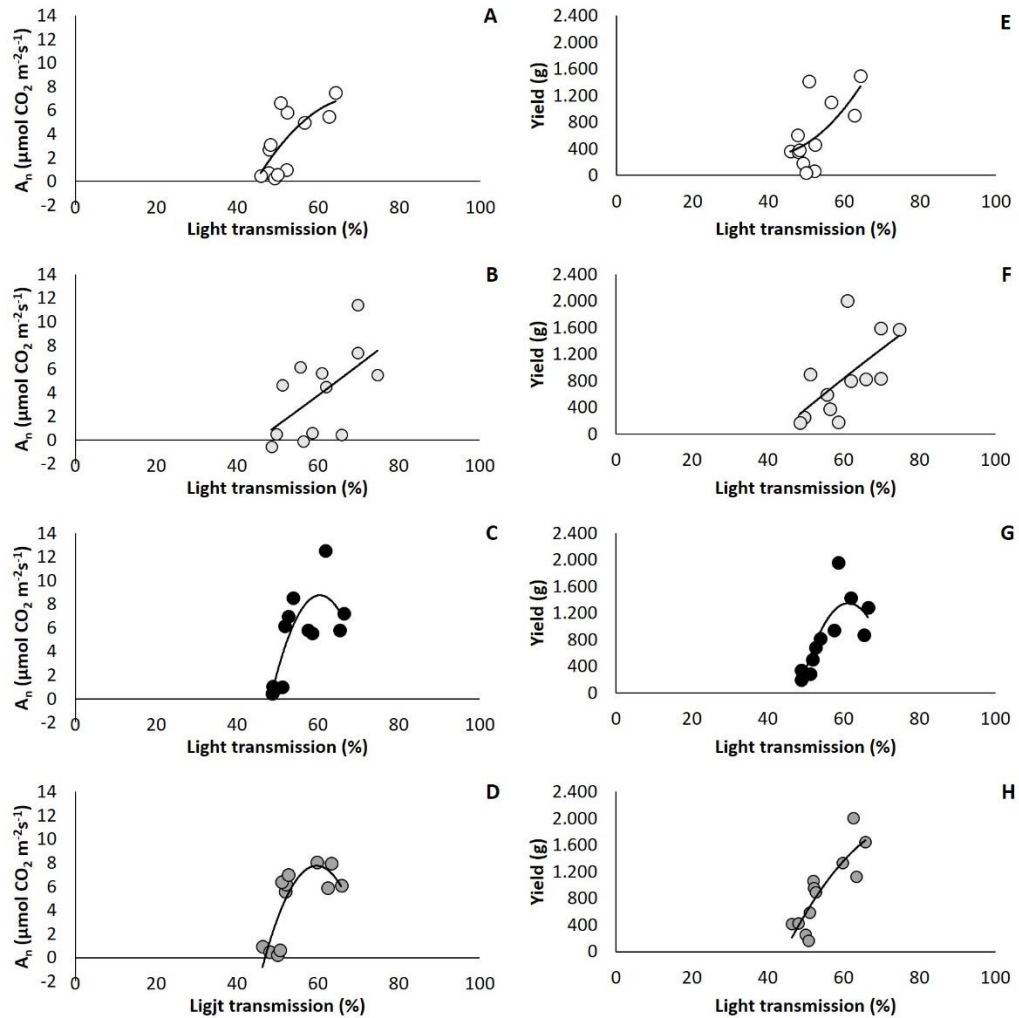
Figure 9. Relationship between net photosynthetic rate (A_n) and light transmission (%) (A, B, C, D), and between *yield* and light transmission (%) (E, F, G, H) affected by the control treatments without summer pruning (*SC*) (A, E), winter pruning of the central axis plus 2 lateral branches (*WCA+2L*) (B, F), summer pruning of the central axis plus 2 lateral branches (*SCA+2L*) (C, G) and summer pruning of the central axis plus 2 lateral branches and kaolin application (*SCA+2L+K*) (D, H). Source: Own elaboration.

4. Discussion

Light transmission into the inner canopy was greater in the top zone, decreasing towards the bottom zone (Figures 2 and 3). This agrees with studies carried out in crops such as blueberries [27], mango [28], apple [29], olive [30], kiwi [31], and European hazelnut [3]. In fact, light transmission into the inner canopy increased in *WCA+2L* and *SCA+2L+K* (Figures 2 and 3), which coincide with the results obtained in european hazelnut by Farinelli et al. [2] and Cristofori et al. [8]. Several studies have reported that as the amount of light available to the leaves increases, production increases [32-34]. This has been related to variables such as net CO_2 assimilation, stomatal conductance, floral development, yield, and fruit quality (30, 31, 34, 35). In this sense, *SCA+2L+K* was the treatment that resulted in the highest increase in light transmission. This effect could be attributed the use of kaolin since, being a white substance, it has the capacity to increase the reflected light [15], increasing the light transmitted into the inner canopy [18, 36]. In the present study, the greater light availability into the inner canopy was associated with an increase in A_n, g_s and E (Figures 4 and 5), which agrees with the results reported in previous studies on crops such as apple [33], blueberry [35], olive [30], mango [28], and European hazelnut [3].

It should be noted that winter pruning did not have a significant effect on A_n, g_s and E despite the increase in light transmission levels in the upper and middle parts of the plant. When analyzing the relationships between A_n and g_s, and between A_n/C_i and g_s, it was observed that the variation in A_n and A_n/C_i is largely explained by the variation in g_s, particularly in *WCA+2L* (Table 7). In addition, no significant relationship was found between A_n and light transmission for *WCA+2L* (Table 8). These results suggest the existence of non-stomatal limitations in the leaves of plants pruned in winter, such as a lower electron transport rate [37, 38], which would prevent an increase in net CO_2 assimilation by increasing light inside the canopy.

Summer pruning had a significant effect on the net CO_2 assimilation rate in the middle canopy zone, resulting in an increased A_n in both *SCA+2L* and *SCA+2L+K* (Figure 5) for that zone. This effect has also been observed in apple trees [29], mainly due to the increase in light transmission into the inner canopy, and in turn to a greater availability of radiant energy for photosynthesis [29]. However, the relationship between light transmission and A_n had a negative polynomial pattern (Figure 9), which could be explained by low acclimatization of the leaves as they were suddenly exposed to high radiation. Several studies have shown lower photosynthetic capacity in leaves under shaded conditions due to changes in anatomy and morphology such as lower development of palisade tissue, greater intercellular space in the mesophyll tissues, reduced leaf specific weight, and lower stomatal density [37, 38]. However, when analyzing the relationship between g_s and A_n, and that between g_s and A_n/C_i, higher β_2 values were observed in *SCA+2L+K* compared to *SCA+2L*, indicating that the values of A_n y A_n/Ci remained stable as g_s increased in plants with kaolin, but not in *SCA+2L* (Table 7; Figure 8).

Several studies have described that kaolin can increase gas exchange capacity and photochemical efficiency of PS-II in leaves, particularly under high temperature conditions, excessive radiation, or severe water stress [4, 15 - 17]. In many cases, this occurs due to an increase in reflected light and thus to a reduction in the potential damage caused by high levels of visible and ultraviolet light on leaves [15, 18], a decrease in leaf temperature, which reduces heat stress [16, 18], or greater tolerance to water stress [15, 36]. In this sense, these finding are confirmed by the higher levels of A_n and g_s found in the pruning treatments that included kaolin application (Figure 5).

The positive effect that winter and summer pruning had on fruit weight, kernel weight and fruit filling rate (Tables 4 and 5) is consistent with previous studies on European hazelnut [8]. Previous findings have shown that pruning

results in increases in yield (after 3 years) and kernel/fruit ratio compared to low intensity of pruning or no pruning. This positive effect of both winter and summer pruning would be mainly due to an increase in light into the inner canopy (Figures 2 and 3), as previously reported in apple [29] and European hazelnut [8]. A study carried out on apple trees [39] showed that the lack of sunlight affects and delays of assimilate partitioning, so that the winter and summer pruning treatments could have increased fruit weight, kernel weight and fruit filling by facilitating carbon movement towards the fruit due to improved light conditions inside the plant.

The yield increase observed with *SCA+2L+K* in the present study could also be explained by increased availability of radiant energy, which in turn led to an increase in the net CO_2 assimilation rate (Figure 5), and therefore to a greater amount of available carbohydrates for fruit growth. However, the same result was not observed with *WCA+2L* or *SCA+2L*, suggesting that the application of kaolin has an effect.

When analyzing the relationship between *yield* and light transmission (Figure 8), it was observed that yield remained stable in *SCA+2L+K* as the amount of transmitted light increased. However, this did not occur in *SCA+2L* ($\beta_2 = -1.58$ vs $\beta_2 = -7.93$; Table 8), suggesting that the increase in luminosity was more productively efficient in the plants in which kaolin was applied. Various studies have shown the effect of kaolin application on fruit yield and quality. Similarly, Dinis et al. [15] reported an increased yield after kaolin application in grapevines, while Gharaghani et al. [16] reported an increase in yield and fruit quality in walnut plants treated with this reflective substance. In addition, the positive results of kaolin application on yield were associated with an increase in net CO_2 assimilation resulting from reduced stress by high temperatures, favoring a greater amount of available carbohydrates for fruit development. Glenn et al. [36] conducted a study on apples and found a significant relationship between weight increase by the application of kaolin, temperature, and vapor pressure deficit,

reporting a greater increase in weight under higher temperatures and greater vapor pressure deficit, which confirms that kaolin is more effective when the plant is subjected to greater stress. In our study, even though there was no significant effect of summer pruning on the photochemical efficiency of PS-II measured through the F_v/F_m ratio, the values of this parameter were lower in *SCA+2L* and increased with the application of kaolin (Figure 6), demonstrating the positive effect of kaolin on the decrease in photo-inhibition of leaves overexposed to light due to summer pruning.

In terms of vegetative growth, the reduction in shoot number and total shoot length in the top canopy zone by *WCA+2L* as well as the increase of these parameters in the middle zone (Table 3) would be explained by higher light transmission into the inner canopy (Figure 2), generating a lower growth of shoots compared to the control. It has been proven that, under low light availability, the plant would prioritize shoot growth by reducing carbohydrate supply to the fruit [40]. This would also explain the higher weight and fruit filling observed in *WCA+2L* (Table 1). Conversely, summer pruning did not exert a significant effect on shoot growth, probably because this practice was carried out in the least active period of shoot growth induced by paradormancy (January in the southern hemisphere), in which carbohydrate movement was mainly required for fruit filling and differentiation of flower primordia rather than shoot growth [41 - 43].

Although pruning affected light transmission, vegetative growth, and photosynthesis, no changes were observed in floral return, either catkins or glomeruli (Tables 5 and 6). This finding agrees with Farinelli et al. [2], who reported that pruning did not significantly affect the number of glomeruli and catkins in ´Tonda di Giffoni´ hazelnut. In our study, the presence of *Fusarium* spp. and *Botrytis* spp*.* in male flowers (Figure 7) could explain the fact that winter and summer pruning did not trigger any response in floral return, since these pathogenic agents can affect the health of flower buds [44, 45]. Nevertheless, the

presence of different fungal genera associated with kernel mold [44, 45] in male flowers was observed, they did not show an increase in fungal incidence by this management cultural practices.

5. Conclusions

In conclusion, summer pruning and kaolin-based particle film application can increase yield, nut, and kernel weight in hazelnut by greater photosynthetic light availability into the canopy, but also by improving leaf net photosynthesis rate. Although winter pruning also increased light transmission into the inner canopy, this was not reflected in changes in yield components and leaf photosynthesis. The results obtained in this study suggest that the adoption of pruning in hazelnut to form a training system with greater light transmission during summer and combined with the use of technologies, such as reflectance particles, to mitigate excess light could help to reach a more sustainable yield in this horticultural crop, especially in orchard conditions with excessive exposition to solar radiation and high temperatures.

6. References

1. Hampson, C., A. Azarenko and J. Potter. 1996. Photosynthetic rate, flowering, and yield component alteration in Hazelnut in response to different light environments. J. Amer. Soc. Hort. Sci. 121(6): 1103–1111. [https://doi.org/10.21273/JASHS.121.6.1103]

2. Farinelli, D.; Boco, M.; Tombesi, A. Influence of canopy density on fruit growth and flower formation. *Acta Hortic.* **2005,** *686,* 247-252. [10.17660/ActaHortic.2005.686.33]

3. Pannico, A.; Cirillo, C.; Giaccone, M.; Scognamiglio, P.; Romano, R.; Caporaso, N.; Basile, B. Fruit position within the canopy affects kernel lipid

composition of hazelnuts. *J. Sci. Food Agr.* **2017,** *97,* 4790-4799. [https://doi.org/10.1002/jsfa.8348]

4. Luciani, E.; Palliotti, A.; Frioni, T.; Tombesi, S; Villa, F.; Zadra, C.; Farinelli, D. Kaolin treatments on Tonda Giffoni hazelnut (*Corylus avellana* L.) for the control of heat stress damages. *Sci. Hortic.* **2020,** *263,* 109097. [https://doi.org/10.1016/j.scienta.2019.109097]

5. Lauri, P.; Costes, E.; Regnard, J.; Brun, L.; Simon, S.; Monney, P.; Sinoquet, H. Does knowledge on fruit tree architecture and its implications for orchard management improve horticultural sustainability? An overview of recent advances in the apple. *Acta Hortic.* **2009,** *817,* 243-250. [10.17660/ActaHortic.2009.817.25]

6. Cherbiy-Hoffmann, U.; Searles, P.; Hall, A.; Rousseaux, M. Influence of light environment on yield determinants and components in large olive hedgerows following mechanical pruning in the subtropics of the southern Hemisphere. *Sci. Hortic.* **2012,** *137,* 36-42. [https://doi.org/10.1016/j.scienta.2012.01.019]

7. Pescie, M.; Borda, M.; Fedyszak, P.; López, C. Efecto del momento y tipo de poda sobre el rendimiento y calidad del fruto en arándano altos del sur (*Vaccinium corymbosum*) var. O´Neal en la provincia de Buenos Aires. *RIA.* **2011,** *37,* 268-274. [http://hdl.handle.net/20.500.12123/6426]

8. Cristofori, V.; Cammilli, C.; Valentini, F.; Bignami, C. Effect of different pruning methods on growth, yield and quality of the hazelnut cultivar 'Tonda Gentile Romana'. *Acta Hortic.* **2009,** *845,* 315-322. [https://doi.org/10.17660/ActaHortic.2009.845.48]

9. Silvestri, C.; Bacchetta, L.; Bellincontro, A.; Cristofori, V. Advances in cultivar choice, hazelnut orchard management, and nut storage to enhance product quality and safety: an overview. *J. Sci. Food Agric.* **2021,** *101,* 27-43. [https://doi.org/10.1002/jsfa.10557]

10. Roversi, A.; Malvicini, G.; Mozzone, G.; Dilmacunal, T. A simple summer pruning trial on hazelnut. *Acta Hortic.* **2009,** *845,* 367-372. [https://doi.org/10.17660/ActaHortic.2009.845.57]

11. Racsko, J.; Schrader, L. E. Sunburn of apple fruit: Historical background, recent advances and future perspectives. *Crit. Rev. Plant Sci.* **2012,** *31,* 455-504. [https://doi.org/10.1080/07352689.2012.696453]

12. Yu, D. J.; Lee, J. I.; Chung, S. W.; Hwang, J. Y.; Yun, S. K.; Lee, H. J. Photosynthetic acclimatisation of leaves in response to a shade-to-sun transition following summer pruning in peach (*Prunus persica* cv. Changhoweonhwangdo) trees. *J. Hortic. Sci. Biotech.* **2014,** 89, 279-286. [https://doi.org/10.1080/14620316.2014.11513080]

13. Olivares-Soto, H.; Bastías, R. M. Photosynthetic efficiency of apples under protected shade nets. *Chil. J. Agr. Res.* **2018,** *78,* 126-138. [http://dx.doi.org/10.4067/S0718-58392018000100126]

14. Jifon, J. L.; Syvertsen, J. P. Kaolin particle film applications can increase photosynthesis and water use efficiency of 'Ruby Red' Grapefruit Leaves. *J. Am. Soc. Hortic. Sci.* **2003,** *128,* 107-112. [https://doi.org/10.21273/JASHS.128.1.0107]

15. Dinis, L. T.; Malheiro, A. C.; Luzio, A.; Fraga, H.; Ferreira, H.; Gonçalves, I.; Moutinho-Pereira, J. Improvement of grapevine physiology and yield under summer stress by kaolin-foliar application: water relations, photosynthesis and oxidative damage. *Photosynthetica* **2018,** *56,* 641-651. [https://doi.org/10.1007/s11099-017-0714-3]

16. Gharaghani, A.; Javarzari, A. M.; Vahdati, K. Kaolin particle film alleviates adverse effects of light and heat stresses and improves nut and kernel quality in Persian walnut. *Sci. Hortic.* **2018,** *239,* 35-40. [https://doi.org/10.1016/j.scienta.2018.05.024]

17. Brito, C.; Gonçalves, A.; Silva, E.; Martins, S.; Pinto, L.; Rocha, L.; Arrobas, M.; Rodrigues, M. A.; Moutinho-Pereira, J.; Correia, C. M. Kaolin foliar spray improves olive tree performance and yield under sustained deficit irrigation. *Sci. Hortic.* **2021,** *277,* 109795. [https://doi.org/10.1016/j.scienta.2020.109795]

18. Glenn, M.; Prado, E.; Erez, A.; McFerson, J.; Puterka, G. A reflective processed-Kaolin particle film affects fruit temperature, radiation reflection, and solar injury in Apple. *J. Amer. Soc. Hort. Sci.* **2002,** *127,* 188-193. [https://doi.org/10.21273/JASHS.127.2.188]

19. Sharma, R.; Reddy, S.; Datta, S. Particle films and their applications in horticultural crops. *Appl. Clay Sci.* **2015,** *116,* 54-68. [https://doi.org/10.1016/j.clay.2015.08.009]

20. Chabbal, M.; Piccoli, A.; Martínez, G.; Avanza, M.; Mazza, S.; Rodríguez, V. Aplicaciones de caolín para el control de golpe de sol en mandarino 'Okitsu'. *Cultivos Tropicales* **2014,** *35,* 50-56.

21. Wünsche, J. N.; Lakso, A. N.; Robinson, T. L. Comparison of four methods for estimating total light interception by apple trees of varying forms. *HortScience* **1995,** *30,* 272-276. [https://doi.org/10.21273/HORTSCI.30.2.272]

22. Bastías, R. M; Widmer, A. Blattflächenindex und lichtaufnahme in verschiedenen Apfel-Anbauformen. *Schweizerischen Zeitschrift für Obst- und Weinbau* **2002,** *4,* 66-69.

23. Reyes-Diaz, M.; Alberdi, M.; Mora, M. Short-term aluminum stress differentially affects the photochemical efficiency of photosystem II in highbush blueberry genotypes. *J. Am. Soc. Hort. Sci.* **2009,** *134,* 14-21. [https://doi.org/10.21273/JASHS.134.1.14]

24. Maxwell, K.; Johnson, G. Chlorophyll fluorescence - a practical guide. *J. Exp. Bot.* **2000,** *51,* 659-668. [https://doi.org/10.1093/jexbot/51.345.659]

25. Tombesi, S.; Farinelli, D. Relationships between flower density and shoot length in hazelnut (*Corylus avellana* L.). *Acta Hortic.* **2014,** *1052,* 137-142. [10.17660/ActaHortic.2014.1052.17]

26. Di Rienzo, J.; Casanoves, F.; Balzarini, M.; Gonzalez, L.; Tablada, M.; Robledo, C. **2011.** InfoStat. Software Estadístico. Universidad Nacional de Córdoba, Argentina.

27. Yáñez, P.; Retamales, J. B.; Lobos, G. A.; del Pozo, A. Light environment within mature rabbiteye blueberry canopies influences flower bud formation. *Acta Hortic.* **2009,** *810,* 471-474. [10.17660/ActaHortic.2009.810.61]

28. Sharma, R. R.; Singh, R.; and Singh, D. B. Influence of pruning intensity on light penetration and leaf physiology in high-density orchards of mango trees. *Fruits* **2006,** *61,* 117-123. [https://doi.org/10.1051/fruits:2006010]

29. Bhusal, N.; Han, S. G.; Yoon, T. M. Summer pruning and reflective film enhance fruit quality in excessively tall spindle apple trees. *Hortic. Environ. Biotechnol.* **2017,** *58,* 560-567. [https://doi.org/10.1007/s13580-017-0375-y]

30. Caruso, G.; Gucci, R.; Sifola, M. I.; Selvaggini, R.; Urbani, S.; Esposto, S.; Taticchi, A.; Servili, M. Irrigation and fruit canopy position modify oil quality of olive trees (cv. Frantoio). *J. Sci. Food Agric.* **2017,** *97,* 3530-3539. [https://doi.org/10.1002/jsfa.8207]

31. Gullo, G.; Branca, V.; Dattola, A.; Zappia, R.; Inglese, P. Effect of summer pruning on some fruit quality traits in Hayward kiwifruit. *Fruits* **2013,** *68,* 315-322. [https://doi.org/10.1051/fruits/2013077]

32. Wünsche, J. N.; Lakso, A. N.; Robinson, T. L.; Lenz, F.; Denning, S. S. The bases of productivity in apple production systems: the role of light interception by different shoot types. *J. Am. Soc. Hort. Sci.* **1996,** *121,* 886-893. [https://doi.org/10.21273/JASHS.121.5.886]

33. Bhusal, N.; Bhusal, S. J.; Han, S. G.; Yoon, T. M. Canopy light distribution and fruit quality in excessive tall spindle apple production system. *Acta Hortic.* **2019,** *1261,* 209-218. [10.17660/ActaHortic.2019.1261.31]

34. Wilkie, J. D.; Conway, J.; Griffin, J.; Toegel, H. Relationships between canopy size, light interception and productivity in conventional avocado planting

systems. *J. Hortic. Sci. Biotech.* **2019,** *94,* 481-487. [https://doi.org/10.1080/14620316.2018.1544469]

35. Kim, S. J.; Yu, D. J.; Kim, T. C.; Lee, H. J. Growth and photosynthetic characteristics of blueberry (*Vaccinium corymbosum* cv. Bluecrop) under various shade levels. *Sci. Hortic.* **2011,** *129,* 486-492. [https://doi.org/10.1016/j.scienta.2011.04.022]

36. Glenn, M. Particle film mechanisms of action that reduce the effect of environmental stress in 'Empire' Apple. *J. Amer. Soc. Hort. Sci.* **2009,** *134,* 314-321. [https://doi.org/10.21273/JASHS.134.3.314]

37. Bastías, R. M.; Losciale, P.; Chieco, C.; Corelli-Grappadelli, L. Red and blue netting alters leaf morphological and physiological characteristics in apple trees. *Plants* **2021,** *10,* 127. [https://doi.org/10.3390/plants10010127]

38. Salazar-Canales, F.; Bastías, R. M.; Calderón-Orellana, A.; Wilckens, R.; González, E. Photo-selective nets differentially affect microclimatic conditions, leaf physiological characteristics, and yield in hazelnut (*Corylus avellana* L.). *Hortic. Environ. Biote.* **2021,** *62,* 845-858. [https://doi.org/10.1007/s13580-021-00365-8]

39. Corelli-Grappadelli, L.; Lakso, A. N.; Flore, J. A. Early season patterns of carbohydrate partitioning in exposed and shaded apple branches. *J. Am. Soc. Hort. Sci.* **1994,** *119,* 596-603. [https://doi.org/10.21273/JASHS.119.3.596]

40. Bastias, R. M.; Manfrini, L.; Corelli-Grappadelli, L. Exploring the potential use of photo-selective nets for fruit growth regulation in apple. *Chil. J. Agric.*

Res. **2012,** *72,* 224-231. [https://doi.org/10.4067/S0718-5839201200 0200010]

41. Beyhan, N.; Marangoz, D. An investigation of the relationship between reproductive growth and yield loss in hazelnut. *Sci. Hortic.* **2007,** *113,* 208-215. [https://doi.org/10.1016/j.scienta.2007.02.007]

42. von Bennewitz, E.; Ramírez, C.; Muñoz, D.; Cazanga-Solar, R.; Lošak, T.; Alba-Mejía, J. E.; Maureira-Butler, I. Phenology, pollen synchronization and fruit characteristics of european hazelnut (*Corylus avellana* L.) cv. tonda de Giffoni in three sites of central Chile. *Rev. FCA. UNCUY.* **2019,** *51,* 55–67.

43. Paradinas, A.; Ramade, L.; Mulot-Greffeuille, C.; Hamidi, R.; Thomas, M.; Toillon, J. Phenological growth stages of 'Barcelona' hazelnut (*Corylus avellana* L.) described using an extended BBCH scale. *Sci. Hortic.* **2022,** *296,* 110902. [https://doi.org/10.1016/j.scienta.2022.110902]

44. Guerrero, J.C.; Pérez, S. F.; Ferrada, E. Q.; Cona, L. Q.; Bensch, E. T. Phytopathogens of hazelnut (*Corylus avellana* L.) in southern Chile. *Acta Hortic.* **2014,** *1052,* 269-274. [https://doi.org/10.17660/ActaHortic.2014.1052.36]

45. Pscheidt, J. W.; Heckert, S.; Wiseman, M.; Jones, L. Fungi associated with and influence of moisture on development of kernel mold of hazelnut. *Plant Dis.* **2019,** *103,* 922-928. [https://doi.org/10.1094/PDIS-09-18-1520-R]