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Influence of the Diffusivity and Transmittance of a Plastic Greenhouse Cover on the Development of Fungal Diseases in a Cucumber Crop

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Abstract: Mediterranean greenhouses are usually covered by plastic materials (films); these films allow light to pass through them, modifying some of their characteristics. The properties of the plastic cover influence the development of greenhouse crops. In addition, it can influence the stresses that the plants endure and the development of fungal diseases in the crop. The aim of this study is to analyze the effect that an experimental film cover, with high transmittance and high light diffusivity, produces on the development of fungal diseases on a cucumber crop (*Cucumis sativus* L.). Two different film covers were compared: (i) commercial film (transmittance of 85%; diffusivity of 60%); and (ii) experimental film (transmittance of 90%; diffusivity of 55%). The study was carried out across two autumn–winter crop cycles in a multi-span greenhouse divided into two isolated sectors. Three fungal diseases caused the main damage to the cucumber crop: downy mildew (*Pseudoperonospora cubensis*), powdery mildew (*Sphaerotheca fuliginia*) and gummy stem blight (*Didymella bryoniae*). In the case of powdery mildew, a greater severity in the sector was observed with the commercial film in comparison with the sector with the experimental film, with significant statistical differences between the two sectors in both crop cycles. Downy mildew and gummy stem blight were fungal diseases with less presence than downy mildew, and a greater presence of these two fungal diseases in the sector with the commercial film was also observed in both crop cycles.

Keywords: greenhouse; *Cucumis sativus* L.; diffuse film; transmittance film; fungal diseases

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1. Introduction

Solar greenhouses, characteristic of the Mediterranean coast, use passive climate control systems, which do not require external energy inputs, such as electricity or gas. With the energy of the sun or natural winds, Mediterranean greenhouses achieve climate control that is less expensive in terms of inputs. Mediterranean greenhouses are mostly covered with plastic films, which have passive systems for climate control; some of the plastic covers materials are infrared reflective films and are interesting materials that allow an increase in PAR transmission and optimal near infrared reflection, which can improve the air temperature management [1].

The type of covering material influences the energy consumption, performance and overall economy of greenhouses. A better understanding of the properties of these materials is of great importance to both researchers and farmers [2]. The physical properties of the cover material influence the quality of the indoor microclimate [3]. Transmittance is considered one of the most important physical properties; the characteristic values of transmittance in plastic films vary between 70–90%. The ideal material has to allow 100% of

the transmission of photosynthetically active radiation, which is what plants use effectively in the photosynthesis process [2].

Innovative greenhouse covering materials have been developed that transform direct radiation from the sun into diffuse radiation, which once inside the greenhouse is dispersed and reaches the crop areas that absorb it to perform photosynthesis [4]. Crops take better advantage of diffuse radiation, allowing for better photosynthetic performance in areas of the plant that under normal conditions would have lower photosynthetic performance [5]. Greenhouses covered with plastics that improve light transmission and diffusion, better distribute light within the crop canopy, reduce stress from high temperatures and increase fruit yield and quality [6]. The distribution of light in the canopy is influenced by the direction of the light and by the fraction of diffused/direct light that falls on the canopy but also depends on the architecture of the crop [7]. Under the influence of cover materials that increase diffuse light, leaf photosynthesis can be 10–15% higher, suggesting that direct and diffuse light affect photosynthetic processes differently [8,9]. With diffuse cover materials (capable of transforming 45–71% of direct light into diffuse light), the light profiles are more homogeneous, increasing crop yield and growth [7,10,11]. In addition, tomato fruit weight increased by 5 g [12] and by 5–8 g [13] under high diffusivity materials.

The plastic covers of greenhouses clearly influence the production and quality of the fruits produced in them, so that the amount of light that reaches the crops before harvest influences the increase in lycopene biosynthesis. Thus, the fruits that receive the greatest amount of light accumulate greater amounts of lycopene, which gives the fruits a better coloration and better quality, both visually and organoleptically [14].

In greenhouses, there are favorable environments for the development of pests on the crop, due to the warm and humid environment that exists under the plastic covers. The plastic covers of Mediterranean greenhouses often favor condensation on the inner surface of the plastic cover, which increases the ambient humidity and can cause this condensed water to fall on the crop, which favors the proliferation of phytopathogenic fungi on the crop [15]. The fall of the condensed water in the plastic cover of the greenhouses on the crops, which are developed inside, favors the development of fungi that parasitize the cultivated plants, causing a yield loss in the crops, in addition to the depreciation of the fruits due to loss of quality, causing serious losses to growers [16]. Interfering in the development of the pathogen cycle is important in any integrated pest management (IPM) strategy. One of the ways to interfere with the environmental conditions of greenhouses is to modify the spectral properties of the greenhouse film cover, which, in turn, affects the development of some pathogens on the plant [17].

Light has an important effect on the formation of the conidia of some fungi; the exposure of the mycelia to ultraviolet light or blue light affects the development of the fungus [18]. It is known that greenhouse cover films, which block or decrease ultraviolet radiation [19], prevent the sporulation of various phytopathogenic fungi [20].

Two of the most frequent fungal diseases in the Mediterranean area are downy mildew and powdery mildew. In greenhouses, the cucurbits crops are normally threatened by different fungi, which belong to the powdery mildews [21]. The attacks of these fungi cause significant economic damage to production, reducing crop yields [22]. The symptoms of the disease are characterized by a growth of fungi, and it appears that white powder develops on the surface of the leaves, petioles and stems, while hardly on the fruits. These diseases can reduce plant growth, produce premature drying of leaves and, subsequently, cause a reduction in the quality and marketability of fruits. Powdery mildew in cucurbits can develop at the beginning of crop production and can rapidly colonize plant tissues [23].

Downy mildew, caused by the fungus *Pseudoperonospora cubensis*, is one of the most dangerous diseases that attack cucumber and other cucurbits, causing serious losses in the harvest of their crops [24]. The symptoms of this disease can be found on true leaves, in geometric shapes on the adaxial surface of the leaves, limited by the leaf veins. The lesions begin with angular watery spots, which first develop into chlorotic spots that end up necrotizing and can necrotize the leaf completely [25]. A reduced canopy leads to the

interruption of fruit development and increases the exposure of the fruits to the sun, which could lead to sunburn and secondary rot [26]. Finally, crop yields and fruit quality are affected by downy mildew [25].

The fungus *Didymella bryoniae* is a pathogen that universally affects cucurbit crops, causing gummy stem blight (GSB), which can affect the host at any stage of its growth and development, affecting stems, leaves and fruits [27]. This pathogen can cause damage and spots on the leaves and black rot on the fruits [28], which can cause many economic losses during the storage of the fruits [29]. The damage begins with yellowing on the margins of the leaves; this yellowing progresses until the leaf ages, gradually causing necrosis until the total death of the plant; these symptoms develop rapidly with favorable environmental conditions for the fungus [30]. There are previous studies that relate the development of the mycelium of pathogenic fungi, such as powdery mildew, depending on the qualities of the light received by the crops [17].

In this study, our objective was to analyze the performance of an experimental film (with high PAR radiation transmissivity and high diffusivity), compared to a commercial film cover on fungal disease development, crop yield and production quality parameters in a cucumber crop (*Cucumis sativus* L.) in a Mediterranean greenhouse.

2. Materials and Methods

2.1. Description of the Experimental Greenhouse

The experimental work was carried out in a multi-span Mediterranean greenhouse of five modules (1800 m^2) with natural ventilation, placed in the experimental station "Catedrático Eduardo Fernández" of the University of Almería (latitude: 36°51′53.2″ N longitude: 2°16′58.8″ W; altitude: 87 m). The greenhouse was divided transversally by a vertical plastic sheet that constituted two independent sectors with similar characteristics (Table 1). In the west sector, the experimental film (E_F) was located, while the east sector was where the commercial film (C_F) was located. The east sector with C_F was the control sector. The experimental film was developed by POLITIV EUROPA S.L. (Israel). The work was carried out in two autumn–winter crop cycles (2020–2021 and 2021–2022); in the first cycle, the greenhouse only had roof vent (vents in all modules), while in the second crop cycle, ventilation was increased due to the side vents (Table 1). To protect the crop against insect pest, insect-proof screens (10 × 20 threads cm^{-2}) were installed in the vents.

Table 1. Characteristics of the two sectors of the experimental greenhouse. L_G, length [m]; W_G, width [m]; S_C, crop area [m^2]; S_V, vent opening area [m^2]; S_V/S_C, ventilation surface percentage [%].

Sector	Plastic Cover	$L_G \times W_G$	S_C	20–21 Crop Cycle		21–22 Crop Cycle	
				S_V	S_V/S_C	S_V	S_V/S_C
West	E_F	40 × 25	1000	109.1	10.9	232.2	23.2
East	C_F	40 × 20	800	84.9	10.6	193.9	24.2

The optical properties of the film covers were provided by the manufacturer (Table 2) and were determined according to the regulations UNE-EN 13,206 [31] and ASTM D 1003-13 [32].

Table 2. Optical properties of plastic cover films. T_{PAR}, transmission of photosynthetically active radiation [400–700 nm]; T_{UV}, transmission of ultraviolet light [300–380 nm]; D, diffusion of light; T, thermal efficiency.

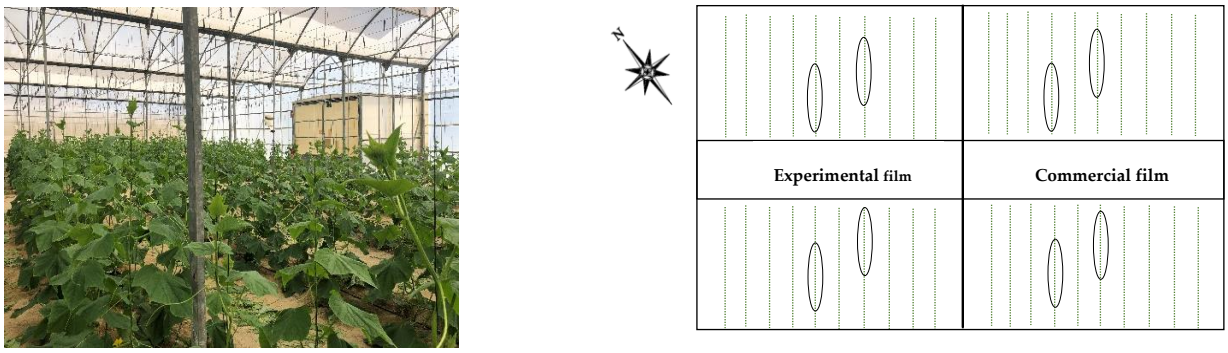
Plastic Cover	T_{PAR}	T_{UV}	D	T
Diffuse experimental film	0.90	0.24	0.55	0.90
Diffuse commercial film	0.85	0.24	0.60	0.85

2.2. Crop System

To study the influence of different film on cucumber crop (*Cucumis sativus* L.), two consecutive autumn–winter crop cycles were carried out with the commercial variety Insula (Rijk Zwaan Ibérica, S.A., Almería, Spain). The transplant of both crops was carried out in the first week of September in "arenado" sand mulched soil, typical of greenhouses in Almería [33]. The plant density was 1.2 plants/m^2, with localized drip irrigation. The crop lines were established perpendicular to the greenhouse ridges. The irrigation scheduling method was the same in both greenhouse sectors.

2.3. Plant Diseases Development Quantification

The identification of the fungi, which causes the disease, was carried out by direct observation. Mycelia, spores and conidia were then observed under the microscope [34]. The analysis of each of the diseases was obtained by means of the percentage values of damage per leaf, for each disease. Fifty random leaves were analyzed in each plot and for each disease, obtaining a total of 200 samples for each disease and for each study area (Figure 1). The diseases were evaluated every 7 days from the beginning of the first symptoms, thus, obtaining the evolution of the development of the damages produced by each disease during the two crop cycles. The diseases studied were not inoculated, since they are endemic to the area and usually appear every year, but they did not appear at the same time, because the disease depended on the environmental conditions and the state of the host plants each year. For this reason, the evaluations at certain points did not coincide, since it can be the case that one of the diseases developed at different times from another, which, on the other hand, is completely normal, since the diseases required slightly different environmental conditions and host susceptibility for each one of the diseases studied. For this reason, the crops were monitored until the first symptoms of each of the diseases were detected; following this occurrence, the diseases were monitored weekly.



(**a**) (**b**)

Figure 1. Detail of cucumber crop (**a**) and distribution of the evaluation plots in each experimental sector (**b**).

For trial design, the European and Mediterranean Plant Protection Organization (EPPO) standards were followed. For downy mildew and powdery mildew diseases, EPPO standards PP 1/181 (conduct and reporting of efficacy evaluation trials), PP 1/152 (design and analysis of efficacy evaluation trials), PP 1/57 (powdery mildew on cucurbits) and PP 1/65 (downy mildew of lettuce and other vegetables, PSPECU) are applicable. Disease development was monitored in 4 plots with 4 replicates of 12 plants for each of the experimental sectors (Figure 1). The plots chosen were away from the edges of the plantation to avoid the edge effect.

2.4. Yield and Fruit Quality Measurements

Four crop lines were selected in each sector (considered statistical repetitions). Marketable yield was measured every day of collection with a Mettler Toledo electronic scale

(Mettler-Toledo, S.A.E., L'Hospitalet de Llobregat, Spain; sensitivity of 20 g and maximum capacity of 60 kg).

To evaluate the quality of the harvested fruits, 10 cucumbers (each harvest day) from each of the experimental sectors were randomly selected. The weight of the cucumber fruits was measured with a PB3002-L Delta Range® scale (Mettler Toledo, SA, Spain; measuring range from 0 to 3200 g and sensitivity of 0.01 g). The equatorial diameter of the fruit was measured with a digital caliber (Medid Precision, SA, Barcelona, Spain; measuring range of 0–150 mm and resolution of 0.01 mm), the length of the fruit was measured with a tape. To know the soluble solids content, several drops of cucumber juice were placed in a PAL1 refractometer (Atago Co., Ltd., Saitama, Japan; measuring range of 0 to 53.0 °Brix and an accuracy of ±0.2 °Brix).

2.5. Statistical Analysis

Statistical analysis was carried out with Statgraphics Centurion v.19 software (Manugistics Inc., Rockville, MD, USA). We used an analysis of variance (considered significant when p value ≤ 0.05) and we compared the mean values with Fisher's minimal significant difference (LSD) method. Bartlett, Cochran and Hartley tests were also used to determine variations of similar parameters. When there was a statistically significant difference between standard deviations, parametric analysis by analysis of variance was not feasible. In this case, a non-parametric analysis was performed with the Friedman test, in which each row represents a block (the measurement date) using the box and whiskers diagram [35].

3. Results

3.1. Development of Diseases

The results show the development of the three diseases evaluated in two cucumber crops planted on similar dates in two consecutive winter–autumn crop cycles. Due to the climatic conditions, the first disease that appeared was downy mildew (pathogen *Pseudoperonospora cubensis*), then gummy stem blight (pathogen *Didymella bryoniae*) and the last one was powdery mildew (pathogen *Sphaerotheca fuliginea*), but at some points of the evaluation, the damage of the three diseases was observed at the same time on a plant (Figure 2). The first symptom of the disease was noticed in November 2020 for the first cycle and end of October 2021 for the second cycle.

Figure 2. Cucumber leaves affected for different study diseases.

The most important disease in both cycles was powdery mildew; however, for the first crop cycle, downy mildew reached infection rates similar to powdery mildew. These infections were very dangerous for the correct development of the crop; powdery mildew and downy mildew significantly affected yield.

In the second crop cycle, statistically significant differences were observed in the three fungal diseases studied, while in the first crop cycle, only statistically significant differences were observed in the incidence of powdery mildew. The incidence of the fungal diseases

studied was generally lower in the greenhouse sector with the experimental film, compared to the commercial film (Table 3).

Table 3. Average value of percentage of infection at the end of the trials in both sectors of the experimental greenhouse.

Sector	Powdery Mildew *S. fuliginea*	Downy Mildew *P. cubensis*	Gummy Stem Blight *D. bryoniae*
End of first crop cycle (24 December 2020)			
C_F	$34.11^{b} \pm 30.32$	$19.05^{a} \pm 23.37$	$7.69^{a} \pm 19.30$
E_F	$12.38^{a} \pm 21.18$	$15.79^{a} \pm 23.78$	$8.94^{a} \pm 20.18$
End of second crop cycle (18 December 2021)			
C_F	$45.22^{b} \pm 34.93$	$47.14^{b} \pm 35.07$	$32.74^{b} \pm 37.58$
E_F	$19.49^{a} \pm 24.17$	$37.86^{a} \pm 33.27$	$25.71^{a} \pm 33.15$

Values with different letters in the same column show statistically significant differences with a confidence level of 95.0% (p-value ≤ 0.05).

For the last evaluation carried out in each crop cycle, a higher level of development of the three diseases studied was observed in the greenhouse sector that was covered with commercial film (C_F), in comparison with the experimental film (E_F). For the first crop cycle, gummy stem blight showed no differences between the two sectors of the experimental greenhouse, possibly due to the low level of infection observed.

3.1.1. Powdery Mildew

For the two crop cycles, the evaluation for powdery mildew infection (*S. fuliginea*, SPHRFU) began in the month of December. At the beginning of the evaluation, with a low level of powdery mildew infection, no differences were observed between the two experimental sectors in the second crop cycle, but statistically significant differences were observed in the first one. For the two crop cycles, from approximately the first ten days of December, the presence of powdery mildew in the two sectors of the greenhouse began to differentiate (Figure 3). Near to the end of the two crop cycles, for the commercial film, we observed infection rates higher in approximately 30%, in comparison with the experimental film (Figure 3). For the two crop cycles, the development of powdery mildew was higher with the commercial film, in comparison with the experimental film, with statistically significant differences.

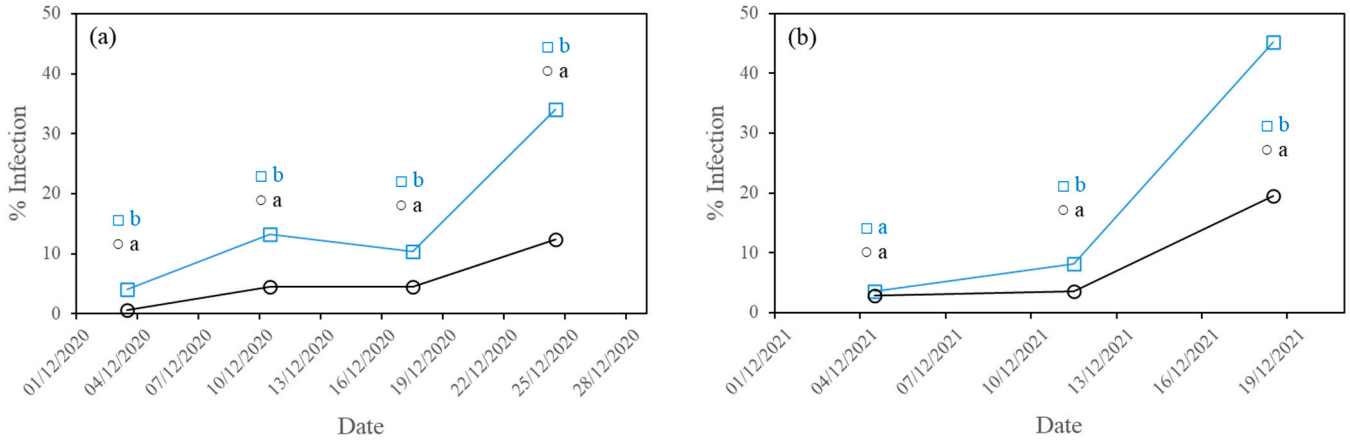


Figure 3. Development of powdery mildew (*S. fuliginea*) percentage of infection over time, for the first crop cycle (**a**) and for the second crop cycle (**b**). Sector with commercial film C_F (□); Sector with experimental film E_F (○). Different letters indicate statistically significant difference (p-value ≤ 0.95).

3.1.2. Downy Mildew

The evaluation for downy mildew infection (*P. cubensis*, PSPECU) began in November for the first crop cycle and in October for the second crop cycle, when the first symptoms of the disease appeared. At the beginning of the disease assessment, at low levels of infection, no statistically significant differences were observed between the two experimental sectors. (Figure 4). In the first cycle, we found statistical differences in the central evaluations (10 and 17 December); in the last evaluation, no differences were observed but there was more downy mildew development numerically in the standard plastic.

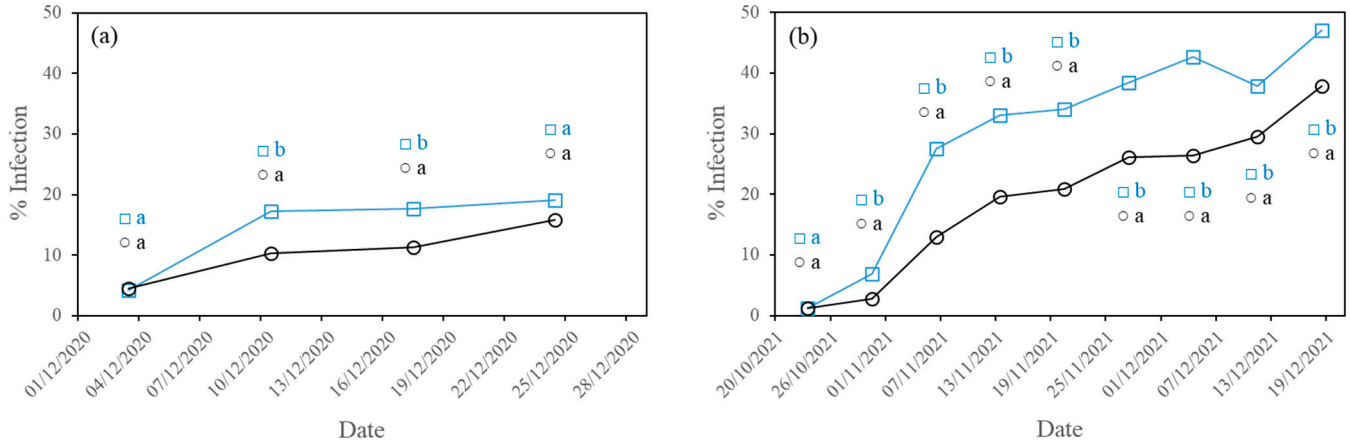


Figure 4. Development of downy mildew (*P. cubensis*) percentage of infection over time, for the first crop cycle (**a**) and for the second crop cycle (**b**). Sector with commercial film C_F (□); Sector with experimental film E_F (○). Different letters indicate statistically significant difference (p-value ≤ 0.95).

For the second crop cycle, downy mildew was more aggressive and began the attack on the crop earlier, in comparison with the first crop cycle. For both crop cycles, there was a one week period when there was a significant increase in damage, from 3–10 December in 2020 and from 30 November to 6 October in 2021, after which the damage increases more slowly.

Figure 4 shows that, for downy mildew, we found a lower level of infection with the experimental film (E_F), in comparison with the commercial film (C_F), with statistically significant differences.

Like powdery mildew, downy mildew (*P. cubensis*) also appeared naturally in the specific case of this study, proceeding in a similar way to powdery mildew.

3.1.3. Gummy Stem Blight

For both crop cycles, the first symptoms of gummy stem blight (*D. bryoniae)* appeared at the end of November and its development was less than that of the other fungal diseases evaluated. In the first crop cycle, in general, no statistically significant differences were found; isolated periods of statistically significant differences appeared on the second day of assessment only (Figure 5a). For the second crop cycle, a higher level of gummy stem blight was observed in comparison with the first crop cycle (Figure 5b), as was also the case with the other two fungal diseases studied. The gummy stem blight of the stem in the second crop cycle showed a lower level of infection with the experimental film, compared to the commercial film, with statistically significant differences (Figure 5b).

3.2. Yield and Fruit Quality

During the second crop cycle, the development of fungal diseases was faster than during the first crop cycle, reaching higher crop damage at earlier dates. This higher level of disease could be the cause of considerable crop losses; the marketable harvest obtained in the first crop cycle was higher than that obtained in the second one (Figure 6). In both crop cycles, the harvest obtained with the experimental film (E_F) was higher than that

obtained with the commercial film (C_F) (Figure 6). In the first crop cycle, similar production values were observed (no statistically significant differences), while in the second crop cycle, there were significantly higher values with the experimental film (statistically significant differences on specific dates) (Figure 6).

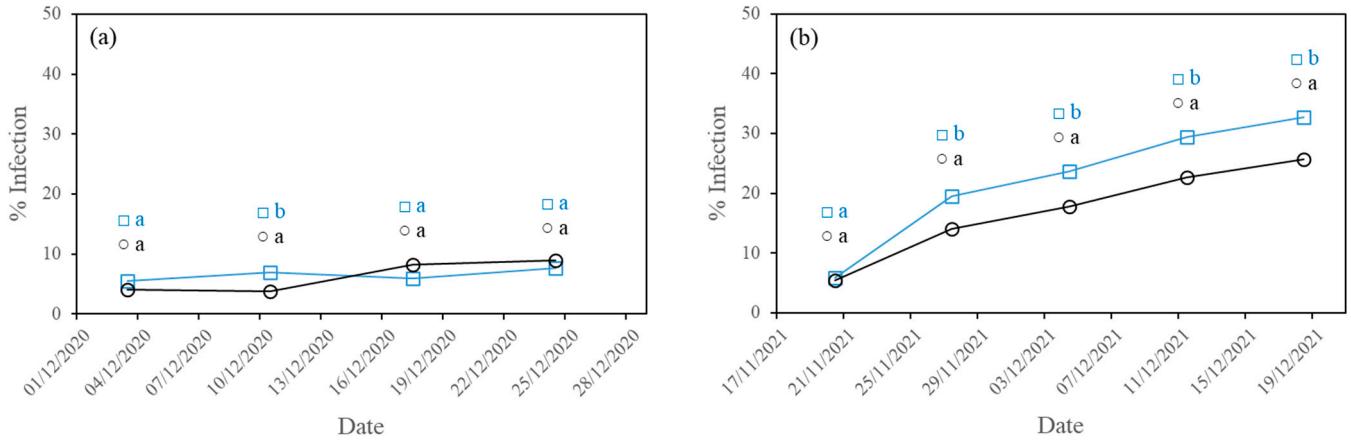


Figure 5. Development of gummy stem blight (*D. bryoniae*) percentage of infection over time, for the first crop cycle (**a**) and for the second crop cycle (**b**). Sector with commercial film C_F (□); Sector with experimental film E_F (○). Different letters indicate statistically significant difference (p-value ≤ 0.95).

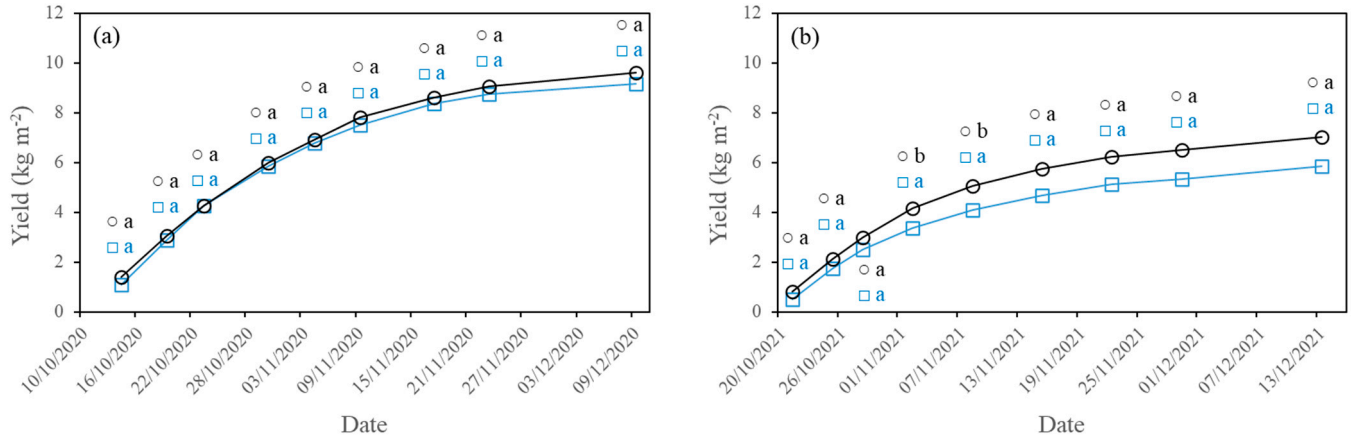


Figure 6. Cumulative production yield over time for the first crop cycle (**a**) and for the second crop cycle (**b**). Sector with commercial film C_F (□); Sector with experimental film E_F (○). Different letters indicate statistically significant difference (p-value ≤ 0.95).

The statistical analysis of the quality parameters of the fruit did not show statistically significant differences between the two experimental sectors tested in the two crop cycles (Table 4). During the first crop cycle, the main differences were observed in the parameters weight and equatorial diameter, both were slightly higher under the influence of commercial film. The soluble solids content was also higher in the experimental sector with commercial film, but, as with the two previous parameters, no statistically significant differences were found. The length of the fruits was practically the same in the fruits harvested in both experimental sectors (Table 4). In the case of this crop cycle, fungal diseases do not seem to have influenced the quality of the harvested cucumber fruits.

In the second crop cycle, the fruit quality parameters also showed no statistically significant differences between the harvested fruits in both experimental sectors. It is worth noting the values of the weight of the fruit; albeit without statistically significant differences, the cucumbers harvested under the experimental film were notably higher. The diameter is also slightly larger in this experimental sector, while the rest of the parameters showed

similar values (Table 4). Fungal diseases had a higher incidence with the commercial film, so it could have harmed the quality of the harvested fruits (Figures 3–5).

Table 4. Average values of production quality parameters, measured for plants grown in areas with different cover film.

Sector	*Weight*, [g]	*Diameter*, [mm]	*Length*, [cm]	*Soluble Solids*, [°Brix]
2020–2021 Crop cycle				
C_F	474.3 ^{a} ± 105.4	33.8 ^{a} ± 4.0	44.4 ^{a} ± 2.7	3.7 ^{a} ± 0.8
E_F	463.0 ^{a} ± 80.9	32.8 ^{a} ± 3.1	44.7 ^{a} ± 4.3	3.4 ^{a} ± 0.5
2021–2022 Crop cycle				
C_F	399.5 ^{a} ± 73.9	41.5 ^{a} ± 3.7	33.4 ^{a} ± 2.2	2.9 ^{a} ± 0.4
E_F	427.7 ^{a} ± 99.6	42.5 ^{a} ± 3.8	33.9 ^{a} ± 2.8	2.8 ^{a} ± 0.4

Values with different letters in the same column show statistically significant differences with a confidence level of 95.0% (p-value $\leq$ 0.05).

4. Discussion

Table 3 shows a higher level of infection of the three diseases studied in the greenhouse with the commercial film C_F, in comparison with the sector with the experimental film E_F, being able to relate the development of diseases with the incidence of light radiation. This difference could be due to the higher light transmission of the experimental film (transmission of photosynthetically active radiation PAR of 90%), compared to that of the commercial film (transmission of photosynthetically active radiation PAR of 85%).

The highest difference in the development of diseases is in the case of powdery mildew, perhaps because this disease was more affected by the light that reached the crop (Table 3). It is known that the development of downy mildew and gummy stem blight are greatly affected by the need for high environmental humidity [36–38].

For the first crop cycle, and with low levels of presence of gummy stem blight, it was observed that there were no statistically significant differences between the percentages of infection in the two greenhouse sectors. However, with a higher level of this disease, it was observed that there were statistically significant differences between the percentages of infection in the two greenhouse sectors, as occurred at the end of the second crop cycle.

The quality of the light that reaches the crops can influence the development of powdery mildew in cucumber [39]. As observed in Figure 3 and in Table 2, with the commercial film, a greater development of the disease was observed.

The two sectors of the experimental greenhouse only differ in the type of film cover used, so these differences in the development of powdery mildew can be explained by the different radiation entering the greenhouse.

Humidity above 90% and the presence of free water in the leaves of the crop favor the development of spores of *P. cubensis* [37]. Host plants of downy mildew show an increase in transpiration and a decrease in photosynthetic activity [40,41]. With the experimental film, there is a greater total light transmission, which increases photosynthetic activity [12] and can slow down the disease development. In addition, the increase in transpiration due to the initial attack of downy mildew can increase the ambient humidity inside the greenhouse, in turn, favoring the development of downy mildew, which needs high levels of humidity to achieve proper development [37].

As in the case of downy mildew, gummy stem blight needs very high relative humidity (higher than 90%) and mild temperatures for its development [42], so its development was observed at times like downy mildew.

Gummy stem blight needs mild temperatures and high humidity for its development, like downy mildew [43]; perhaps the greater development of the disease with the commercial film is due to indirect effects on the crop and not the direct incidence of light transmission variants, diffusion of light and thermicity, which differentiates the two plastic

covers studied. Even so, the effect on the development of the disease was due to the film cover, since it was the only difference between the two greenhouse sectors.

Gummy stem blight causes significant yield losses in cucumber crops that are affected by the disease when they reach infection rates between 15 and 30% [44]. Additionally, gummy stem blight causes many economic losses during the storage of the fruits [29] by producing internal damage to the fruit [30], which sometimes goes unnoticed during harvesting but shows up over time during storage or transport of the fruit. In this trial, no post-harvest damage evaluations were carried out. For the first crop cycle, the percentage of the infection of the gummy stem blight did not exceed 9% and for the second crop cycle the highest percentages of infection occurred after a prolonged period of damage due to downy mildew. So, in this trial, although gummy stem blight caused damage to the crop, it is not the main cause of yield losses.

P. cubensis is possibly the most widespread pathogen that affects cucurbit crops both outdoors and in greenhouses worldwide and causes significant losses in crop production [45]. In this trial, in the first growing cycle, 20% infection was reached, while in the second, the disease reached levels of over 45%. In this trial, 20% infection was reached in the first growing cycle, while in the second growing cycle, the disease reached levels above 45%. The higher incidence of this disease with commercial film cover could be the cause of the lower crop yields. In the first cycle, no statistical differences were obtained in all the evaluations, possibly due to it being the lowest level reached by the disease, but numerical differences were observed when there were no statistical differences. So, a trend similar to that seen in the second cycle was observed, in which there were statistical differences in most of the evaluations, which reinforced the hypothesis that under the experimental film, downy mildew had more difficulty developing than in the commercial film.

The pathogen *S. fuliginea* attacks a wide range of plants [46], but it is especially dangerous in cucurbits because the fast development on the host makes it difficult to prevent crop damages [47]. In our case, for the two crop cycles, powdery mildew appeared in the final moments of the cycle and showed fast development on the crop, reaching infection levels above 30% in a few days. The appearance of this disease led to the end of the crop, with the last harvests having unprofitable production values.

5. Conclusions

From the results obtained in this work, comparing the experimental film E_F with a commercial film C_F, the following conclusions can be drawn:

- The higher PAR radiation transmissivity of the experimental film reduced the incidence of the three fungal diseases studied (powdery mildew, downy mildew and gummy stem blight) in the second crop cycle and of powdery mildew in the first crop cycle, with statistically significant differences.
- Powdery mildew was the disease most affected by the lower radiation transmissivity of the commercial cover film in both crop cycles. The fast development of powdery mildew caused the end of the crop.
- The marketable yield of the cucumber crop was higher with the experimental film E_F (with an increase of 4.9% in the first crop cycle and 14.7% in the second one).
- No statistically significant differences were observed in any of the fruit quality parameters (weight, fruit diameter, length and soluble solids content).

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