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Identification of greenhouse characteristics which affect the incidence of *Sclerotinia sclerotiorum* (Lib.) de Bary in pepper crops in a Mediterranean climate

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Abstract

The effect of the main construction factors and design features of greenhouses on the incidence of 'white rot' disease, caused by *Sclerotinia sclerotiorum* (Lib.) de Bary, was studied in peppers grown under plastic-roofed greenhouses typical of Almería (SE Spain). At the height of the pepper-growing season in the province, fifty greenhouses were repeatedly sampled. Incidence of the disease was measured and the different construction features of the greenhouses were evaluated: types of roof cover, colour and age of the plastic cover, dimensions (ground plan, surface area, average height), estimated ventilation capacity and the presence of netting on the sides of the greenhouses (laterals). Statistical analyses were undertaken to see if the choice of various design options for each factor had any significant influence on the incidence of the disease. To achieve this single factor ANOVA was undertaken. The incidence of this disease was significantly affected ($p < 0.05$) by the following greenhouse characteristics: ground plan, surface area, mean height, colour of the plastic cover, estimated ventilation and use of lateral netting.

Introduction

'White rot' disease, caused by the ascomycete *Sclerotinia sclerotiorum* (Lib.) de Bary, is one of the most widely-occurring diseases in the world, and particularly in zones with a temperate climate (Purdy, 1979). It is widespread in Spain due to its large polyphagous capacity. Its host plants include tomato, aubergine and pepper (Torés, 1983).

The cultivation of pepper in Almería (SE Spain) in plastic-covered greenhouses takes place during the autumn and winter periods (plantation: June–September; harvest: August–April). It is destined for the fresh food market and is harvested as much at the green stage as in the more mature from (Cánovas, 1993). The extent of this crop in the region is considerable (6500 ha), and heavy losses are caused by white rot.

The greenhouse structures principally used for pepper crops in Spain corresponds to the 'parral' or 'Almería' type (Nuez et al., 1996). This type of greenhouse is characterized by the use of a plastic cover over structures of wood and wire. The sheets of polyethylene used for the cover are placed between two wire meshes supported on wooden posts. The covers are usually flat or have a gentle slope (5–20%), and need to be perforated to allow rainwater to drain away. The height ranges from less than 2 m to more than 2.5 m. Their dimensions are variable, but the norm is some 30–50 m long and 20–25 m wide. However, much wider greenhouses can be found as well as ones over 100 m in length (López, 1993). The current trend is towards the replacement of the wooden posts in the ‘parral’ greenhouses by tubes made of galvanized iron. With this arrangement, one can also see greenhouses with arched roof covers, resembling a series of joined macrotunnels (Nuez et al., 1996).

Pepper cultivation under greenhouse cover is usually done using the ‘enarenado’ method: this consists of putting a uniform layer of sand of 10–12 cm thickness over the top of soil (previously levelled and ploughed). Before the sand is deposited over the soil, a layer of manure equivalent to about 80 t/ha is laid, which separates the sand from the soil. Currently, almost all of the greenhouses dedicated to pepper cultivation use drip irrigation (Nuez et al., 1996).

The main difficulty in controlling the disease stems from the adaptation of the ascomycete to the crop cycles that are characteristic of the area under study. Infection, which occurs by means of ascospores liberated by the asci in the apothecia, gives rise to rapid mycelial growth and the subsequent appearance of sclerotia. This resistant form persists in the soil for many years and is responsible for the development of the disease in subsequent crops (Adams and Ayers, 1979; Purdy, 1979) through the consequent production of sexual spores from apothecia.

This report contributes to the study of the epidemiology of white rot (caused by the *S. sclerotiorum* pathogen) in pepper crops in Almería, by evaluating the significance of the characteristics of plastic-roofed greenhouses on the incidence of the disease (% diseased plants) observed *in situ*. The characteristics of the greenhouses that were considered to be of interest in this study were as follows:

1. *Roof cover:* form (flat or arched), colour (white or yellow) and age (1, 2 or 3 years) of the plastic.
2. *Dimensions of the greenhouse:* ground plan (square or rectangular), surface area (ha) and mean height (2, 3 or 4 m).
3. *Ventilation of the greenhouse:* ventilation capacity (high or low).
4. *Laterals of the greenhouse:* lateral netting (present or absent).

All these characteristics define to a large degree the characteristics of the environment inside the greenhouse, as well as the possible transfer of inoculum from nearby greenhouses. Accordingly, the phytopathological interest of each of the factors are detailed below.

The *form of the greenhouse cover* is a feature which determines the uniformity of its interior space. It is probably important as a determining factor in the cultural practices and habits of the farmer, which may have repercussions on the development of the disease. The *colour of the plastic* might seem at first not to be of interest, but different coloured plastics transmit different wavelengths of light. If one bears in mind that the main source of inoculum of *S. sclerotiorum* are the ascospores released by the apothecia (Abawi and Grogan, 1978), and that these in turn have been derived from a carpogenic germination of the sclerotia, one can see the possible relationship between wavelength and germination. The *age of the plastic* is not decisive in itself, but older plastic contains more tears, that is to say, more entry routes for the infection.

The *dimensions of the greenhouse* may indicate the advantage of either a larger or smaller area within a single greenhouse with respect to a possible attack of the fungus. The height will be closely related to the heat differential between night and day and, more importantly, to the internal humidity regime. The different ground plans that greenhouses of the same surface area can have might have implications for greater or lesser ventilation of the various parts of the greenhouse.

Ventilation is another important factor. In the study area it is customary, during moments of maximum relative humidity characterized by excessive condensation of water on the roof, to open the side sashes of the greenhouse to bring about a decrease in humidity. The speed at which humidity falls is determined by the ventilation capacity of the greenhouse (which is a product of its situation and wind regime). The term ‘high ventilation’ is used to describe greenhouses in which humidity falls rapidly and ‘low ventilation’, where changes are less rapid. This attribute is relative, serving to compare one greenhouse with another, and depends on the farmer’s knowledge of the corresponding.

The *laterals of the greenhouse* may be covered by netting to protect the crop from the exterior. They are principally situated along the outer sides of the greenhouse. A study of their efficacy or significance, above all when they are lowered, is interesting with respect to the degree of infection, due to their possible action as a barrier to spores and other inocula derived from other crops or from outside residues.

Materials and methods

The study zone incorporated the Poniente region of Almería. This is a coastal fringe about 10 km wide and 30 km long, located between 36°41′–36°48′ N and 2°33′–2°54′ W. The absolute minimum temperatures lie above 0 °C and the coolest months are January and February. The absolute maximum temperatures recorded exceed 30 °C during June–October. Rainfall is scarce, with an annual mean of less than 250 mm (López, 1993).

Five subzones with similar agroclimatic characteristics were defined (coast, La Mojonera, El Ejido, El Ejido north, and El Parador). Within each of these ten greenhouses were selected belonging to different owners.

Fifty units were analysed each month during November and December 1993 and January 1994, coinciding with the period of maximum activity of *S. sclerotiorum* is pepper plantations. The analysis was undertaken by direct observation, except for data relating to ventilation which were obtained from the farmer. The study focused on commercial cultivars of pepper (*Capsicum anuum* L.), namely *Gedeón, Mazurca, Ray, Lido, Drago, Roldán, Spartacus, Asimi* and *Orobelle*.

The incidence of the disease was expressed in terms of *frequency of the disease* (% diseased plants), using a total of twenty plants of each crop. The methodology followed consisted of the subjective division by eye of the greenhouse area in to four well-differentiated parts. Within each of these, and before observing the individual plants, five plants were selected at random.

Statistical analysis was undertaken using the STATISTICA program, version 4, applying a single factor analysis of variance (ANOVA test). This was used to determine the influence of the factors described above on the incidence of the disease sampled. Multifactorial ANOVA indicated that there were no interactions between all the possible combinations tested.

In Figures 1–3 the lines of best fit have been drawn using a second order polynomial.

Results and discussion

The results of the statistical analyses are summarized in Table 1. These results are discussed below.

The first thing to note is the importance of *date of sampling* ($p = 0.0160$) on the results and the need, therefore, to consider it in subsequent analyses. This effect was verified in a two-factor ANOVA, though the results are not presented here. There was a greater incidence of the disease in the months of November and December, followed by January (Figure 1). This fall-off is more obvious in the smaller greenhouses. The *subzone* was not significant ($p = 0.5231$) and for this reason it was not considered further.

Greenhouse roof

A comparison of the number of diseased plants in greenhouses with different *roofing cover type*, namely the flat-roofed ‘parral’ or ‘Almería’ type and the arched type (of tubular construction), showed no significant difference ($p = 0.7353$) for the number of samples taken.

Table 1. ANOVA table for construction features of greenhouses with respect to incidence of ‘white rot’

Factor	df factor	MS factor	df error	MS error	F	p
Date	2	1204.17	147	282.97	4.2555	0.0160*
Subzone	4	239.33	145	296.88	0.8062	0.5231
Roof type	1	34.09	148	297.10	0.1147	0.7353
Colour of plastic	1	755.90	148	285.47	6.1510	0.0143*
Age of plastic	2	12.09	147	299.19	0.0404	0.9604
Ground plan	1	2730.16	148	278.88	9.7896	0.0021**
Surface area	14	699.92	135	253.38	2.7624	0.0013**
Mean height	2	2566.23	147	264.44	9.7044	0.0001**
Ventilation	1	11495.17	148	219.66	52.3317	0.0000**
Lateral netting	1	2374.67	148	281.28	8.4422	0.0042**

df: degrees of freedom; MS: Mean of Squares; F: ANOVA test statistic; p: level of significance; $^{*}p < 0.05$; $^{**}p < 0.01$.

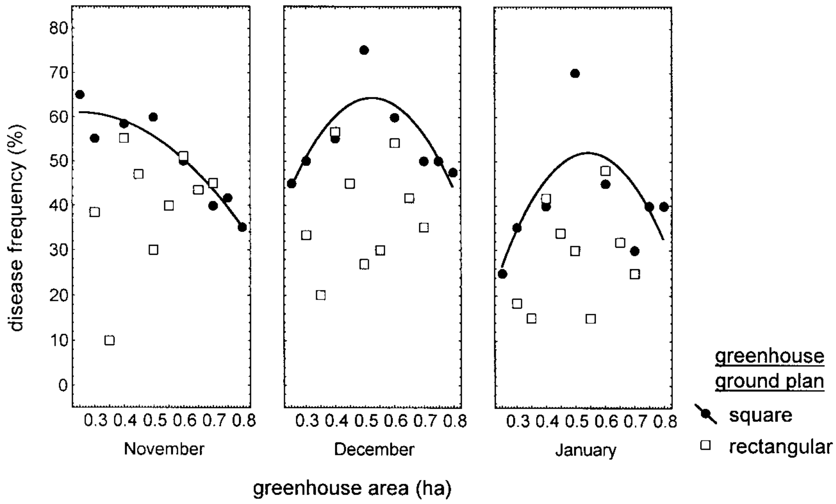

Figure 1. Comparison of the mean frequency of 'white rot' for different greenhouse areas, date of sampling and greenhouse ground plans.

Significant differences did exist with respect to the behaviour of the fungus to different *colours of plastic* roofing. Yellow gave a mean incidence of 37%, whilst white gave a mean incidence of 43%. The difference between the two seems sufficient to attribute a lesser development of the disease to the yellow plastic.

The behaviour of the disease during the sampling period was very similar for plastic covers of 1, 2 and 3 years of age. The mean incidences were 41%, 39% and 40% respectively. These data do not suggest a difference between the three cases, and so there does not seem to be an influence on the disease as a result of the age of the plastic.

Greenhouse dimensions

The *ground plan of the greenhouse* emerged as having significant effect ($p = 0.0021$) on the incidence of the disease. Thus, the mean frequency of the disease in greenhouses with a square floor plan (47%) was greater than in those with a rectangular floor plan (38%). Initially, one might think that the ground plan could not affect the development of the fungus at an epidemiological level. However, for a given surface area (Figure 1) the square form presents the minimum perimeter and so there is a larger area that is difficult to ventilate. For this reason, there is a greater development of the disease than in the various rectangular models that exist.

The *surface area of the greenhouse* significantly affected the development of the disease ($p = 0.0013$). The smallest greenhouses (0.3 ha) produced 33% disease. However, the incidence increased with surface area (up to approximately 0.5 ha) and then diminished (Figure 2).

Different greenhouse areas have different thermal and humidity regimes. This affects both the crop as well as the fungus. It appears that a small crop (0.3 ha) favours rapid ventilation. However, as the surface area increases so the volume of air contained within the greenhouse grows. A large volume may act as a buffer against rapid changes in both temperature and humidity. The risk of condensation of water vapour on the plastic and the possible risk of later cooling, which is very harmful, is more likely in a greenhouse of limited dimensions than in a larger one.

As *mean greenhouse height* increased, there was a significant ($p = 0.0001$) and progressive decline in the incidence of the disease (Figure 2). In the 2 m-high structures there was an incidence of 55%. At 3 m the mean disease incidence was 48%. In the tallest greenhouses (4 m) the disease incidence was 30%.

An increase in height signifies that a greater volume of air is contained in the interior. This serves both as a thermal and a humidity buffer. With a greater volume the likelihood of excessive condensation is less and, at the same time, the possibility of night-time cooling by temperature inversion is reduced. A greater warming occurs at ground level and, if there is sufficient height, this would produce a rising current towards the plastic roof which descends once the temperature drops. If the greenhouse is not very high the temperature equalizes and the vertical currents are minimal, whilst with a

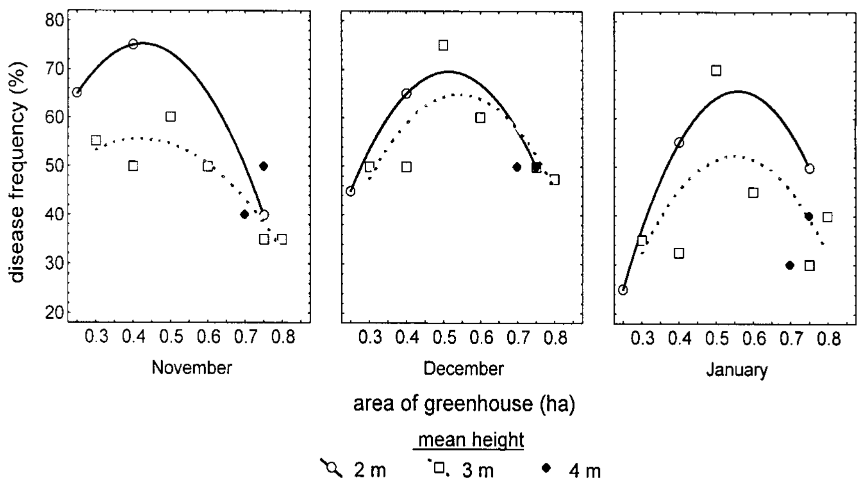

Figure 2. Comparison of the mean frequency of 'white rot' for different surface ares and heights of sampled greenhouses with a square ground plan.

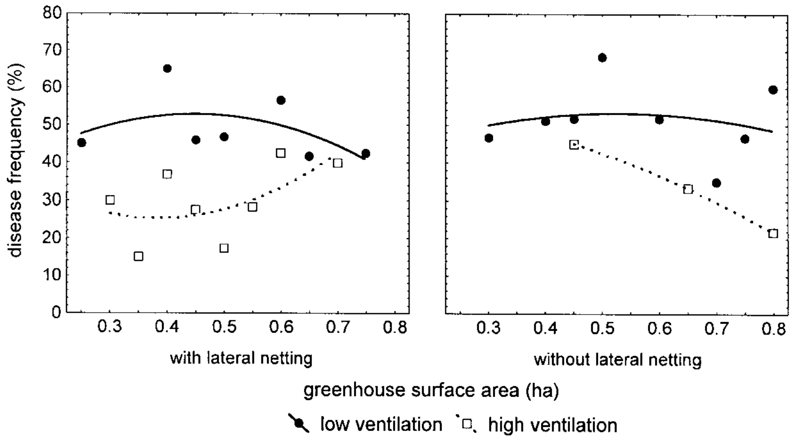

Figure 3. Comparison of the mean frequency of 'white rot' for different sized greenhouses according to the lateral netting and observed ventilation.

greater height the current too is larger. This air flow will inhibit saturation point being reached near to the ground surface, which is where the sclerotia will be found awaiting optimal conditions to germinate.

Greenhouse ventilation

This factor depends principally on the wind regime and the orientation of the greenhouse. In addition, it is probably related to other factors, such as shape, surface area etc. Its importance is clear ($p = 0.0000$). The mean frequency of the disease was 30% for high ventilation greenhouses, rising to around 48% for low ventilation structures (Figure 3). In a greenhouse that receives more frequent ventilation because of its elevated situation or its position in an area with a stronger wind regime, it is possible to rapidly reduce excess humidity by opening the side sashes.

Greenhouse laterals

For the greenhouses sampled the incidence of white rot was less in those that utilize *lateral netting* to protect their interiors from the external environment. The mean incidence was 38% for greenhouses with lateral netting and 47% for those without. The lateral netting used appears to have no effect on the ventilation of the greenhouse (Figure 3), so that its value must be considered to lie in inhibiting the entry of inocula into the greenhouse in some way. Thus, the exterior could be a significant source of inoculum. Sclerotia can be carried by the wind, and they can also produce apothecia, each of which will give rise to many ascospores. So, if there is no barrier to impede their entry the rate of infection will be considerably increased.

In conclusion, the best type of greenhouse to avoid white rot in pepper crops grown in a Mediterranean climate should have yellow plastic roofing material, a rectangular ground plan, a surface area of 0.8–1 ha, a mean height of 3–4 m, high aeration and lateral netting.

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References

Abawi GS and Grogan RG (1975) Source of primary inoculum and effects of temperature and moisture on infection of beans by *Whetzelinia sclerotiorum*. Phytopathology 65: 294–308

Adams PB and Ayers WA (1979) Ecology of sclerotinia species. Phytopathology 69: 895–899

Cánovas F (1993) El cultivo del pimiento en Almería. Hortofruticultura 5: 23–28

Haas D and Bolwyn B (1973) Predicting and controlling white mold epidemics in white beans. Canada Agriculture 18: 28–29

López J (1993) Problemática general de los cultivos de invernadero de la zona de Almería: la hidroponía, elemento fundamental de las nuevas tecnologías de cultivo. In: Curso superior de especialización sobre cultivos sin suelo. Serie Agriculturas Mediterráneas Vol. 1 (pp 17–25), IEA-FIAPA, Almería

Nuez F, Gil R and Costa J (1996) El cultivo de pimientos, chiles y ajíes. Ediciones Mundi-Prensa, Madrid

Purdy LH (1979) *Sclerotinia sclerotiorum*: history, diseases, and symptomatology, host range, geographic distribution and impact. Phytopathology 69: 875–882

Steadman JR (1979) Control of plant diseases caused by sclerotinia species. Phytopathology 69: 900–910

Torés JA (1983) Contribución al estudio epidemiológico del ascomiceto *Sclerotinia sclerotiorum* (Lib.) de Bary. Tesis doctoral, Universidad de Granada (inéd.)