Efficiency of Anti-Insect Screens placed in the Vents of Almería Greenhouses

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Abstract

The use of anti-insect screens placed on greenhouse vents has become generalized in warm climate areas, where there is a big pressure from insect pests which transmit virus diseases. Increasing the efficiency of the screens to reduce the entrance of pests into the greenhouse generally involves a reduction of the ventilation rate as the screen porosity is lower. This can, in part, be compensated by using screens with lower diameter of the threads which allows a higher porosity for the same efficiency to exclude insects. In the present work the characteristics of the most commonly used anti-insect screens in Almería greenhouses, including their porosity, hole size and thread diameter were measured. Equations were developed which determined the geometric parameters of the screens accounting for their three dimensional nature. These equations enabled the effectiveness of screens in excluding insects from the greenhouse to be quantified. This allows a comparison between screens, and therefore selecting the most efficient giving maximum insect exclusion with maximum porosity.

INTRODUCTION

The horticultural crops in warm climate regions suffer from agronomic and climatic conditions which favours pest and disease pressure (Cabello et al., 1990; Alcázar et al., 2000). More importantly insect vectors of virus diseases are the most serious concern of greenhouse farmers in warm regions (Franco et al., 1999; Lacasa Plasencia and Sánchez Sánchez, 1999; Hanafí, 2005). In order to fight these insects in the greenhouses different methods can be used such as chemical methods, use of photoselective covering materials, integrated pest management, biological control or physical methods (Antignus, 1999; Hanafí et al., 2003), amongst these are the use of anti-insect screens.

The European Union is continuously decreasing the maximum residue limits of pesticides permitted, making it necessary to search for alternative solutions to chemical control such as integrated pest management including among others the use of photoselective plastic films and physical control. Physical control consists of placing denser anti-insect screens on the greenhouse vents which may limit the entry of virus vectors such as *Frankliniella occidentalis* and *Bemisia tabaci*. However, the use of denser screens, has the disadvantage of reducing greenhouse ventilation (Pérez-Parra et al., 2003).

Despite the decrease in the ventilation capacity and in the transmission of solar radiation, the use of anti-insect screens is widespread as a physical control method to fight vectors (Bethke et al., 1994; Baker and Shearin, 1994; Bell, 1997; Bell and Weatherley, 1999; Teitel et al., 2000; Critten and Bailey, 2002; Díaz Pérez et al., 2003).

There have been a large number of studies dealing with the geometrical characterization and calculation of the porosity, of commercial anti-insect screens (Ross and Gill, 1994; Bell and Baker, 1997; Teitel, 2001; Bartzanas et al., 2002; Cabrera et al., 2002; Valera et al., 2003). Field experiments to test the exclusion of different types of anti-insect screens have been performed (Bell and Weatherley, 1999; Bell and Baker, 2000; Taylor et al., 2001; Berlinger et al., 2002; Giordano et al., 2003; Hanafí et al., 2003; Camacho Ferre et al., 2004), The important parameters are the uniformity in hole size and the three dimensional effect which increases the maximum diameter inscribed in the hole (Cabrera et al., 2002).

Therefore, it is necessary to characterize the screens and to determine the most efficient way to limit the penetration of pest vectors with the least negative impact on greenhouse ventilation.

MATERIAL AND METHODS

Geometrical characterization and exclusion of pest insects

Twenty one commercial anti-insect screens were studied (S01-S21) (Table 1). Six 1 cm^2 samples of each screen were digitised with a scanner (HP PhotoSmart S20, Hewlett-Packard Company, USA) at a resolution of 2400 ppp which provided a precision of 10.6 µm $píxel^{-1}$, in order to analyse their holes (Figs. 1 and 2). In addition, two samples of 0.2 cm^2 of each screen were also digitised, to measure the thread diameter (Fig. 3) and to correct the hole size measurements, using an electronic microscope MIC-D (Olympus Corporation, Japan), with a precision of 3.8 µm $píxel^{-1}$. The digitised samples were converted from greyscale to black and white images and analyzed using software (UTHSCSA ImageTool v3.0, University of Texas Health Science Center at San Antonio, USA) to finally obtain the size of all the holes, the maximum diameter inscribed in each hole, the thread diameter and the screen uniformity.

Considering that the anti-insect screen (Fig. 4a) is made with only one type of thread of D (mm) diameter, and knowing the number of threads cm^{-1} in the X and Y directions (N_X, N_Y), the average size of the hole in both directions L_X (mm) and L_Y (mm) can be calculated:

$$L_X = \frac{10}{N_X} - D, \qquad (1); \qquad L_Y = \frac{10}{N_Y} - D \qquad (2)$$

The porosity ε (m^2 m^{-2}), or the relation between the hole area and the total area of the screen, can be obtained through the following equation:

$$\varepsilon = \frac{100 - 10\,D\,N_X - 10\,D\,N_Y + N_X\,N_Y}{100} = \frac{\mathrm{L_X}\,\mathrm{L_Y}\,N_X\,N_Y}{100} = \frac{\mathrm{L_X}\,\mathrm{L_Y}}{(\mathrm{L_X} + D)\,(\mathrm{L_Y} + D)} \qquad (3)$$

The study of the exclusion of pest insects of each screen was performed only for the insects which cause most problems in horticultural crops in Almería greenhouses, i.e. *Bemisia tabaci* (white fly) and *Frankliniella occidentalis* (thrips), as both are vectors of important virus diseases (Cohen and Berlinger, 1986; Nucifora, 1994; Gill et al., 2001). To exclude these insects, the maximum diameter inscribed in each hole of the screen Ø (mm), must be smaller than the thorax diameter of the insect, which are for *Bemisia* Ø<0.24 and for *Frankliniella* Ø<0.19-0.21 (Bethke and Paine, 1991; Bethke et al., 1994;

Ross and Gill, 1994; Cabello et al., 1996). The thorax of the insects has an elliptic section, so these measurements correspond to the smaller size axis.

Three dimensional characterization

The three dimensional effect of woven screens increases the maximum diameter inscribed in the hole, decreasing the effectiveness of the screen in excluding insects. This three dimensional effect has been characterized with equations which take into account how the screen has been woven (Fig. 4). The maximum three dimensional diameter $\varnothing_{3D}$ (mm), has been obtained with the following equations:

$$x = \tan(\phi)\,(\varnothing + D), \qquad (4); \qquad \gamma = \arctan\left(\frac{2D - x}{D + L}\right), \qquad (5);$$

$$e = \frac{\tan(\gamma)\,(L - \varnothing)}{2}, \qquad (6); \qquad \delta = \arctan\left(\frac{2\,e}{\varnothing}\right), \qquad (7);$$

$$z = \frac{\varnothing}{2\cos(\delta)}, \qquad (8); \qquad \varnothing_{3D} = [D^2 + 4\,z^2 - 4\,D\,z\cos(180\text{-}\delta)]^{0.5} - D, \quad (9)$$

where: ϕ and γ are the angles formed by the threads with the Y and X axes respectively, in degrees; x, represents the distance in the Z direction, in mm; e and z are distances, in mm and δ is expressed in degrees.

There are different possibilities for a woven screen, which correspond to different values of x, which may range between $0 \leq x \leq 2D$, depending on which threads weave predominately (those of the Y axis or the X axis). The normal situation is that $0 \leq x \leq G$, because $N_X \geq N_Y$, and therefore, an equilibrium is reached between the threads woven in the X and Y axes to the point that the threads of both axes weave equally ($x/D=1$).

Ventilation rate reduction

The implementation of anti-insect screens on greenhouse vents, causes a reduction in the air flow which crosses the vent and therefore, reduces the ventilation rate. For screens with high porosities this reduction is small. The decrease in the ventilation flow will depend, mainly, on the porosity of the screen but it is also influenced by the incident wind velocity, so when the wind velocity is low, with small Reynold number values ($Re<10$), the resistance of the screen to the air flow becomes larger. This is an important fact because in the absence of wind, the greenhouse is still ventilated due to the buoyancy effect and in this case, Re of the convective air flow is very low, limiting conditions even more.

The reduction in the ventilation rate of a screen R (%), in relation to the absence of the screen ($\varepsilon=1$), taking porosity into account, has been estimated by means of the equation experimentally obtained by Pérez-Parra et al. (2004) from screens with different porosities.

$$\frac{Q_{sc}}{Q_{(\varepsilon=1)}} = 2\,\varepsilon - \varepsilon^2 \qquad (10)$$

$$R = \left[1 - \frac{Q_{sc}}{Q_{(\varepsilon=1)}}\right]100 = \left[\varepsilon^2 - 2\,\varepsilon + 1\right]100 \qquad (11)$$

where; Q_{sc} is the ventilation rate with an anti-insect screen of porosity ε, in $m^3\ s^{-1}$; and $Q_{(\varepsilon=1)}$ the ventilation rate without a screen (porosity equal to 1), in $m^3\ s^{-1}$.

Besides porosity, there is another important factor influencing the ventilation rate decrease, and that is the angle of incidence which is the angle between the vector perpendicular to the screen and wind direction vector (Dierickx et al., 2003).

RESULTS AND DISCUSION

Table 1 show the geometric characteristics, the porosity and estimated reduction of the ventilation for the 21 studied anti-insect screens. The number of threads in the X and Y axes ranges from 4.6x2.8 (S20) to 30.1x21.4 (S18). The thread diameter is an important characteristic of the screen, a thread with the lowest possible diameter being desirable to allow a higher porosity. In the screens studied, D ranged from 0.36 mm for the less dense screens to 0.19 mm for the screen with the higher number of threads, S18.

The average hole size is different for the different screens, ranging from 6% to 16% for holes of the same screen, which indicates a lack of uniformity.

In relation to insect pest exclusion it is desirable to have holes of the smallest possible size. If we consider at least a 50 % exclusion to avoid the penetration of insects and maximum porosity, for whiteflies using the S12 screen (18.4x9.6, $\varnothing$=0.24±0.05 mm) in which 72 % of the holes have $\varnothing \leq 0.24$ mm, should suffice. However, to exclude thrips we would have to use at least the S14 screen (20.7x9.2, $\varnothing$=0.22±0.02mm) in which 51 % of the holes have $\varnothing \leq 0.19$ mm, (Fig. 6). To obtain more than 95% exclusion of whiteflies and maximum porosity, the S11 screen (20.5x8.7, $\varnothing$=0.21±0.01 mm) with 99% exclusion would have to be used and the S17 screen (27.9x13.4, $\varnothing$=0.16±0.03 mm) with 97% exclusion would have to be used for thrips.

The porosity varied in all the screens being compared between 0.22 and 0.75, for the S15 screen (22.5x11.0, D=0.30 mm) and the S20 screen (4.6x2.8, D=0.36 mm), respectively. In general, the denser screens had a smaller thread diameter which makes these screens more effective in excluding insects yet with low porosity. Other authors obtained similar porosities (Álvarez et al., 2005; Valera et al., 2005) for screens with similar characteristics.

The reduction in the ventilation rate (R) (Table 1 and Fig. 5), was 6 % for the screen with higher porosity S20 (4.6x2.8, D=0.36 mm), and 61% for the screen with lower porosity S15 (22.5x11.0, D=0.30 mm).

If we consider the three dimensional effect of the woven screens, the maximum diameter inscribed in the three dimensional hole is higher.

Using Eqs (1), (2), (3), (9) and (11) it is possible to specify the dimensions of screens to exclude specific insects, but which also have high porosity. This was undertaken to specify the most efficient screens to exclude whiteflies and thrips, i.e. the screen with the smallest three dimensional diameter inscribed in the hole (for maximum insect exclusion) and maximum porosity (for low reduction in air flow). It was assumed the screen was completely uniform, with $N_Y=0.5 \cdot N_X$ (which is a very common distribution of threads in commercial screens, e.g. 20x10, 16x8), the weave of both threads was equal i.e. x/D=1, and the thread had the smallest diameter of those measured (Table 1) i.e. D=0.19 mm. This calculation showed the most efficient screen for whitefly exclusion would be a 23.8x11.9 threads cm^{-1} screen, with D=0.19 mm, $\varnothing_{3D}$=0.24 mm and ε=0.42, for which the diameter inscribed in the three dimensional hole is 4.6% larger than the diameter inscribed in the hole in the XY plane. The most efficient screen against thrips, would be a 27.2x13.6 threads cm^{-1}, D=0.19 mm, $\varnothing_{3D}$=0.19 mm and ε=0.36 screen, in this case the three dimensional diameter is 6.8% larger than the diameter in the XY plane.

CONCLUSIONS

The measured screen porosity ranged between 0.75 (4.6x2.8 threads cm^{-1}, D=0.36 mm) and 0.22 (22.5x11.0 threads cm^{-1}, D=0.30 mm). The reductions in ventilation rates ranged from 6% to 61% respectively.

To obtain a higher porosity with a higher exclusion of pest insects, that is, a more efficient screen, a smaller thread diameter is necessary, in the screens studied the smallest thread diameter was 0.19 mm.

The anti-insect screens analyzed were not woven completely uniformly. Even in the screens with higher thread density, there was always a small percentage of non uniform holes which make the screen loose its effectiveness in excluding specific insects.

The maximum three dimensional diameter inscribed in the hole is higher than the maximum diameter inscribed in the XY plane, and this difference becomes larger as the diameter of the thread increases.

Using the results of the geometric analysis of screens and a commonly used screen thread distribution and the smallest thread size used in commercial screens, the most efficient screen for the exclusion of *Bemisia tabaci* with the highest porosity and the following dimensions D=0.19 mm, x/D=1 and $N_Y=0.5\cdot N_X$, would have 23.8x11.9 threads cm^{-1}, $\varnothing_{3D}=0.24$ mm and $\varepsilon=0.42$. This screen would give a 33% reduction in ventilation rate.

The most efficient screen for excluding *Frankliniella occidentalis* with the highest porosity and dimensions D=0.19 mm, x/D=1 and $N_Y=0.5\cdot NX$ is a 27.2x13.6 threads cm^{-1} screen with $\varnothing_{3D}=0.19$ mm and $\varepsilon=0.36$. This screen would give a 41% reduction in ventilation rate.

The unfortunate fact is that these fine mesh screens coupled with the dusty conditions of the warm regions can even reduce further ventilation rates.

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Tables

Table 1. Screen characteristics and reductions in ventilation rate (screens ordered by decreasing porosity).

Sample	N_X x N_Y (threads cm^{-1})	D (mm)	L_X (mm)	L_Y (mm)	∅ (mm)	ε (m^2 m^{-2})	R (%)
S20	4.6x2.8	0.36	3.22±0.19	1.81±0.10	2.01±0.05	0.75	6
S03	15.3x8.7	0.32	0.86±0.04	0.32±0.05	0.33±0.05	0.37	40
S01	15x9.2	0.32	0.79±0.05	0.33±0.05	0.34±0.05	0.37	40
S05	15.3x8.6	0.33	0.86±0.04	0.30±0.05	0.31±0.05	0.35	42
S11	20.5x8.7	0.26	0.92±0.03	0.20±0.01	0.21±0.01	0.36	41
S02	15.6x9.5	0.33	0.76±0.05	0.30±0.03	0.31±0.03	0.33	44
S14	20.7x9.2	0.27	0.83±0.03	0.22±0.02	0.22±0.02	0.33	45
S04	16.1x10.2	0.32	0.66±0.03	0.30±0.03	0.30±0.03	0.33	45
S12	18.4x9.6	0.29	0.77±0.04	0.24±0.05	0.24±0.05	0.34	44
S08	14.9x10.4	0.33	0.69±0.05	0.31±0.03	0.34±0.02	0.33	44
S07	19.8x10.2	0.28	0.72±0.04	0.21±0.02	0.21±0.02	0.32	46
S17	27.9x13.4	0.20	0.55±0.04	0.16±0.03	0.16±0.03	0.32	46
S10	20.2x9.3	0.30	0.78±0.02	0.19±0.02	0.19±0.02	0.28	51
S21	20.7x10.6	0.29	0.67±0.03	0.18±0.02	0.18±0.02	0.28	52
S06	19.3x11.1	0.30	0.61±0.03	0.17±0.02	0.17±0.02	0.28	52
S09	19.8x10.6	0.31	0.64±0.03	0.20±0.02	0.19±0.02	0.26	55
S18	30.1x21.4	0.19	0.31±0.06	0.12±0.02	0.13±0.03	0.25	56
S19	22.6x10.7	0.28	0.78±0.11	0.13±0.02	0.16±0.02	0.26	55
S13	20.8x10.3	0.30	0.68±0.03	0.18±0.02	0.18±0.02	0.26	55
S16	22.3x10.8	0.29	0.66±0.06	0.13±0.02	0.15±0.02	0.24	57
S15	22.5x11	0.30	0.62±0.03	0.13±0.02	0.13±0.02	0.22	61

Figures

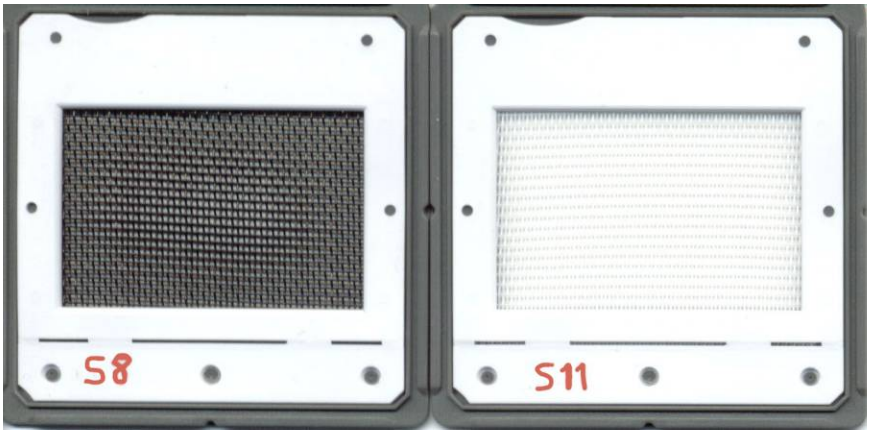
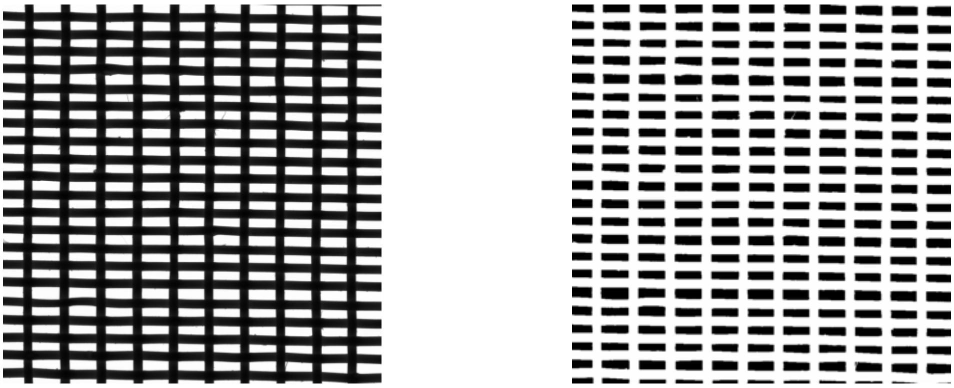


Fig. 1. Anti-insect screens mounted on slides for digitization.



Grey-scale

Black and white

Fig. 2. Digitized area of 1 cm^2 of an anti-insect screen (S21), in greyscale and in black and white (hole=black, thread=white). Scale 5:1.

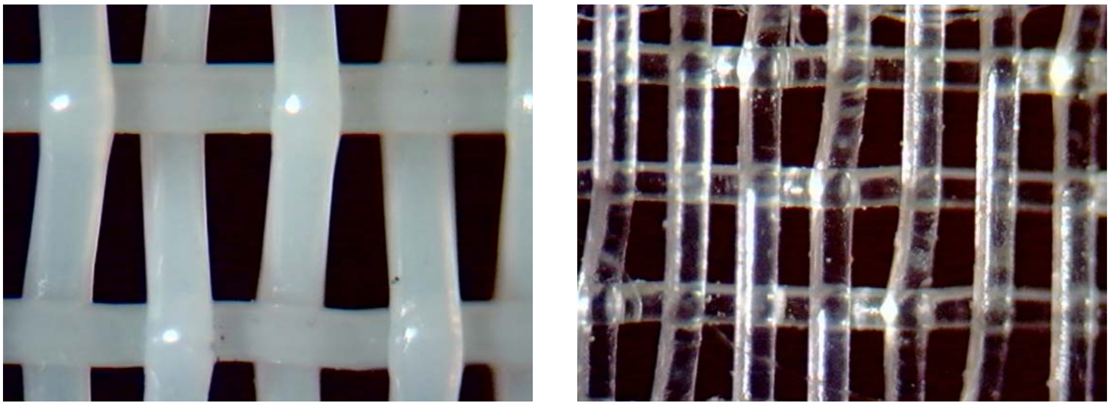


Fig. 3. Detail of the three dimensional woven threads of two anti-insect screens, S09 white (left) and S18 transparent (right). Scale 50:1.

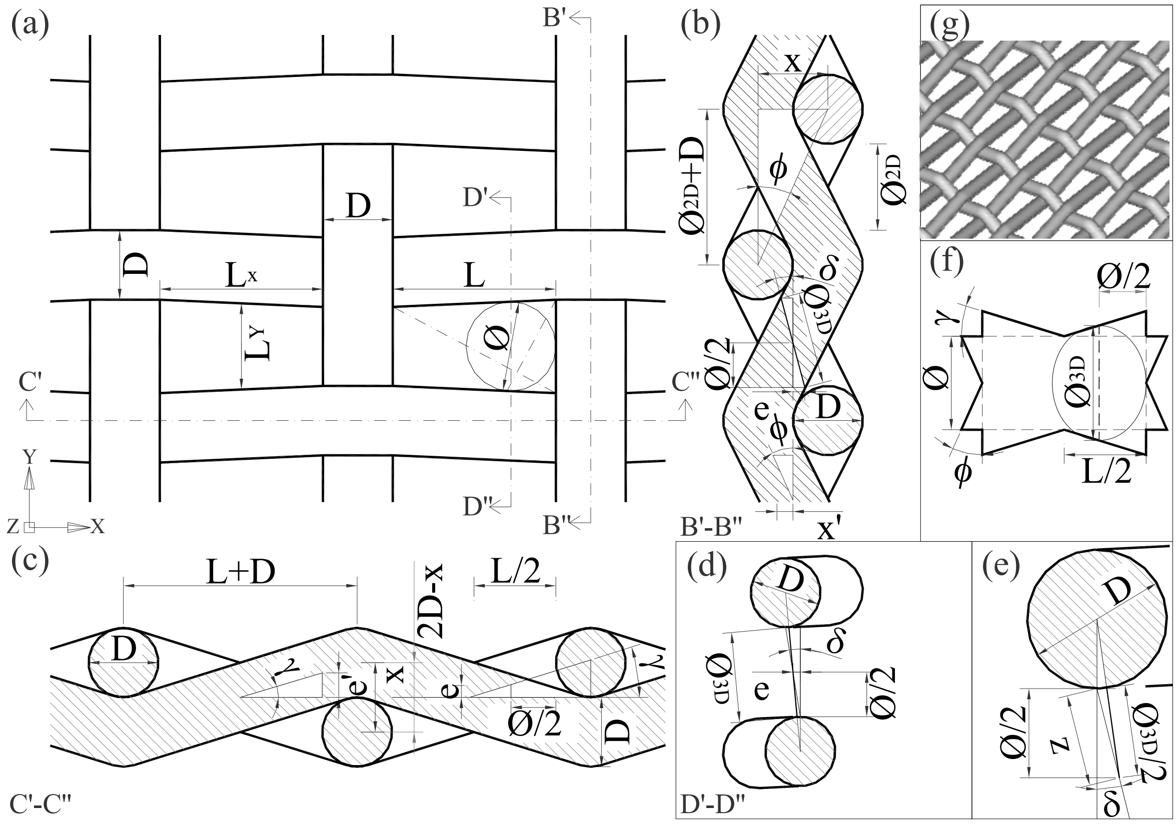
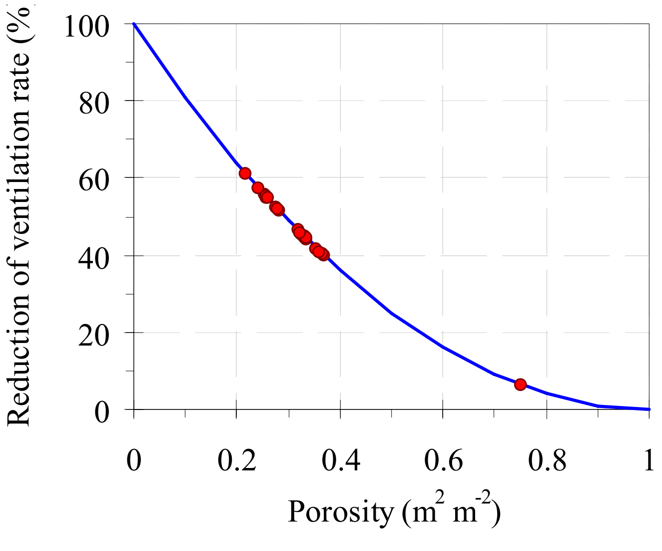
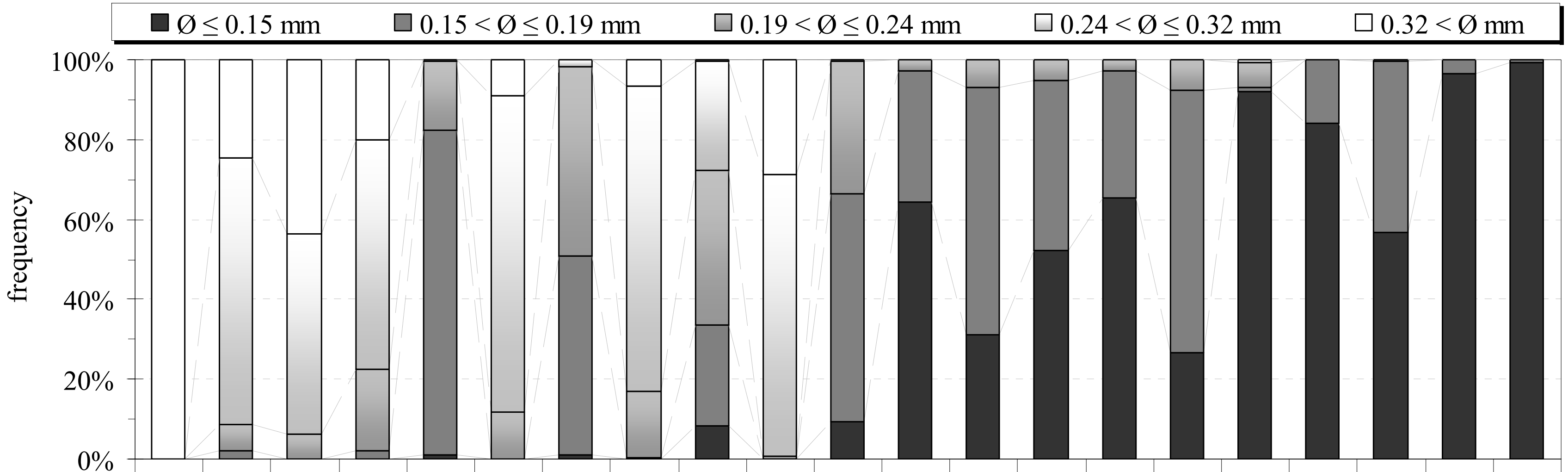


Fig. 4. (a) Plan view, slightly twisted in relation to the X axes; (b and c) side views; (d) section; (e) detail of the maximum diameter section; (f), projection in the XY plane of the helicoidal surface which contains the maximum area of a hole; and (g) three dimensional view of a woven anti-insect screen in which the threads in both axes weave equally (x/D=1).



Perez-Parra et al. (2004): $R=100\ \varepsilon^2 - 200\ \varepsilon + 100$

Fig. 5. Estimated reduction of ventilation rate for anti-insect screens.



N_X x N_Y (threads cm^{-1}) D (mm)	4.6x 2.8 (0.36)	15.3x 8.7 (0.32)	15.0x 9.2 (0.32)	15.3x 8.6 (0.33)	20.5x 8.7 (0.26)	15.6x 9.5 (0.33)	20.7x 9.2 (0.27)	16.1x 10.2 (0.32)	18.4x 9.6 (0.29)	14.9x 10.4 (0.33)	19.8x 10.2 (0.28)	27.9x 13.4 (0.20)	20.2x 9.3 (0.30)	20.7x 10.6 (0.29)	19.3x 11.1 (0.30)	19.8x 10.6 (0.31)	30.1x 21.4 (0.19)	22.6x 10.7 (0.28)	20.8x 10.3 (0.30)	22.3x 10.8 (0.29)	22.5x 11.0 (0.30)
0.32 < Ø mm	100%	25%	44%	20%	0%	9%	0%	7%	0%	29%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
0.24 < Ø ≤ 0.32 mm	0%	67%	50%	57%	0%	79%	2%	77%	27%	71%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%
0.19 < Ø ≤ 0.24 mm	0%	7%	6%	20%	17%	12%	48%	17%	39%	1%	33%	3%	7%	5%	3%	7%	7%	0%	0%	0%	0%
0.15 < Ø ≤ 0.19 mm	0%	2%	0%	2%	81%	0%	50%	0%	25%	0%	57%	33%	62%	42%	32%	66%	1%	16%	43%	4%	1%
Ø ≤ 0.15 mm	0%	0%	0%	0%	1%	0%	1%	0%	8%	0%	9%	64%	31%	52%	65%	27%	92%	84%	57%	96%	99%
Sample	S20	S03	S01	S05	S11	S02	S14	S04	S12	S08	S07	S17	S10	S21	S06	S09	S18	S19	S13	S16	S15

Fig. 6. Frequency diagram of the diameter of the largest circle inscribed in the hole in the XY plane, ∅, of the screens (screens ordered by decreasing porosity).