Incidence of Misshapen Fruits in Strawberry Plants Grown under Tunnels Is Affected by Cultivar, Planting Date, Pollination, and Low Temperatures

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Abstract. Misshapen fruit represent a significant problem for strawberry (Fragaria ×ananassa Duch.) producers around the world. We investigated the effect of cultivar and different cropping practices on the productivity of strawberry plants growing in tunnels at Huelva (Spain) over three years. In the first experiment, ‘Camarosa’, ‘Ventana’, and ‘Medina’ were planted on 10 or 22 Oct. at standard (30 × 25 cm), wide (35 × 25 cm), or narrow (25 × 25 cm) spacings. In the second experiment, ‘Camarosa’ was grown in macro- or microtunnels with and without bees. There was no effect of plant density. Planting time resulted in higher early yields in ‘Ventana’ and higher misshapen fruit in ‘Camarosa’ with an early compared with a late planting. ‘Camarosa’ had the lowest yields and the highest incidence of misshapen fruit. More of the early crop was misshaped and this was related to low temperatures in the 7 weeks before harvest. Pollination reduced the incidence of misshapen fruit and increased yield. Plants grown in macro-tunnels were only more productive than those grown in microtunnels when they were pollinated by bees. These results demonstrate that the productivity of strawberry plants growing in tunnels can be enhanced by the selection of the appropriate cultivar, planting date, tunnel system, and pollination protocol. The use of macrotunnels with supplementary pollination results in better economic returns by increasing yield and decreasing the incidence of misshapen fruit. In addition, in some cultivars this profit can be enhanced by early planting, which enables early arrival of fruits into the markets at better prices for growers.

Additional index words. fruit malformation, berries, cultivation systems, Fragaria ×ananassa, yield

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Materials and Methods

Site description and agronomy

Two field experiments were carried out from 2004 to 2006 at the IFAPA experimental station “El Cebollar” at Moguer in Huelva, Spain (lat. 37°16’ N, long. 6°50’ W, alt. 63 m a.s.l.). This area has a Mediterranean climate with dry, warm summers and moderately cold winters. Mean annual precipitation is 508 ± 57 mm (2004–2009) occurring mainly in fall and winter. Average mean temperature is 17.1 ± 0.8 °C.

Strawberry (Fragaria ×ananassa Duch.) plants were propagated during summer at high-elevation nurseries in Castille-Leon (lat. 4°13’30” N, long. 4°55’ W, alt. 900 to 1200 m a.s.l.) with at least 150 to 200 h of temperatures below 7 °C (López-Aranda et al., 2003). Standard agronomy for strawberry production in Huelva was used. In mid-October (22 Oct.) plants were transplanted...
into double-row (30 × 25 cm apart; ∼60,000 plants/ha) mulched raised beds (35 cm high and 50 cm wide) on a sandy soil covered by plastic to conserve water and keep the fruit clean (Kasperbauer, 2000). Before planting, the soil was solarized and biofumigated (biosolarization; Medina-Minguez et al., 2009) to reduce the incidence of soil pathogens. Most of the strawberry plants at Huelva are grown under plastic tunnels (80% macrotunnel and 20% microtunnel; CAP, 2007) to protect the crop from frost and rain during winter and early spring. Polyethylene-covered (150-μm thick plastic) tunnel structures are installed in mid-November and removed in mid-March, in the case of microtunnels, or at the end of the cropping season for macrotunnels. Fruit set takes place from January (midwinter) to the end of May (late spring). Bumblebees are used as pollinators (250 to 300 bumblebees/ha) to improve fruit fertilization under macrotunnels. The plants received: 175 kg nitrogen/ha, 77 kg phosphorus/ha, 185 kg potassium/ha, 85 kg calcium/ha, and 14 kg magnesium/ha between mid-November and mid-May through the irrigation.

Expt. 1: Effect of planting date, plant density, and cultivar on yield and the incidence of misshapen fruit. In 2004, an experiment was conducted to evaluate the effect of different planting dates (PDate) and plant densities (PDensity) on the performance of ‘Camarosa’ (Larson, 2001), ‘Ventana’ (Larson, 2001), and ‘Medina’ (López-Aranda et al., 2005). The plants were planted on 10 or 22 Oct. at standard (30 × 25 cm), wide (35 × 25 cm), or narrow (25 × 25 cm) plant spacings. Plants were planted under a polyethylene-covered macrotunnel structure (25 m long × 6.6 m wide × 3 m high) in a split-split plot design with three replicate plots and 50 plants per plot. The different planting dates were in the main plots, the different planting densities were in the split plots, and the different cultivars were in the split-split plots. From January to May, all mature fruit on each plot were harvested once or twice a week and separated into well-formed and marketable fruit (WF) and misshapen fruit (MF). There was no additional non-marketable fruit. Total yield (i.e., sum of WF and MF fruits; g/plant) and the percentage of misshapen fruit [MF (%)] were calculated for the entire season as well as for early (January to March) and late (April to May) season. Marketable fruit yield can be easily calculated by multiplying total yield by [1-MF (%)].

Temperatures under the tunnel were recorded using one Escort Mini data logger (Escort Data Logging Systems Ltd., New Zealand).

Expt. 2: Effect of tunnel structure and the use of pollinators on yield and the incidence of misshapen fruit. In 2005 and 2006, an experiment was carried out at the same site as in Expt. 1 to evaluate the effect of the cover structure and the use of pollinator insects on the performance of ‘Camarosa’. Plants were grown in macro- (25 m long × 6.6 m wide × 3 m high) or microtunnels (20 m long × 0.6 m wide × 0.4 m high) with or without bumblebees ('Bombus terrestris L.'). Plants in the different plots were isolated from neighboring plots by the use of insect-proof mesh. Approximately 250 to 300 bumblebees/ha were released under the mesh for pollination. Data on yield (g/plant) and the incidence of MF were collected as described previously.

The experiment was set up in a split plot design with three replicate plots and 80 plants per plot spaced at 30 × 25 cm. The different tunnels were in the main plot and the presence or absence of pollinator in the subplots. The incidence and relative humidity under each tunnel were recorded every 15 min. These data were used to assess the relationship between the incidence of misshapen fruit and environmental conditions.

Statistical analysis

Data were analyzed using the analytical software STATISTIX 9.0 (Analytical Software, FL). Before analysis of variance (ANOVA), normality and homogeneity assumptions were tested by using the Kolmogorov-Smirnov and Cochran’s C tests, respectively. In Expt. 1, data on yield and on the incidence of MF on each harvesting period were evaluated by a split-split plot ANOVA (two planting dates × three plant spacing × three cultivars). In Expt. 2, data on yield and on the incidence of MF for the entire season or for the two harvesting periods separately were analyzed by a split-split plot ANOVA (two planting dates × two pollinators). For comparisons between years and harvesting periods, data on total yield and on the incidence of MF were subjected to a repeated-measures ANOVAR. In this model “year” and “period” were the within subject factor. For assessing the interaction between harvesting period and the use of pollinators, in the ANOVAR model, “Pollinator” was introduced as a between-subjects factor. A series of one-way ANOVAs were used to assess the differences in environmental variables under the different tunnels during the two harvest periods. Differences at the 5% probability level were considered significant and Fisher’s least significant difference (LSD) test was used to compare means.

Pearson’s correlations and stepwise linear regressions were performed with the STATISTICA 7.0 (StatSoft Inc.) analytical software for assessing the relationship between the variation of environmental variables under the tunnel structures and the incidence of MF. For correlations with environmental variables, we only considered weekly averaged data of MF recorded on the three plots of each tunnel structure and from the “without” pollinator treatment. Because it has been reported that fruit malformation is closely related to the low temperatures during flower and fruit development (Ariza et al., 2011), regressions were made with average minimal temperatures on the week of harvesting and from 1 to 9 weeks before harvesting (Tmin-1: Tmin-3: ...: Tmin-9, respectively).

For the analysis of the data expressed as percentages (i.e., MF), a mean value (P%) was calculated for each plot and an arcsine transformation was used (i.e., arcsine [sqrt(P%)/100]) to normalize treatment means. However, for convenience, data of MF presented in tables and figures are back-transformed means.

Results

Effect of planting date, plant density, and cultivar on yield and on the incidence of misshapen fruit. During the study, mean maximum and minimum temperatures under the tunnels were 27.5 ± 0.5 °C and 8.7 ± 0.3 °C, respectively, with an absolute maximum of 39.5 °C and an absolute minimum of 0.5 °C.

Yield over the entire season was higher in ‘Medina’ (1156 ± 33 g/plant), intermediate in ‘Ventana’ (1023 ± 43 g/plant), and lower in ‘Camarosa’ (887 ± 43 g/plant) ( LSD critical T-value 2.064; P < 0.05). In contrast, there was no significant (P > 0.05) effect of “PDate” or “PDensity” on yield over any period. The only exception to this was in ‘Medina’, which had higher early yields (up to 30% compared with the standard planting date) when planted early (Fig. 1A). Results were similar when marketable fruit yield was analyzed separately (data not shown).

Most of the misshapen fruit occurred early in the season (Fig. 1B). The incidence of the disorder was higher in ‘Camarosa’ than in the other two cultivars and higher with the early planting (Fig. 1B). In contrast, planting density had no significant (P > 0.05) effect on the incidence of the disorder (data not presented).

Effect of the tunnel structure and the use of pollinating insects on yield and the incidence of misshapen fruit. It was 1 to 2 °C warmer under the macro- compared with conditions under the microtunnel (Table 1). It was also slightly drier under the macrotunnel.

Yield over the entire season was similar in 2005 than in 2006 (P > 0.05). Yield was equally shifted between the two harvesting periods (data not shown). Yields were higher with pollination than without (P < 0.001) but there were no significant (P > 0.05) differences between the two types of tunnels (Fig. 2A). However, a significant interaction (P < 0.05) between “Pollinator” and “Type of Tunnel” was detected. Yield was higher in the macro- than in the microtunnel with pollination, but yield did not differ between the tunnels in absence of pollinators (Fig. 2A). Results were similar when marketable fruit yield was analyzed separately (data not shown).

The incidence of MF was similar over the two years and higher early in the season than later in the season (P < 0.05; Table 2). The use of pollinator insects decreased the incidence of the disorder (Fig. 2B) and this effect was greater early in the season than later in the season (P < 0.05; Table 2). No significant effects of the “Type of Tunnel” were found on the %MF with average values for the...
The incidence of the disorder depends on the susceptibility of the cultivar to low temperatures, which is probably the result of insufficient chilling hours for cold hardening at the nursery. Cross-pollination by bumblebees reduces the incidence of misshapen fruit under high-tunnel structures but does not eliminate it completely.

**Effects of different cropping conditions on total yield.** The most important factors influencing yield were cultivar, tunnel system, and pollination. Fruit production was higher in ‘Medina’ than in ‘Ventana’ and ‘Camarosa’ and unaffected by planting date or by planting density. Overall, the cultivars were relatively productive compared with yields in commercial fields in this area. In ‘Medina’, planting early in the season resulted in higher early yields compared with the standard planting. Previous studies have reported differences in early and total extraclass (i.e., first category marketable fruit yield) production either per hectare or per plant among strawberry cultivars at different planting dates or plant densities (López-Medina et al., 2001; Turemis et al., 1996). ‘Camarosa’ growing under microtunnels opened in warm days to enhance pollination and performed better when planted early and at high plant densities (López-Medina et al., 2001). Our results in ‘Camarosa’ apparently are in contrast to that but differences may be the result of the experimental setup. Thus, we have evaluated total yield per plant, which includes all marketable fruit yield and misshapen fruit, and our plants were grown under high tunnels with bumblebees as pollinators.

‘Camarosa’ had the highest yields when pollinators were released under macrotunnels (>32% greater than in microtunnels with pollinator), which are the most common cropping conditions in southwestern Spain. Bumblebees facilitate cross-pollination, which is essential for fruit development in strawberry plants (Albano et al., 2009; Paydas et al., 2000). Similar results have been reported using stingless bees as pollinators for strawberry plants in greenhouses (Malagodi-Braga and Kleintert, 2004; Roselino et al., 2009). The differences in total yield between the two tunnels with pollinators indicate some impediment of insect movement in the microtunnels.

**Effects of different cropping conditions on the incidence of misshapen fruit.** The incidence of misshapen fruit was higher early in the season, when low temperatures occur concomitantly, and was influenced by the cultivar, the use of pollinators, and the time of planting. ‘Camarosa’ was more affected than ‘Medina’ and ‘Ventana’, especially early in the season, suggesting it is susceptible to low temperatures during flower and fruit development. These results agree with those reported by Ariza et al. (2011) for ‘Camarosa’, where the achenes failed under low temperatures. In our experiments, minimum temperatures under the tunnel structures still fell below 7°C early in the season. Minimum temperatures in the 7 weeks before the fruit are harvested appear to have a decisive influence decreased as temperature increased from ≈2°C to ≈14°C.

**Discussion**

The present work indicates that strawberry crop production is reduced by misshapen fruit. Factors determining yield and the occurrence of misshapen fruit overlap and are associated with the choice of cultivar and pollination. However, unlike yield, fruit malformation is closely related to low temperatures during winter. The extent of the incidence of the disorder during winter.

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**Table 1.** Average minimum and mean temperatures (T_{min} and T_{mean}, respectively) and mean relative humidity (RH_{mean}) under macro- and microtunnels in the experiments with strawberry plants grown in Huelva, Spain, in 2005 and 2006.

| 2005 | 2006 |
|------|------|
|       | Macrotnnell | Microtunnel | Macrotnnell | Microtunnel |
| **T_{min} (°C)** | | | | |
| January to March | 6.2 ± 0.5 a | 5.0 ± 0.5 b | 7.9 ± 0.3 a | 6.7 ± 0.4 b |
| April to May | 12.7 ± 0.3 a | 12.1 ± 0.3 b | 13.8 ± 0.3 a | 12.5 ± 0.3 b |
| **T_{mean} (°C)** | | | | |
| January to March | 12.4 ± 0.4 a | 11.3 ± 0.4 b | 13.3 ± 0.3 a | 12.2 ± 0.3 b |
| April to May | 20.2 ± 0.3 a | 18.7 ± 0.3 b | 20.7 ± 0.3 a | 18.8 ± 0.3 b |
| **RH_{mean} (%)** | | | | |
| January to March | 73.5 ± 1.1 a | 74.8 ± 1.1 a | 77.9 ± 0.7 b | 80.4 ± 0.7 a |
| April to May | 65.8 ± 1.1 b | 72.2 ± 1.1 a | 68.6 ± 1.3 b | 68.8 ± 2.0 a |

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*a* Each value represents the mean ± se (n = 60 to 80).

*b* Between tunnels different letters indicate significant differences at P < 0.05 (one-way analysis of variance followed by least significant difference test).

*c* January to March = early; April to May = late.
on the incidence of misshapen fruit. It would affect early flower developmental stages, because in ‘Camorosa’, it takes \(\approx 40\) to \(\approx 49\) d to go from anthesis to red fruit (i.e., time to ripening) (Kano and Asahira, 1981; Perkins-Veazie and Huber, 1987) in the early season (Ariza et al., 2011).

In the absence of pollinators, most of the flowers are self-pollinated and this gives rise to poor quality fruit (Malagodi-Braga, 2002). Cross-pollination by bumblebees reduces the incidence of misshapen fruit (up to \(\approx 50\%\)) in both types of tunnels, even at low temperatures (Del Pino, 1998). However, pollinators cannot completely eliminate the disorder.

On the other hand, the higher incidence of misshapen fruit when strawberry cultivars were planted early is suggesting a loss of flower and/or fruit quality when shortening the cold-hardening dormancy period at the nursery (Carew et al., 2003; García-Méndez et al., 2008; Kronenberg and Wassenaar, 1972). In fact, a low fruit quality has been associated with poor stamen and pollen quality (Liethen, 1997), which in turn is closely related to the incidence of misshapen fruit in ‘Camorosa’ (Ariza et al., 2011). In this cultivar, the higher amount of MF even at a standard planting date is suggesting higher chilling requirements to ensure proper flower and fruit development, which would explain its susceptibility to low temperatures along the cropping season.  

**Relationship between yield and the incidence of misshapen fruit.** The effect of cultivar and cropping conditions on yield and the incidence of MF was not always related. Compared with the other two cultivars, low yields in ‘Camorosa’ were consistently associated with a higher incidence of misshapen fruit. In contrast, in two out of the three cultivars, early yields were similar between planting dates but incidence of misshapen fruit was not. Early planting in ‘Medina’ resulted in the highest early yields concomitantly with the highest incidence of MF. These results suggest that yield and the development of misshapen fruit are affected by different processes.

**Conclusion**

Misshapen fruit mainly appear early in the season, when prices are high (\(\approx 2.5\) times higher for early than for late fruit). Thus, any factor that can increase yield and/or fruit quality at this time would enhance returns for growers. The use of macrotunnels with supplementary pollination results in better economic returns by increasing yield and decreasing the incidence of misshapen fruit in strawberry. This is especially recommended in cultivars that are more susceptible to the disorder such as ‘Camorosa’, in which important savings (up to EUR 18 million) for the strawberry industry can be achieved by reducing substantially the incidence of misshapen fruit in the early season. In cultivars that are less susceptible to the disorder and with greater overall returns such as ‘Ventana’ and ‘Medina’, this profit can be also enhanced by early planting, which enables early arrival of fruits into the markets at better prices for growers.

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