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Short Contribution

Testing the effect of a rainproof protection net on the apple production regarding disease and pest damages

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Abstract

In a field trial within the CORE Organic project DOMINO, the effect of a rain protection combined with lateral insect nets ("Keep in touch – Antiacqua") was tested for organic apple production. The rain-proof roof should protect the trees from rainwater, reducing the emergence of fungal infections such as scab and rotting diseases including post-harvest diseases, while the lateral nets should markedly decrease the damages caused by pests. The Keep in touch system without any spray from the blooming on was compared to an uncovered and unsprayed treatment (control) as well as an uncovered and organically sprayed treatment. The trial was carried out from 2019 to 2021 on 'Gala' in South Tyrol and 'Topaz' and 'Ariwa' in Switzerland. Diseases and pests on the trees resp. on the fruits were assessed during the season resp. at harvest. Furthermore, fruit quality and post-storage diseases on fruits were rated.

Keywords: organic apple production, rain protection, plant protection, diseases, pests

Introduction

Table apple production requires an intensive direct plant protection in order to reach the fruit quality demanded by the market. The plant protection is primarily used against fungal pathogens (apple scab, sooty blotch etc.) and pests (codling moth, aphids etc.). One approach to reduce the application of plant protection products in intensive organic apple orchards is the use of a physical barrier to protect the trees and fruits against rain and insects. Using a rain coverage is expected to reduce fungal infections as most fungi need a water film to infect the plant. Rain cover protections were first tested for organic apricot and plum production to protect the trees from fungal and bacterial infections. Furthermore, the use of a rain coverage combined with insect nets is widely used for organic cherry production to protect both from rain and from insects. Rain covers integrated to hail nets or single-row rain protection combined with lateral insect nets have now been tested for apple production for several years in France, Germany, Switzerland, and Italy, not only in organic production but also in integrated production. In this study, a single-row rain protection combined with lateral insect nets, marketed as "Keep in touch – Antiacqua" system, has been tested for three years, from 2019 to 2021, on 'Gala' in South Tyrol and 'Topaz' and 'Ariwa' in Switzerland.

Material and Methods

The trial was conducted in two organically managed apple orchards, one located at the Research Institute of Organic Agriculture (FiBL) in Frick (Switzerland, 350 m.a.s.l., ∅ annual rainfall 1000 mm, ∅ T 10.6 °C) and one located at the Research Center Laimburg in Vadena, South Tyrol (Italy, 222 m.a.s.l., ∅ annual rainfall 815 mm, ∅ T 11.6 °C). Three treatments were tested: a covered treatment (Keep in touch, KT), an organic treatment with no cover

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and standard organic plant protection, and a control with no cover and no plant protection. For the KT treatment, the protective system was opened (i.e. the trees were covered) during full flowering (phenological stage BBCH 65), and from this point in time no more plant protection products (PPP) were used for the KT and control treatments. At LAIM the lateral net was closed above the ground, whereas at FiBL the net was closed on the ground (Figure 1). The trial included three repetitions with 5 (FiBL) resp. 12 (LAIM) sampled trees (excl. border trees) per repetition and was conducted for the apple cultivar 'Gala' in South Tyrol and the two apple cultivars 'Topaz' and 'Ariwa' in Switzerland.

The disease incidence of apple scab was assessed in mid-June using a scoring from 1 (= 0% visible symptoms) to 9 (> 90% visible symptoms) (Patocchi *et al.*, 2009). The same scoring scale was used for powdery mildew, except that percentage of infected shoots instead of infected leaves were assessed. At harvest, the incidence of diseases (apple scab, sooty blotch, lenticel rot and other rotting diseases), physiological disorders (bitter pit, underdeveloped fruits), and pest damages on fruits (aphid damage, insect feeding damage) was determined. Yield was assessed by weighing the fruits, which were classified into three categories: marketable fruits, fruits for cider production, and waste fruits. Fruit quality was assessed by estimating the percentage of overcolour, and measuring fruit weight and size, sugar content, and firmness for ten fruits per repetition (30 fruits per cultivar and treatment). Additionally, at LAIM, mineral content in fruits were assessed. Storage damages on fruits were assessed after 2.5 months in cold storage at 1°C, and the shelf-life after further 12 days at room temperature.

Table 1: Assessments performed at Laimburg (LAIM) in South Tyrol and at FiBL in Switzerland in 2019, 2020 and 2021 (A= only 2019, B= only 2020 and 2021).

Assessment	**LAIM**	**FiBL**
Apple scab on leaves mid-June and on fruits in August	X	X
Fruit quality (fruit size, weight, colour, sugar content, firmness)	X^A	X
Mineral content in fruits	X^A	-
Pest and disease damages on fruits at harvest	X	X
Post-storage evaluation	X	X
Shelf-life evaluation	X	X^B
Light measurements	X^A	-
Insect diversity (beating tray)	-	X^B

Figure 1: The Keep in touch (KT) cover system was closed above the ground at LAIM (a), and on the ground at FiBL (b, c).

Results

Due to the Keep in touch (KT) system, it was possible to reduce between 70 % and 85 % of the plant protection treatments (fungicides, insecticides) carried out in the apple orchard,

without an increase in pest or fungal damages at LAIM but some increase in fungal damages over the years at FiBL. Both orchards, at LAIM and FiBL, had a high pest and disease pressure.

Apple scab

The apple scab pressure was very high in both orchards. At LAIM, apple scab was found on 86 % (Gala) of the leaves in the control plots in 2019 already in June. Similar scab infection values were found on the harvested fruits with about 90 % (2019), 80 % (2020), and 70 % of the apples in the control treatment showing fruit scab. Apple scab on leaves and fruits of the KT treatment showed to be similar to the organic treatment, both in terms of incidence and severity. Nevertheless, it is worth to mention how the primary scab infection of the KT treatment, even if classified as light, reached 10 % (2019) resp. 6 % (2020), and 30 % (2021) and secondary scab between 16 % (2019) resp. 3 % (2020) and 10 % (2021).

At FiBL, apple leaf scab was found on 80 % ('Ariwa') resp. 70 % ('Topaz') of the trees of the control in June 2019, with in general a lower level of scab severity for 'Topaz' (only up to 5 % of leaves with scab) compared to 'Ariwa' (up to 75 % of leaves with scab). Even though 'Ariwa' and 'Topaz' are apple scab resistant cultivars, the resistance was broken due to many years of no plant protection. For both cultivars, scab infections were reduced in 2019 for the KT treatment compared to the control and comparable to the organic treatment, with 25 % of trees with scab for 'Ariwa' (up to 5 % of leaves) and 2 % for 'Topaz' (1 % of leaves). In June of the second and third year, 2020 and 2021, the disease pressure built up in the control, and some apple fruit scab was found in the control, while none was found in the KT or organic treatment. However, the disease pressure also increased in the organic and KT treatment. For the KT treatment, apple leaf scab was found on all trees of 'Ariwa' under the net (up to 25 % of leaves infected) and 80 % of trees of 'Topaz' (up to 5 % of leaves infected).

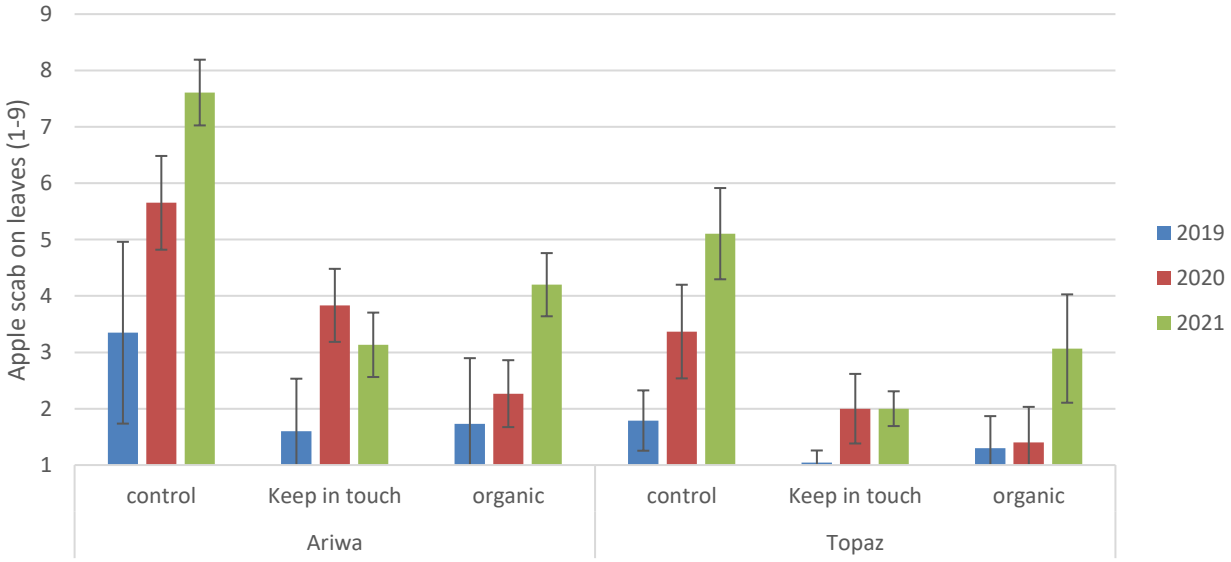

Figure 2: Apple scab on the cultivars 'Ariwa' and 'Topaz' for the year 2019, 2020, and 2021 at FiBL in Frick (Switzerland). Scoring from 1 to 9 (1= 0 %, 2= 0-1 %, 3= 1-5 %, 4= intermediate, 5= +/-25 %, 6= intermediate, 7= +/-50 %, 8= +/- 75 %, 9= >90 %).

Powdery mildew

No powdery mildew was found on 'Gala' at LAIM. At FiBL, however, some powdery mildew was found on 'Topaz' in 2020 and 2021. In 2020, 10 % of the trees in the control and 5 % of the trees under the KT had 1-2 infested shoots. In 2021, the number of infections with powdery mildew increased with 40 % of the trees infested in the control and 60 % of the trees under the KT with up to several infected shoots per tree.

Fruit diseases and other losses at harvest

The amount of fruits with sooty blotch was almost reduced to zero under the KT for both 'Ariwa' and 'Topaz', whereas on average 56 % ('Ariwa') resp. 70 % ('Topaz') of fruits in the control were infested by sooty blotch with a significant difference depending on the cultivar.

Less than 2 % of lenticel rot was found on 'Topaz' regardless of the treatment. For 'Ariwa', in 2019, the amount of lenticel rot found under the KT was lower than in the control and the organic treatment, which both had 30 % of fruits infected. In 2020, however, under the KT almost all fruits i.e. 70 % of the fruits showed lenticel rot, whereas it was 55 % and 30 % for the control and the organic treatment respectively. And in 2021, 60 % of the fruits showed lenticel rot, while it was only 5-10 % in the control and organic treatment. Furthermore, an important reduction of fruit rottenness was observed for the KT, especially during the first year when 10 % of control fruits were rotten.

Pest pressure

For both sites, a clear reduction in the fruits damaged by the codling moth was observed under the KT, even in 2020 with a much lower pest's pressure than 2019. No reduction of 'other feeding' damages, mainly caused by larvae of pests, was observed except at LAIM in 2019. In 2021, punctually some San José scale and bug attacks were found on fruits in the lower part of the trees under the KT at LAIM. An infestation by the woolly apple aphid was observed at FiBL on 'Topaz' in one covered replicate in 2019 and in several replicates in 2020 and 2021, with an increased damage over the years.

Post-storage losses

The KT allowed to reduce the post-storage losses on 'Gala' caused by post-storage scab in both years at LAIM. *Colletotrichum acutatum* infections were lower in 2019 for the KT compared to the organic treatment, but no differences were found in 2020. No differences were observed for *Monilia spp.,* cracked apples and bitter pit in both years at LAIM. At FiBL, no significant reduction in total post-storage losses was observed for the KT treatment in 2019 and 2020.

Regarding the shelf life, no differences were found for *C. acutatum*, *Phytophthora cactorum*, bitter pit, post-storage scab in 2019 at LAIM, however, *Neofabraea alba* in 2019 resulted lower on KT apples compared to the control. In 2020, post-storage scab resulted lower on KT apples compared to the control, but no differences were found for *N. alba*. As for losses caused by cracking in 2019 the highest number of cracked apples was recorded in organic plots, while in 2020 the most cracked ones were the covered apples. At FiBL, the shelf-life evaluation showed no significant reduction in rotten apples for the KT treatment.

Fruit quality

At FiBL, the share of underdeveloped or deformed fruits was around 50 % under the KT in 2019 both for 'Ariwa' and 'Topaz', while lower than 20 % for the control and organic treatment. It was also higher in 2021 with around 30 % under the KT, while below 10 % for the control and organic treatment. No significant differences were found in 2020 (low yield).

Additionally, no significant differences were found in the internal quality of the fruits (pH, acidity, firmness, and total suspended solids) or the micro-nutrients content between the treatments in 2019 at LAIM. However, significant differences were found in N, P, K and Mg content of the fruits, all higher in the KT treatment compared to the organic treatment. At FiBL, two out of three years, fruit sugar content and overcolour were significantly lower for the KT than for the organic treatment and the control.

Discussion

As observed from the two years results obtained with the trials performed at LAIM and FiBL, it is effectively possible to reduce the PPPs sprayed in the orchards, but it is of major importance to well plan the plant protection strategy until full bloom, before the system should be opened.

Fungal infections

In line with other studies using rain roofs, apple scab was reduced for the KT treatment, sometimes even completely avoided, and infections were cultivar-dependent (Zavagli *et al.*, 2016; Kelderer *et al.*, 2018; Chouinard *et al.*, 2019; Buchleither *et al.*, 2021; Zwahlen *et al.*, 2021). The apple scab infections were found in the lower part of the trees, mostly in the outer part, on leaves close or touching the net, which probably got wet. Leaves close to the net can get wet when there is heavy lateral rain (Zavagli *et al.*, 2016). This leads to the conclusion that a slender canopy (fruit wall), as opposed to a large canopy, is better adapted for this covering system. Furthermore, closing the net under the tree instead of on the ground has the advantage on the one hand to reduce potential infections from inoculum on the ground, and on the other hand facilitate the management of the understory in the tree strip as well as the tree alley. Because of a reduction of air humidity under coverage (Zavagli *et al.*, 2016; Chouinard *et al.*, 2019), one of the main challenges is the control of powdery mildew infections. As seen in 2020 and 2021 at FiBL, the number of infections with powdery mildew can increase much faster under the KT than on trees without cover. Other studies found an increase of powdery mildew for susceptible cultivars under coverage (Zwahlen *et al.*, 2021).

The KT was able to prevent sooty blotch almost completely from the fruits, confirming the results of previous studies with rainproof coverage (Kelderer *et al.*, 2018; Chouinard *et al.*, 2019; Buchleither *et al.*, 2021). Even in 2021, a year of high precipitation and humidity, the amount of fruits with sooty blotch remained at 10 % (‘Topaz’) resp. 3 % (‘Ariwa’), while it was 92 % for ‘Topaz’ and 56 % for ‘Ariwa’ in the control. Regarding lenticel rot, it was not clear if it was caused by a fungus or rather a physiological disorder leading to a lenticel decay, for example induced by calcium deficiency. The reduction of post-storage losses caused by *Neofabraea spp.* was not as clear as found in other studies (Arnegger *et al.*, 2018; Kelderer *et al.*, 2018).

Pest pressure and insect diversity

The exclusion nets of the KT act as a physical barrier against flying pests, and a clear reduction of damages by the main apple pest, the codling moth, was observed as in other studies (Kelderer *et al.*, 2010; Alaphilippe *et al.*, 2016; Kelderer *et al.*, 2018; Aoun *et al.*, 2020; Marshall *et al.*, 2022). However, it does not protect the trees and fruits against pests overwintering on the trees or migrating onto the trees prior to the opening of the KT which can then freely multiply under the net if no preventive treatment is performed prior to opening the KT. Furthermore, some beneficials that were found in the control and the organic treatment, were not observed under KT, such as *Aphelinidae* and *Braconidae*, or vice versa (data not shown). In the absence of antagonists, some secondary pests can emerge under netting, such as the woolly aphids, lace bugs, leaf miners or the tortrix moths, as underlined in the review of Chouinard *et al.* (2016).

Effect on fruit quality

The higher share of underdeveloped and deformed fruits could indicate a negative effect of the KT system on pollinators’ activity. The data also suggests, that the KT system leads to reduced overcolour and sugar content of the fruits, as found in other studies (Zavagli *et al.*, 2016; Chouinard *et al.*, 2019). A hypothesis could be the reduced availability of light leading to a reduced photosynthesis under the KT. Even though collected data (data not shown) indicated that there was a clear reduction in the total light caused by the KT nets on both

the sun-faced and shaded side, the diffuse light component increased in the first two meters of the sunny side and did not differ on the shaded side between covered and control plots. Secondly, neither on the sunny nor on the shaded side statistically significant differences were found for the photosynthesis measurements with or without coverage. However, Zavagli *et al.* (2016) found that PAR was around 30 % reduced under coverage (Zavagli *et al.*, 2016; Arnegger *et al.*, 2018; Zwahlen *et al.*, 2021).

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