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# EFFECTS OF HAIL NETS ON ORCHARD LIGHT MICROCLIMATE, APPLE TREE GROWTH, FRUITING AND FRUIT QUALITY

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**Abstract.** Hail nets are necessary protection in some fruit growing regions. Several trials showed that the net color may influence tree growth and fruiting. The influence of hail nets on orchard light microclimate, growth, flowering and fruiting of apple trees was examined in field experiment in the years 2004–2010. 'Šampion' and 'Rubinstar' apple trees grafted on M.9, were planted in spring 2004. After planting, half of the experimental plot was covered with three kinds of hail nets: white, gray and black. The other half was kept uncovered as the control. Tree growth, fruit bud formation, fruiting and fruit quality were recorded. Solar radiation was measured above and below the nets and within tree canopy. Black and gray nets stimulated tree growth and yield of 'Šampion' tree, but had no positive influence on 'Rubinstar' trees. Covering the trees with gray and black nets caused poor red blush development and reduced soluble solids content in apples of both cultivars. Fruit firmness was unaffected by netting.

**Key words**: fruit firmness, TSS, hail damage, tree vigor

## INTRODUCTION

In Europe, mainly in Austria, Italy, Switzerland and Germany hail damage to fruit crops is a pain problem. According to some authors [Botzen et al. 2010] hailstorm damage will increase in the future if global warming leads to a further temperature increase. It was estimated that by 2050 climate change may have led to a 25–50% increase in crop damage due to hailstorms [Botzen et al. 2010].

Hail nets are mounted above fruit plantations to protect trees and fruits from damage. Applied polypropylene nets have different color: white, black, gray, blue, green,

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red [Funke and Blanke 2003, Iglesias and Alegre 2006, Blanke 2014]. In many regions in Europe hail nets are additional, indispensable costly investment in orchard. In Poland installation of hail nets is very costly (15 000 EUR/ha), twice as much as establishing a new apple plantation. However, hail netting is a long term investment [Borin and Saoncella 2000].

Hail nets change orchard light microclimate what affects yield and fruit quality [Widmer 2001]. Iglesias and Alegre [2006] reported that white net intercepted 12% of irradiation, while black net 25%. Mostly black nets are mounted, that in opinion of Stampar et al. [2002], have disadvantageous influence on fruit growth and red blush development. The results of experiments with hail nets of different colors are ambiguous though. Chen et al. [1998] and Girona et al. [2012] reported, that nets reduced amount of apple and peach yield and fruit quality. In the contrary Funke and Blanke [2003] stated that there was no influence of hail netting on fruit ripening and their quality.

In warm regions with high solar radiation a positive effect of shading on growth of fruit trees was observed [Giaccone et al. 2012]. Lower intensity of radiation reaching trees and a consequently decreased level of evapotranspiration resulted in a reduction of plant water stress symptoms and an increase in photosynthesis and carbohydrate metabolism [Iglesias and Alegre 2006]. Moreover, in sunny and hot climates hail nets may reduce incidence of sunburn improving skin quality and limit insect infestation [Middleton and McWaters 2002, Gindaba and Wand 2005, Iglesias and Alegre 2006]. On the other hand by limiting sun irradiation reaching the trees and fruits, orchard netting can lower efficiency of photosynthesis, decrease fruit bud formation and fruit quality [Vercammen 1999, Widmer 2001, Iglesias and Alegre 2006, Amarante at al. 2011].

Amarante et al. [2011] found, that white hail net deteriorated fruit bud formation and flowering in comparison to uncovered trees. This result was supported by Middleton and McWaters [2002] who showed that lower yield from apple trees covered with hail net was due to weaker fruit set. The relation between sunlight exposition and fruit set is well known. However, in the experiment of Shahak et al. [2004] fruit set was more abundant under red-white nets and apple size was higher than on control trees. Solomakhin and Blanke [2010] showed that mean fruit mass was higher under color nets than from uncovered trees and the effect of netting depended on cultivar and climatic condition. Nets reduced the maximum temperature by 3–6°C and this could have advantageous influence on fruit set and fruit size. Solomakhin and Blanke [2010] noted lower temperature by 1.3°C and higher humidity by 2–5% under nets in comparison to the control. Apples from trees covered by white nets possessed more dry matter than apples from color nets. According to these authors white nets assure better light availability to trees than color nets, protect fruits from hail and sun damages, and enhance fruit quality. Iglesias and Alegre [2006] reported that nets did not increase apple size of 'Mondial Gala'. Gindaba and Wand [2005] found that shading apple trees by nets restrained fruit growth of 'Royal Gala' due to poor light interception. On the contrary Solomakhin and Blanke [2010] obtained larger apple fruits from trees covered with color nets than from uncovered trees. Bastias et al. [2012] reported that fruit weight of apple under blue net was greater than control.

McArtney et al. [2004] reported that insufficient light availability during early stage of fruit development had adverse effect on their later growth (stimulated more fruit drop), possibly as the consequence of lower carbon assimilation rates [Zibordi et al. 2009]. Fruits from trees covered with hail nets can have poorer red blush than control trees [Casierra-Posada and Ludders 2001, Funke and Blanke 2003, Gindaba and Wand 2005, Solomakhin and Blanke 2010]. Iglesias and Alegre [2006] reported that covering apple trees with black net reduced intensity of red blush on apples of 'Mondial Gala', while white net had no much effect on red blush of apples. Iglesias and Alegre [2006] and Amarante et al. [2011] found less firmness and lower sugar content in apples harvested from trees covered with hail nets in comparison to the control. According to Jackson at al. [1977] "well-illuminated" apple fruit had higher sugar content (compared to the shaded ones). On the other hand Gindaba and Wand [2005] did not found less sugar and firmness in apples coming from trees covered with white, gray or black nets in comparison to the control.

The above presented examples show that the effect of netting depends on a cultivar and climatic condition. Therefore, examination of plant response to orchard netting should be performed at a regional (country) level. In the present study we examined the influence of white, gray and black hail nets on changes in orchard light microclimate, as well as on vigor, flowering and fruiting of apple trees.

## MATERIAL AND METHODS

Two-year-old, feathered 'Šampion' and 'Jonagold' (strain 'Rubinstar') apple trees grafted on M.9 rootstock were planted in spring 2004 on sandy-loam soil in the Experimental Orchard of the Research Institute of Horticulture in Dąbrowice, Poland (longitude 51°57'N, latitude 20°08'E, altitude 120 m). The experimental field consisted of two plots. One plot was covered with hail nets of three colors: white, gray and black. Another plot, without any net, served as the control. On the plot with netting two cultivars were planted represented by 3 trees, repeated 4 times, under each net color. Trees were spaced in 6 rows, 3.8 × 1.2 m and were trained to spindle system. Supporting construction for hail nets consisted of impregnated wooden poles 4.5 m long driven to the ground to 0.7 m. The poles were anchored to withstand 8 tons of weight. Hail net (3 × 7 mm mesh, consisted of 3.2 mm threads) was spread 4 m above the ground. On the plot without nets trees were planted in the same manner as on the field covered with nets.

To evaluate tree growth, the stem diameter and the total length of shoot growth produced per tree were measured. Trunk diameter was measured 30 cm above the ground in years 2004–2010 using a slide caliper. Analysis of annual shoot length was performed in years 2004–2006. Flowering intensity was recorded in years 2005–2010 by counting flower clusters on each tree. Amount of yield and fruit quality were recorded in years 2005–2010. To estimate fruit quality samples of 30 fruits from each treatment were taken and sorted for color, mean fruit mass, firmness and soluble solids content (TSS). Flesh firmness was measured with the hand-held penetrometer, TSS with the digital refractometer (PAL-1, Atago, Tokyo, Japan).

To estimate light interception by the nets, solar radiation levels above the nets and under the nets was measured in years 2009 and 2010 with the Tube Solarimeters (Delta-T Devices, Burwell, UK). Also the light distribution within tree canopies was measured on four trees grown under the each net (on 'Šampion' cultivar ) in four horizontal zones: 0.5; 1.0; 1.5; 2.0 m, across the row, near tree leader. The measurements were done on sunny days, at midday hours, with SS1 SunScan Canopy Analysis System (Delta-T Devices, Burwell, UK).

The results of the experiment were worked out by the Statistica software package (StatSoft, Poland). The significance of differences between means were assessed using Duncan's multiple range t-test at $p < 0.05$. The standard error of the mean (SE) was calculated and used to indicate error ranges on graphs.

## RESULTS

During the trial (2004–2010) none storm with hail was observed. Hail nets altered light microclimate on the experimental plots. A black net reduced solar irradiation level by 19–22%, a gray net by 16–18%, a white net by 6–8% in comparison to the control plot. The total irradiation intercepted to the tree canopy was then dispersed between shoots and leaves. The measurements within the tree canopy revealed that the upper part (2 m) received approx. 80% of incident sunlight levels, middle part (1.5 m) 70% and the bottom part (0.5 m) only 50% (fig. 1, control trees).

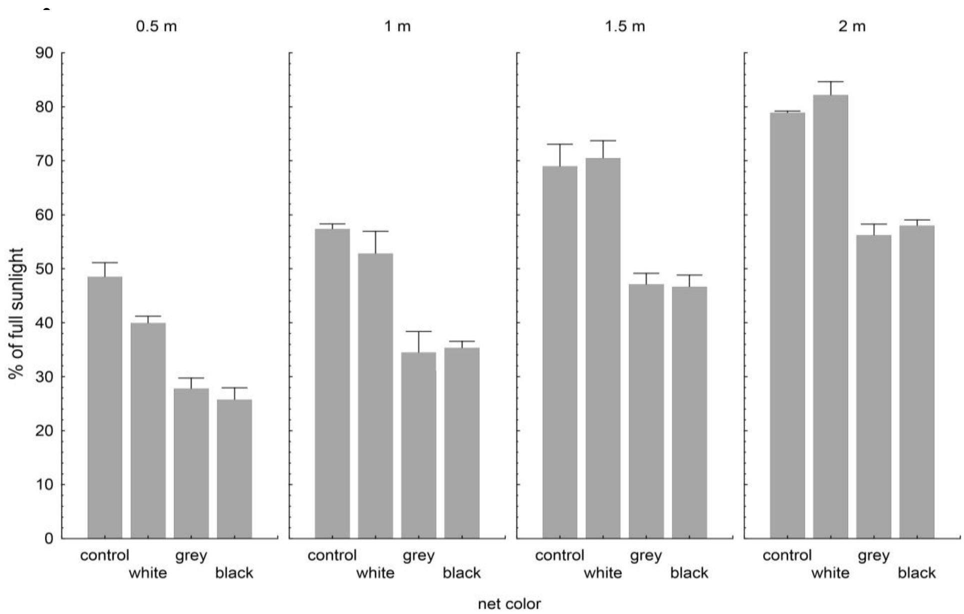


Fig. 1. Distribution of light at different levels within the tree canopy (0.5, 1, 1.5 and 2 m above the ground, vertical bars represent the standard error of the mean)

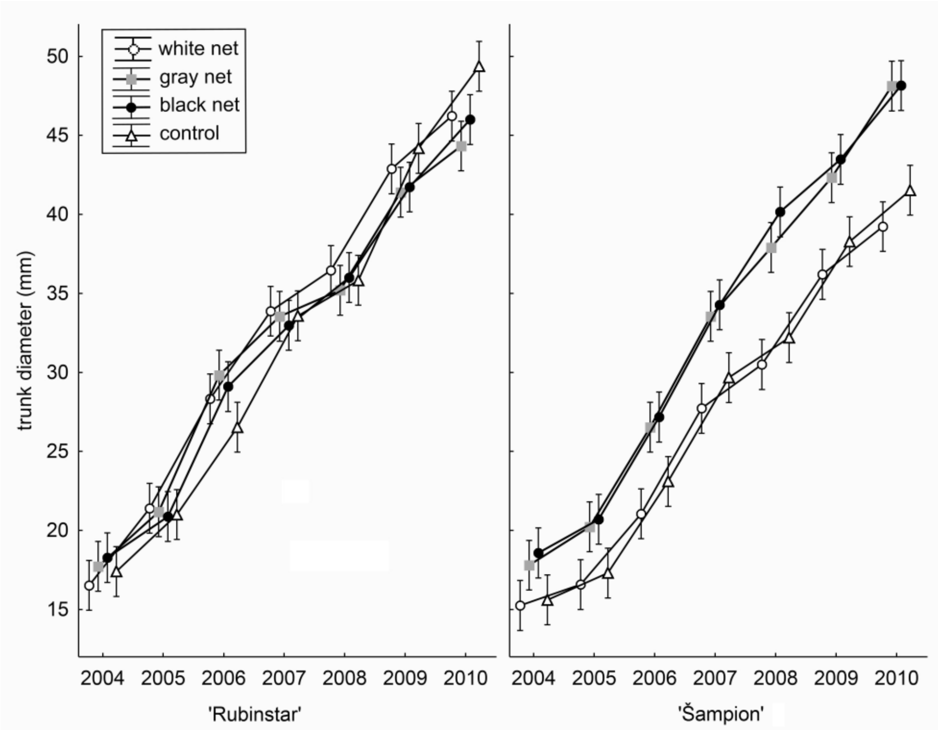


Fig. 2. Trunk diameter of apple trees uncovered and covered with hail nets of different colors (vertical bars represent the standard error of the mean)

Light distribution within 'Šampion' tree canopy was altered with nets. Black and gray nets decreased light intensity in the upper, middle and bottom part of the tree canopy, while for the white net some reduction was noted only in the bottom zone. Generally, the lowest light intensity (below 30% for the dark nets) was observed in the bottom part of the canopy, while in the main fruiting zone (1 m above the ground) solar irradiation under black and gray nets decreased from approx. 60 to 35% (fig. 1).

In years 2004–2010 trunk growth of 'Šampion' trees was higher under gray and black nets, than under white net and the control. In the same years trunk growth of 'Rubinstar' trees was variable. Mostly there was no significant differences between the treatments with the exception of 2010 when trunk diameter was the highest in the control trees (fig. 2).

Gray and black nets significantly increased annual shoot growth of 'Šampion' trees in years 2004–2006.There was no influence of white net when compared to the control. There was no clear effect of nets on shoot growth of 'Rubinstar'. In 2005–2006 gray net increased shoot growth but the differences were seldom proved statistically significant fig. 3).

Number of fruit bud clusters was significantly higher on 'Šampion' trees than on 'Rubinstar' trees. 'Šampion' trees formed significantly more fruit buds under black and gray net than under white net. Opposite results were observed at 'Rubinstar' trees, that set the lowest number fruit buds under black net (tab. 1).

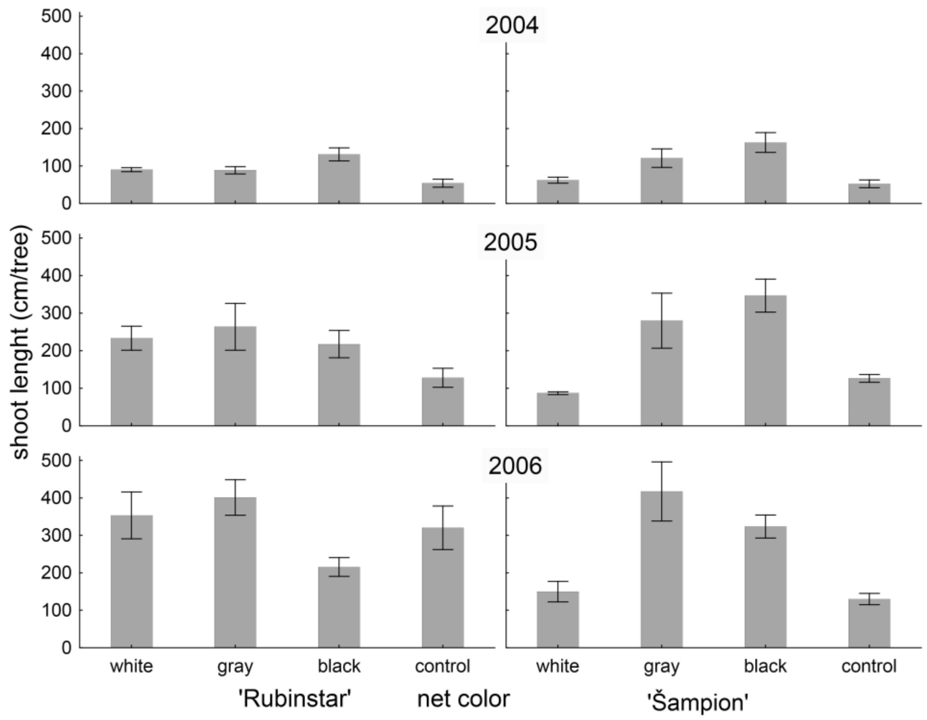


Fig. 3. Total annual shoot length of apple trees uncovered and covered with hail nets of different colors (vertical bars represent the standard error of the mean)

The cumulative yield of 'Šampion' trees was the highest under black and gray nets. In case of 'Rubinstar', higher yield (compared to the control) was obtained from the trees grown under the gray net (tab. 1). The mean fruit mass of 'Šampion' was lower in comparison to 'Rubinstar' fruit. Differences observed between the treatments were minor (tab. 1).

Table 1. Number of fruit bud clusters, cumulative yield and mean fruit mass of apple trees uncovered and covered with nets (values represent the average or total of six seasons 2005–2010)

| Treatment | Fruit bud clusters (pcs/tree) | | Cumulative yield (kg·tree$^{-1}$) | | Mean fruit mass (g) | |
|---|---|---|---|---|---|---|
| | 'Rubinstar' | 'Šampion' | 'Rubinstar' | 'Šampion' | 'Rubinstar' | 'Šampion' |
| White net | 160.4 bc* | 172.4 cd | 84.9 abc | 60.9 a | 194.0 d | 168.1 abc |
| Gray net | 149.3 bc | 210.9 e | 86.8 c | 80.9 bc | 184.8 cd | 160.9 a |
| Black net | 116.2 a | 213.9 e | 77.6 abc | 88.9 c | 181.7 bcd | 165.1 ab |
| Control | 127.8 ab | 197.9 de | 68.7 ab | 68.1 ab | 192.8 d | 171.2 abc |

* – means marked with the same letter do not differ at the significance level of α = 0.05 according to Duncan's test. Statistical analyses were performed separately for each cultivar

The red blush on fruit surface deteriorated with tree age probably due to increasing shading within the tree canopy (fig. 4). In both cultivars red blush was found to be significantly lower under the black and gray netting (compared to the white net and the control, tab. 2).

Large differences in soluble solids content (TSS) of apples were observed between the seasons during the experimental period. Generally dark nets reduced the TSS content in fruits of both cultivars (tab. 2, fig. 5). In most years, netting had no significant effect on fruit firmness (tab. 2).

Table 2. Fruit quality attributes from trees uncovered and covered with nets (values represent the average of six seasons 2005–2010)

| Treatment | Red blush (%) | | Total soluble solids content (%) | | Fruit firmness (N) | |
|---|---|---|---|---|---|---|
| | 'Rubinstar' | 'Šampion' | 'Rubinstar' | 'Šampion' | 'Rubinstar' | 'Šampion' |
| White net | 94.0 b* | 93.1 c | 14.1 ab | 12.9 b | 8.1 ns | 7.4 |
| Gray net | 85.2 a | 85.8 b | 13.6 a | 12.8 ab | 7.9 | 7.3 |
| Black net | 78.7 a | 77.3 a | 13.5 a | 12.4 a | 8.0 | 7.0 |
| Control | 94.8 b | 92.1 c | 14.8 b | 13.2 b | 8.1 | 7.4 |

– means marked with the same letter do not differ at the significance level of α = 0.05 according to Duncan's test. Statistical analyses were performed separately for each cultivar. ns: non-significant

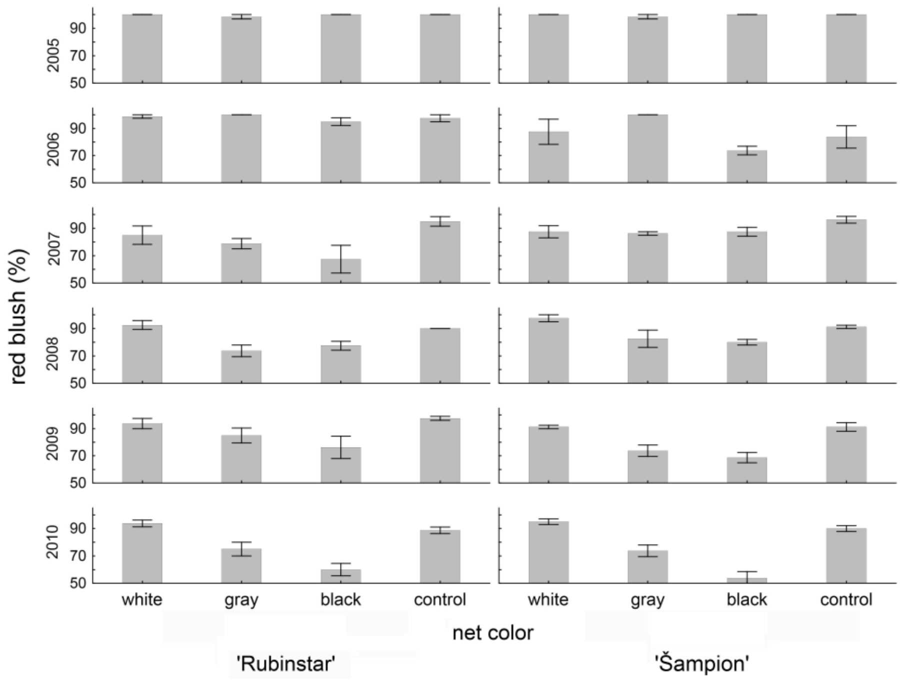


Fig. 4. Percentage of red blush in the skin of apples from trees uncovered and covered with hail nets of different colors (vertical bars represent the standard error of the mean)

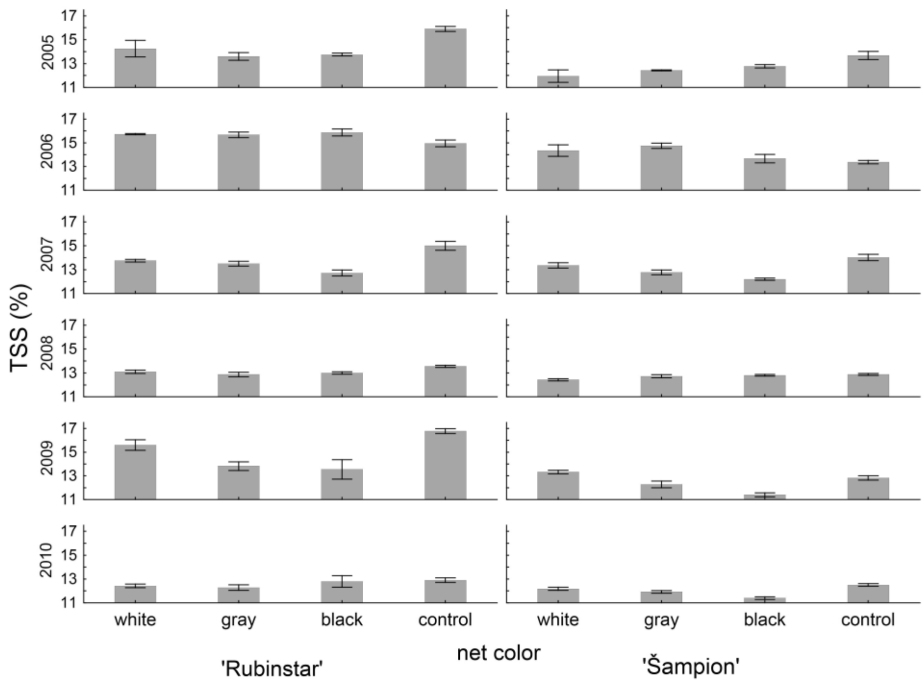


Fig. 5. Soluble solids content of apples from trees uncovered and covered with hail nets of different colors (vertical bars represent the standard error of the mean)

## DISCUSSION

Light interception and distribution in fruit orchards are the keys to high yields and fruit quality. When hail nets are mounted above fruit trees one must expect that orchard light microclimate will be changed. Our measurements showed that nets reduced solar irradiation (by 6–22% depending on the net color) and altered light distribution within apple tree canopy. Deteriorated irradiation above the trees covered with nets may cause depletion of sunshine level in interior part of tree canopies, below critical level of 30% of full sunlight that is required for many life processes [Cain 1971, Flore 1980]. In our earlier experiment [Buler et al. 2009], alterations in photosynthesis of individual leaves under nets was recorded, however, the effect was not consistent between years.

The presented results support earlier findings, that the reaction of cultivars to hail nets can be various [Widmer 2001, Stampar et al. 2001, Funke and Blanke 2003, Gindaba and Wand 2005, Iglesias and Alegre 2006, Amarante et al. 2011]. 'Šampion' cultivar planted in our trial is known as slowly growing, very productive and annual bearing. It produces many short shoots with numerous fruit buds on them. The tree canopy is sparse. At limited irradiation under black and gray nets 'Šampion' trees were growing better, produced larger trees, more shoots and gave higher yield than control trees. The reason of such reaction of this cultivar is unknown. We can only suppose that this is the effect of its physiological particularity. The sparse construction of 'Šampion' tree canopy requires less sunlight than tree of 'Rubinstar' cultivar. Tree of 'Rubinstar' cultivar is a strong growing tree producing many long shoots and forming fruit buds only on short, slowly growing shoots. It requires heavy pruning to keep the tree in size to allocated space. This cultivar is productive but has a tendency to biennial bearing. The characteristic silhouette of 'Rubinstar' tree is irregular position of the most of shoots and massive leaves covering tree. Such a tree requires good exposure to sunlight to support its life processes. When part of incident solar radiation is intercepted by the hail nets stretched above the trees, the light intensity within tree canopy is depressed more than above the trees. Dwarf apple trees trained to spindle system and not covered by nets show usually 70–80% of full sunlight in the top part of the tree canopy, 40–50% in the middle part, and 20–30% in the bottom part compared to that above the trees [Mika et al. 2002, Buler and Mika 2004, Buler and Mika 2009]. When gray or black nets were stretched, the light intensity in the main fruiting zone (1 m above the ground) decreased to approx. 35%, whereas at the basal part of tree canopy dropped even below 30% of full sunlight. At these values apples are not able to develop intensive red color [Mika et al. 2002, Buler and Mika 2004]. Moreover, the red color on apples diminished with years. Other authors reached similar conclusions. Stampar et al. [2001] observed the lower amount of red fruit color on trees covered with a black net than on the ones covered with a white net. Amarante et al. [2011] reported that 'Gala' and 'Fuji' apples from trees protected by the net had a poor skin color (pale blush and a more intense green background color) at harvest.

In our study, reduced light penetration into the tree canopies (caused by dark nets) had adverse effect on soluble dry matter content, while the effect on fruit firmness was minimal. These results contradict those reported by Stampar et al. [2001] who found a higher content of soluble solids in fruits of covered 'Jonagold' and 'Elstar' trees. On the other hand, reduced flesh firmness and soluble solids content at harvest was observed by Amarante et al. [2011] on 'Gala' apple trees covered by white net. This may be considered as a main disadvantage of orchard protection by nets, negatively affecting storage and fruit shelf-life. The reduced storage potential of fruit originated from net covered trees was presented by Amarante et al. [2011].

## CONCLUSIONS

1. Hail nets reduced light penetration into the apple tree canopies. The deterioration of light conditions inside the canopy was higher under dark nets compared to a white one.

2. The influence of net color on tree growth, fruit bud setting and amount of yield differed with cultivar.

3. At limited irradiation under dark nets 'Šampion' trees were more vigorous and produced higher yield than control ones. Response of 'Rubinstar' to net shading was less pronounced.

4. Nets of dark color depressed red fruit blush and soluble dry matter content, while fruit firmness was affected in a minimal degree by shading.

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## WPŁYW SIATEK PRZECIWGRADOWYCH NA MIKROKLIMAT ŚWIETLNY SADU, WZROST DRZEW ORAZ PLONOWANIE I JAKOŚĆ OWOCÓW JABŁONI

**Streszczenie.** W niektórych regionach sadowniczych siatki przeciwgradowe są niezbędną ochroną dla rozwijających się owoców. Badania naukowe wykazały, że kolor siatek przeciwgradowych może wpływać na wzrost drzew i ich owocowanie. W latach 2004–2010 badano wpływ siatek przeciwgradowych na mikroklimat świetlny sadu, wzrost, kwitnienie, owocowanie oraz jakość owoców jabłoni. Wiosną 2004 r. posadzono dwie odmiany jabłoni: 'Šampion' i 'Rubinstar' na podkładce M.9. Po posadzeniu drzew połowę poletka doświadczalnego przykryto siatkami przeciwgradowymi w trzech kolorach: białym, szarym i czarnym. Druga połowa poletka traktowana była jako kontrola. Wykonano pomiar nasłonecznienia nad siatkami i pod siatkami oraz wewnątrz koron drzew. Czarne i szare siatki poprawiały wzrost i plonowanie drzew odmiany 'Šampion', ale nie wpływały dodatnio na drzewa odmiany 'Rubinstar'. Drzewa obu odmian rosnące pod szarą i czarną siatką miały słabiej wybarwione owoce, które zawierały mniej cukru. Jędrność owoców nie zależała od rodzaju siatki.

**Słowa kluczowe:** jędrność owoców, zawartość cukru, uszkodzenia gradowe, siła wzrostu drzew

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