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The impact of location, row direction, plant density and rootstock on the sunburn damage of apple cultivars

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Summary: The effect of row direction (N-S, E-W), plant density (conventional and intensive) and rootstock (M9, MM106 and crab apple) on the sensitivity of 41 apple cultivars to sunburn injury was studied at 6 locations (Derecske, Kálmánháza, Nagykutas, Nagylapos, Siófok, Tornyospálca).

During the observations the cultivars had rootstock-specific properties in respect of sunburn-susceptibility. Accordingly, the injury was decreased in the order: M9, MM106 and seedling rootstocks. The differences in sensitivity depend on the canopy of trees, caused finally by the growing vigour of rootstocks. Accordingly, the highest value of sunburn injury was observed on M9 rootstock, because this rootstock has a dwarfing effect upon the scion cultivars. Thus, vegetative area of these trees grow very slowly and the foliage is not enough compact to protect the fruit from solar radiation. The size and density of the foliage increased in the order: M9, MM106 and crab apple seedling as rootstock. Moreover, relationships were demonstrated between the diameter of upper part of the crown, the leaf area, the number of fruits per tree and the injury of sunburn.

Authors categorized the cultivars in respect of values of sunburn incidence: I. „Not sensitive", II. „Moderately sensitive" and III. „Strongly sensitive" categories were constituted. Generally, Topaz and Gala cultivars showed low damage (or were free from symptoms), in contrast to this, Golden mutants suffered relatively much. The most sensitive cultivar was Jonica on all the three rootstocks. We searched for relationship between the fruit quality parameters and the frequency of sunburn. Significant correlation was found in the cases of fruit size and the extent of cover-colour. The latter is interpreted with the fact that the best coloured fruits are found on the periphery of crown as a consequence of more intense irradiation.

Key words: sunburn injury, apple, location, row direction, plant density, rootstock

Introduction

The symptoms of drought are manifested mostly in the quality of fruit, particularly on apples. The most characteristic is sunburn of fruits (*Gonda*, 1998; *Soltész* et al., 2004). This is a superficial injury caused by solar radiation manifested in the initial phase in a light corky layer, golden or bronze discolouration. It is a consequence of necrosis in epidermal cells on the surface exposed to radiation. The symptoms are generally found on the sunny side of the fruit (*Wünsche* et al., 2000; *Racskó* et al., 2005). According to the definition of *Retig & Kedar* (1967) "sunscald" is the physiological injury of the fruit that affects its quality significantly. As market requirements for enhanced colour increase, sunburn is likely to become more prevalent as growers carry out tree management practices designed to obtain better fruit colour (*Soltész* et al., 2004). Meteorological elements, the physiological condition of the plant, its variety all may contribute to the formation of the injury (*Arndt*, 1992). The change mainly occurs in the surface layers or at least close to the surface. Later, plant pathogens such as *Alternaria tenuis, Physalospora obstusa, Monilia fruticola, Monilia laxa, Monilia fructigena, Glomerella cingulata, Venturia inaequalis* can infect the apple fruit through the injured epidermal tissue making the fruit unmarketable (*Gurnsey & Lawes*, 1999, *Holb*, 2002; *Leeuwen* et al., 2000, 2002). Therefore this phenomenon means serious economic loss in apple plantations (*Brooks & Fisher*, 1926; *Ware*, 1932; *Meyer*, 1932; *Whittaker & McDonald*, 1941; *Moore & Rogers*, 1942; *Barber & Sharpe*, 1971; *Bergh* et al., 1980; *Simpson* et al., 1988; *Warner*, 1997; *Schrader* et al., 2001).

Barber & Sharpe (1971) studied the injuries on pepper and pumpkin fruits and separated three sunscald types: heat injury sunscald -HIS, ultra-violet radiation sunscald -UVS and photo-dinamic sunscald of heated tissues -PSHT. Besides the above mentioned grouping, American apple growers divide the phenomenon called sunscald into three groups. They distinguish "sunburn", "sunscald" and "delayed sunscald". Previously, *Walker* (1952, 1957) used the phrase of "sunscald" for all injuries caused by solar radiation. On the basis of the triggering reasons *Schrader* et al. (2001) determined two main types of "sunburn" injuries. The so-called "sunburn necrosis" is caused by the effect of heat and necrosis of the epidermal and sub-epidermal cells ensues. This phenomenon causes spottiness on the sunlit side of the apple fruit. The second type is called "sunburn browning" and causes yellowish or brownish patches on the sun exposed side of the apple fruit (*Piskolczi* et al., 2004). *Schrader* et al. (2001) also determined the physiological reasons of the two phenomena. Sunburn necrosis already happens when the overheating of the surface of the fruit reaches 52±1°C, meanwhile, the permeability of cell

membranes are injured. Sunburn browning forms at 46–49°C surface temperature, but sunlight has a decisive role in its formation as well. In this case the membranes of the surface cells of the apple fruit are injured at a lower extent (*Schrader* et al. 2001, 2003).

The phrases of "sunburn" and "sunscald" are often mixed in the common practice (*Piskolczi,* 2003).

The American Phytopathological Society defines sunburn as a fruit injury caused by solar radiation, while sunscald as an injury occurs on the surface or in sub-surface layers caused by freeze (*Jones & Aldwinckle*, 1990).

Due to the injury the amount and quality of yield decrease significantly many times (*Gonda,* 1998, 2002). According to *Arndt* (1992) in case of the Jonagold variety it may cause a 50% loss in yield, but this variety is sensitive to sunburn. Even in the beginning of ripening on the surface of the fruit discolorations caused by solar radiation or surface scars may appear, which influence the further colouration as well as taste, then marketability and storability of the fruit (*Piskolczi,* 2003; *Racskó,* 2001; *Racskó,* et al., 2003). *Gurnsey & Lawes* (1999) stated that under American market conditions the excellently coloured apple is worth even 3–4 dollars more per case. *Schrader* et al. (2001) report on several million dollar loss in the American apple industry. On the other hand, *Gonda* (1998) estimated that the damage does not attain 5% at most unfavourable climatic conditions.

More detailed knowledge of the process of sunburn may contribute to the estimation of the risks caused by climatic factors, depending on variety. In planning of fruit plantations the information obtained may help to decrease farther losses (e.g. direction and distance of rows, irrigation, shaping of the structure of canopy). Applying proper phyto-technical methods, the frequency of the occurrence of sunburn may decrease in apple plantations (*Meheriuk* et al., 1994).

Material and method

The experiments were carried out at several locations of Hungary in conventional and intensive apple orchards. The location and the characteristics of the orchards are presented in *Figure 1* and *Table 1*.

Table 1. The characteristics of the experimental orchards

Location	Cultivars	Number of cvs.	Rootstock	Plant density	Row direction	Year of plantation
Derecske	Braeburn Schneider, Elstar, Gala Must, Golden Reinders, Granny Smith, Idared, Jonagold, Mutsu, Pinova, Snygold (Earligold), Summerred, Topaz	12	M9	3.8×0.8	N-S	1998.
Kálmánháza	Elstar, Gala Must, Gala Royal, Gloster, Golden Reinders, Granny Smith, Idared, Jonagold, Jonagored, Jonathan Csány 1, Mutsu	11	MM106	4.0×0.9	E-W	1998.
Nagykutas	Arlet, Boskoop, Braeburn Hillwell, Braeburn Schneider, Elstar, Gala Delbard, Gala Imperial, Gala Mundial, Gala Prince, Gala Royal, Galaxy, Gloster, Golden B, Golden FGA, Golden Reinders, Golden Rust, Granny Smith, Green Sliws, Idared, Jonagored, Jonica, Mollie's Delicious, Novayo, Pink Lady, Prima, Red Elstar, Rubinette, Smoothee, Snygold (Earligold), Summerred, Šampion, Topaz, Vista Bella	33	M9	3.2×0.54	N-S	1999.
Nagykutas	Arlet, Boskoop, Braeburn Hillwell, Braeburn Schneider, Elstar, Gala Delbard, Gala Imperial, Gala Mundial, Gala Prince, Gala Royal, Galaxy, Gloster, Golden B, Golden FGA, Golden Reinders, Golden Rust, Granny Smith, Green Sliws, Idared, Jonagored, Jonica, Mollie's Delicious, Novayo, Pink Lady, Prima, Red Elstar, Rubinette, Smoothee, Snygold (Earligold), Summerred, Šampion, Topaz, Vista Bella	33	MM106	3.2×0.54	N-S	1999.
Nagykutas	Arlet, Boskoop, Braeburn Hillwell, Braeburn Schneider, Elstar, Gala Delbard, Gala Imperial, Gala Mundial, Gala Prince, Gala Royal, Galaxy, Gloster, Golden B, Golden FGA, Golden Reinders, Golden Rust, Granny Smith, Green Sliws, Idared, Jonagored, Jonica, Mollie's Delicious, Novayo, Pink Lady, Prima, Red Elstar, Rubinette, Smoothee, Snygold (Earligold), Summerred, Šampion, Topaz, Vista Bella	33	Crab apple seedlings	3.2×0.54	N-S	1999.
Nagylapos	Gala Must, Gloster, Golden Reinders, Granny Smith, Idared, Jonagold, Mutsu	7	MM106	6.5×4.0	N-S	1998.
Siófok	Braeburn Schneider, Gala Must, Golden Reinders, Idared, Jonagored	5	M9	3.5×0.8	N-S	1999.
Tornyospálca	Gala Must, Gala Royal, Golden Reinders, Granny Smith, Idared, Jonagold, Mutsu, Pinova, Red Rome Van Well, Starking, Summerred, Šampion, Topaz, Watson Jonathan	14	MM106	6.0×4.0	N-S	1996.
Tornyospálca	Gala Must, Golden Reinders, Granny Smith, Idared, Jonagold, Red Rome Van Well, Starking, Summerred, Šampion, Topaz	10	MM106	6.0×4.0	E-W	1996.

Figure 1. The locations of the experimental orchards

Table 2. The ecological parameters of orchards relevant to the sunburn damage for the growing season of 2004 (between 1 April and 31 October)

Location	Global radiation ($MJ \times m^{-2}$)	Sunny hours (h)	Degree of cloudiness (%)	Number of hot days per year (day)	Relative humidity (%)
Derecske	3620	1490	52	21	68
Kálmánháza	3480	1350	54	18	69
Nagykutas	3650	1300	55	17	68
Nagylapos	3500	1340	54	18	67
Siófok	3750	1350	50	20	71
Tornyospálca	3410	1300	56	17	67

The different sites have different ecological characteristics, which have a considerable, sometimes decisive role in the damaging process at several cultivars. The characteristic climatic figures are shown in *Table 2*. It has to be mentioned that in the majority of the experimental orchards (Derecske, Kálmánháza, Nagylapos, Siófok, Tornyospálca), the weather is continuously sunny, the sudden changes in sunshine are rare. On the contrary, peculiarities of the orchard at Nagykutas are the frequency of cloudiness and the relatively high sum of global radiation in the growing season (between 1 April and 31 October): 3650 $MJ \times m^{-2}$. This should be taken into consideration, since the high damage is primarily due to the fact that the sudden sunshine dosage resulting from the frequent cloudy periods means a significant stress for the plants.

In the experiments, 41 apple cultivars and the indirect effect of three rootstock types on the degree of sunburn damage were studied. Depending on the location, the size of trees grafted on M9 dwarf rootstock is 20–30% of that of trees grafted on crab apple. The fruits have a good colouration due to the small size of the canopy, however, they receive strong radiation. This is the most important type of rootstock of the intensive, high-density orchards. The growth rate of MM106 is between the semi-dwarf and medium, grafted with cultivars of strong and very strong growth it gives medium-size trees on good soils. It has a 50–60% higher area requirement compared with M9. Consequently, the vegetative surface, the canopy of significant size, protects the fruits from the harmful effects of sunshine. The trees grafted on crab apple seedlings grow vigorously, their canopies develop large shading surface, but the quality of fruit is the least favourable on this rootstock.

In the experiments, conventional cultivation and integrated plant protection were applied. The trees were trained to a spindle shape. The space between the rows was covered with grass and the swath was left on the spot under the trees to preserve moisture and to prevent the growth of weeds. Irrigation was not applied in any of the orchards. The assessments were made in 2004 at different times for the different cultivars after the biological ripening of fruits.

Examination methods

Assessments and measurements were made on 20 trees/combination, in total on 4960 trees. Mean dates are included in the tables. The trees were assigned at the beginning of the experiments in 4 blocks per cultivar and 5 trees per block were examined. In the fruit assessments, 10 fruits/tree, in total 200 fruits were examined.

In the assessments, the following traits were measured or calculated:

(1) Diameter of the sunburn spot (sd): it has been determined for combinations by using a vernier calliper. When the shape of the sunburn spot was not circular but elliptical,

Table 3. Dates of assessing sunburn symptoms in 2004 for the different cultivars

23–30. July	5–12. August	11–18. September	23–30. September	10–17. October	24–31. October
Vista Bella	Snygold (Earligold)	Arlet Elstar Gala Delbard Gala Imperial Gala Mundial Gala Must Gala Prince Gala Royal Galaxy Jonathan Csány 1 Mollie's Delicious Prima Red Elstar Summerred Šampion Watson Jonathan	Gloster Green Sliws Idared Novayo Rubinette Smoothee Starking	Golden B Golden FGA Golden Reinders Golden Rust Jonagold Jonagored Jonica Mutsu Pinova Red Rome Van Well Topaz	Boskoop Braeburn Hillwell Braeburn Schneider Granny Smith Pink Lady

the diameter of the spot was calculated as the average of the longest and shortest diameters. The boundary of the spot was indicated by a different shade from that of the cover colour. Its value was determined with 0.1 mm precision.

(2) *Incidence of sunburn injury (si):* the number of fruits with sunburn injury expressed as a percentage of all the fruits examined, calculated per combination. For determining the incidence of sunburn injury, we adapted the method of *Holb* et al. (2003) developed for apple scab

(3) *Severity of sunburn injury (ss):* the size of the surface of sunscald expressed as a percentage of the total fruit surface for each fruit. For determining the sunscald area, we adapted the method of *Holb* et al. (2003) developed for apple scab by using the following measures a) the diameter of the sunscald spots and b) the largest diameter of the fruit. It was calculated as follows:

$$ss = [\pi (sd/2)^2] / [4 \pi (fd/2)^2] * 100$$

ss= severity of sunburn injury (it was assumed that each fruit is spherical and each spot is circular and so the area of the sunscald spot is = $\pi (sd/2)^2$ and the surface of the fruit is = $4 \pi (fd/2)^2$

sd= diameter of the sunscald spot [mm]

fd= the largest diameter of the fruit [mm]

(4) *Intensity of sunburn injury (is):* It was determined by visual observation, where the size of the sunburn injury compared to the size of the fruit, the difference in colour intensity from the cover colour and the depth of the damage were considered. The assessments were made visually on a scale from 1 to 10, the smaller values representing lower damage, small damaged surface and shallow symptoms with subtle differences in colour intensity.

Results and discussion

The effect of location on the sunburn injury of apple cultivars

In the experiment, there were great differences between the apple cultivars as regards sunburn injury. The sensitivity was different at the different locations.

In the eastern region of Hungary at Derecske, cvs. Braeburn Schneider, Gala Must, Snygold and Topaz showed no symptoms on M9 rootstock, while the highest damage incidence was detected on cvs. Idared (4.4%), Elstar (5.2%) and Golden Reinders (7.2%) (*Table 5*). There was no relationship between incidence and other parameters (severity, diameter of the sunscald spot, intensity), though cultivars with high damage incidence often had high severity values (r=0.68). Accordingly, the severity of injury was high for Jonagold (23.8%), while the incidence was low (1.7%). Compared to the fruit surface, Idared and Golden Reinders also showed a relatively high severity value 22.1% and 24.5%, respectively.

Table 5. Sunburn injury on apple cultivars grafted on M9 rootstock (Derecske, 2004)

Cultivar	si(%)	ss (%)	sd (mm)	is
Braeburn Schneider	0.0 h	0.0 d	0.0 e	0.0 f
Elstar	5.2 b	20.1 ab	33.4 b	5.1 b
Gala Must	0.0 h	0.0 d	0.0 e	0.0 f
Golden Reinders	7.2 a	24.5 a	37.9 ab	3.7 cd
Granny Smith	1.8 d	16.5 bc	21.5 d	2.5 e
Idared	4.4 bc	22.1 a	40.2 a	5.5 a
Jonagold	1.7 d	23.8 a	35.2 b	4.2 c
Mutsu	0.1 g	17.0 bc	31.9 c	3.8 cd
Pinova	1.4 de	19.6 b	29.7 c	4.0 c
Snygold	0.0 h	0.0 d	0.0 e	0.0 f
Summerred	1.1 ef	20.7 ab	36.4 ab	3.8 cd
Topaz	0.0 h	0.0 d	0.0 e	0.0 f
LSD (P=0.05)	**0.94**	**2.11**	**2.25**	**0.86**

The significance level was examined between cultivars (within columns). The different letters indicate significant difference at P=0.05

This tendency is also valid for the size of the sunburn spot, since there is a stromg correlation (r=0.99) between severity and the diameter of the spot.

Furthermore, a strong correlation between severity and intensity of sunburn injury (r=0.95) was also revealed, though the strongest symptoms were detected on cvs. Elstar (5.2) and Idared (5.5). It should be mentioned that the symptoms were the weakest at this location and that we have found light, whitish and shallow spots on the fruits of some cultivars *(Figure 2)*.

Figure 2. Typical symptoms of sunburn injury in the orchard at Derecske (Golden Reinders/M9)

The other orchard in the eastern part of Hungary is at Kálmánháza, where a relatively low damage was detected on MM106 rootstock (*Table 6*). Cultivars Gala Must, Jonathan Csány 1 and Mutsu showed no symptoms, while the incidence of cvs. Gala Royal, Jonagold, Jonagored and Gloster were below 1%. Fruit damage was the highest on cvs. Golden Reinders (2.1%), Granny Smith (2.3%) and Idared (2.5%). The correlation between damage incidence and severity was similar to that of Derecske (r=0.67). The ratio of sunscalds was the highest on fruits of cvs. Jonagold (20.4%) and Idared (21.6%). The tendency was similar for

the diameter of the sunscald spots, though the largest spot (due to the large-size fruits) was detected on cv. Gloster (31.2 mm). The intensity of sunburn damage strongly correlated with its severity (r=0.97).

Table 6. Sunburn damage on apple cultivars grafted on MM106 rootstock (Kálmánháza, 2004)

Cultivar	si(%)	ss (%)	sd (mm)	is
Elstar	1.1 c	18.6 b	18.4 de	5.9 c
Gala Must	0.0 f	0.0 d	0.0 f	0.0 e
Gala Royal	0.2 e	17.8 bc	18.6 de	5.7 c
Gloster	0.9 cd	19.9 ab	31.2 a	5.0 cd
Golden Reinders	2.1 ab	19.5 ab	21.3 c	6.9 b
Granny Smith	2.3 a	18.6 b	20.5 cd	6.6 bc
Idared	2.5 a	21.6 a	30.4 ab	7.3 a
Jonagold	0.5 d	20.4 a	24.1 b	7.5 a
Jonagored	0.6 d	17.4 c	19.7 d	6.4 bc
Jonathan Csány 1	0.0 f	0.0 d	0.0 f	0.0 e
Mutsu	0.0 f	0.0 d	0.0 f	0.0 e
LSD (P=0.05)	**0.71**	**1.92**	**1.66**	**0.91**

The significance level was examined between cultivars (within columns). The different letters indicate significant difference at P=0.05

Table 7. Sunburn damage on apple cultivars grafted on M9 rootstock (Nagykutas, 2004)

Cultivar	si(%)	ss (%)	sd (mm)	is
Arlet	1.2 h	12.2 i	23.8 i	4.0 f
Boskoop	1.6 g	29.3 b	39.6 c	7.4 cd
Braeburn Hillwell	0.0 j	0.0 j	0.0 j	0.0 g
Braeburn Schneider	0.0 j	0.0 j	0.0 j	0.0 g
Elstar	6.6 cd	20.9 g	32.6 ef	6.2 e
Gala Delbard	1.8 g	27.0 c	28.0 h	8.2 bc
Gala Imperial	0.0 j	0.0 j	0.0 j	0.0 g
Gala Mundial	0.0 j	0.0 j	0.0 j	0.0 g
Gala Prince	1.5 gh	20.6 g	31.2 ef	7.1 d
Gala Royal	0.0 j	0.0 j	0.0 j	0.0 g
Galaxy	2.6 f	21.9 fg	31.0 ef	6.4 e
Gloster	3.1 e	29.2 b	40.5 c	9.8 a
Golden B	7.1 c	21.7 fg	34.7 de	8.2 bc
Golden FGA	3.2 e	18.1 h	33.5 e	7.4 cd
Golden Reinders	11.0 b	22.4 f	36.4 d	8.6 b
Golden Rust	0.0 j	0.0 j	0.0 j	0.0 g
Granny Smith	3.3 e	20.8 g	31.4 ef	8.2 bc
Green Sliws	0.0 j	0.0 j	0.0 j	0.0 g
Idared	0.0 j	0.0 j	0.0 j	0.0 g
Jonagored	2.4 f	26.3 cd	45.3 b	7.1 d
Jonica	2.4 f	29.0 b	52.1 a	8.2 bc
Mollie's Delicious	0.0 j	0.0 j	0.0 j	0.0 g
Novayo	21.8 a	25.6 d	34.4 de	8.3 b
Pink Lady	0.0 j	0.0 j	0.0 j	0.0 g
Prima	0.0 j	0.0 j	0.0 j	0.0 g
Red Elstar	0.6 i	19.9 gh	32.4 ef	7.4 cd
Rubinette	0.8 hi	20.5 g	35.8 d	7.1 d
Smoothee	5.3 d	37.1 a	38.4 cd	7.9 c
Snygold (Earligold)	2.0 fg	24.6 de	37.4 cd	7.5 cd
Summerred	2.5 f	20.3 g	29.6 g	7.0 d
Šampion	1.2 h	24.1 e	33.1 e	6.9 d
Topaz	0.0 j	0.0 j	0.0 j	0.0 g
Vista Bella	0.0 j	0.0 j	0.0 j	0.0 g
LSD (P=0.05)	**1.14**	**2.53**	**1.77**	**0.69**

The significance level was examined between cultivars (within columns). The different letters indicate significant difference at P=0.05

In the Transdanubian region, the damage was high, especially in the case of M9 rootstock (Tables 7–9). Extremely high incidence values were detected on cvs. Novayo (21.8%) and Golden Reinders (11.0%). No symptoms were observed on the Braeburn-type cultivars (Hillwell, Schneider), some Gala-type cultivars (Imperial, Mundial, Royal), Green Sliws, Mollie's Delicious, Pink Lady and surprisingly on Golden Rust and Idared that are described by the literature as sensitive cultivars.

These cultivars were not damaged even in such rootstock/cultivar combinations (MM106, crab apple) which develop a more dense canopy and are of bigger size. Damage at the orchard at Nagykutas will be discussed later under the title "the effect of the rootstock". Here, we only mention that only those cultivars were damaged on MM106 and crab apple rootstocks that were damaged also on M9 rootstock, therefore, a cultivar response was identified. Otherwise, other cultivars would also have been damaged on these rootsocks though to a lower extent.

Table 8. Sunburn damage on apple cultivars grafted on MM106 rootstock (Nagykutas, 2004)

Cultivar	si(%)	ss (%)	sd (mm)	is
Arlet	0.0 j	0.0 i	0.0 i	0.0 h
Boskoop	0.3 h	24.7 cd	37.3 b	5.2 f
Braeburn Hillwell	0.0 j	0.0 i	0.0 i	0.0 h
Braeburn Schneider	0.0 j	0.0 i	0.0 i	0.0 h
Elstar	0.0 j	0.0 i	0.0 i	0.0 h
Gala Delbard	0.1 i	13.9 h	25.5 g	7.8 bc
Gala Imperial	0.0 j	0.0 i	0.0 i	0.0 h
Gala Mundial	0.0 j	0.0 i	0.0 i	0.0 h
Gala Prince	0.5 gh	19.4 f	30.1 e	5.1 fg
Gala Royal	0.0 j	0.0 i	0.0 i	0.0 h
Galaxy	0.7 g	21.7 e	30.5 e	6.2 e
Gloster	1.8 e	24.6 cd	34.6 c	6.2 e
Golden B	5.8 ab	28.3 b	30.5 e	8.0 b
Golden FGA	0.7 g	30.1 a	30.8 e	7.1 cd
Golden Reinders	3.6 d	26.8 bc	32.7 d	8.7 a
Golden Rust	0.0 j	0.0 i	0.0 i	0.0 h
Granny Smith	6.0 a	18.5 g	27.4 fg	8.7 a
Green Sliws	0.0 j	0.0 i	0.0 i	0.0 h
Idared	0.0 j	0.0 i	0.0 i	0.0 h
Jonagored	0.0 j	0.0 i	0.0 i	0.0 h
Jonica	4.5 c	23.9 d	45.9 a	5.4 f
Mollie's Delicious	0.0 j	0.0 i	0.0 i	0.0 h
Novayo	1.8 e	25.6 c	31.3 de	8.0 b
Pink Lady	0.0 j	0.0 i	0.0 i	0.0 h
Prima	0.0 j	0.0 i	0.0 i	0.0 h
Red Elstar	0.0 j	0.0 i	0.0 i	0.0 h
Rubinette	0.0 j	0.0 i	0.0 i	0.0 h
Smoothee	0.4 gh	21.4 e	19.5 h	7.4 c
Snygold (Earligold)	0.4 gh	20.2 ef	33.6 cd	7.3 c
Summerred	1.3 f	20.1 ef	0.0 i	6.3 de
Šampion	0.2 ih	19.4 f	28.5 f	6.7 d
Topaz	0.0 j	0.0 i	0.0 i	0.0 h
Vista Bella	0.0 j	0.0 i	0.0 i	0.0 h
LSD (P=0.05)	**0.55**	**1.99**	**1.84**	**0.71**

The significance level was examined between cultivars (within columns). The different letters indicate significant difference at P=0.05

Table 9. Sunburn damage on apple cultivars grafted on crab apple seedling (Nagykutas, 2004)

Cultivar	si (%)	ss (%)	sd (mm)	is
Arlet	0.0 d	0.0 d	0.0 f	0.0 e
Boskoop	0.0 d	0.0 d	0.0 f	0.0 e
Braeburn Hillwell	0.0 d	0.0 d	0.0 f	0.0 e
Braeburn Schneider	0.0 d	0.0 d	0.0 f	0.0 e
Elstar	0.0 d	0.0 d	0.0 f	0.0 e
Gala del Bar	0.0 d	0.0 d	0.0 f	0.0 e
Gala Imperial	0.0 d	0.0 d	0.0 f	0.0 e
Gala Mundiál	0.0 d	0.0 d	0.0 f	0.0 e
Gala Prince	0.0 d	0.0 d	0.0 f	0.0 e
Gala Royal	0.0 d	0.0 d	0.0 f	0.0 e
Galaxy	0.0 d	0.0 d	0.0 f	0.0 e
Gloster	0.0 d	0.0 d	0.0 f	0.0 e
Golden B	1.1 b	18.8 b	19.1 b	7.0 a
Golden FGA	0.0 d	0.0 d	0.0 f	0.0 e
Golden Reinders	0.2 c	19.3 ab	15.4 d	4.5 cd
Golden Rust	0.0 d	0.0 d	0.0 f	0.0 e
Granny Smith	0.0 d	0.0 d	0.0 f	0.0 e
Green Sliws	0.0 d	0.0 d	0.0 f	0.0 e
Idared	0.0 d	0.0 d	0.0 f	0.0 e
Jonagored	0.0 d	0.0 d	0.0 f	0.0 e
Jonica	3.2 a	19.8 a	14.8 de	5.0 c
Mollie's Delicious	0.0 d	0.0 d	0.0 f	0.0 e
Novayo	1.1 b	19.1 ab	27.8 a	7.0 a
Pink Lady	0.0 d	0.0 d	0.0 f	0.0 e
Prima	0.0 d	0.0 d	0.0 f	0.0 e
Roth Elstar	0.0 d	0.0 d	0.0 f	0.0 e
Rubinette	0.0 d	0.0 d	0.0 f	0.0 e
Smoothee	0.0 d	0.0 d	0.0 f	0.0 e
Snygold (Earligold)	0.0 d	0.0 d	0.0 f	0.0 e
Summerred	0.0 d	0.0 d	0.0 f	0.0 e
Šampion	0.1 c	16.5 c	18.6 c	5.6 b
Topaz	0.0 d	0.0 d	0.0 f	0.0 e
Vista Bella	0.0 d	0.0 d	0.0 f	0.0 e
LSD (P=0.05)	**0.47**	**1.19**	**1.52**	**0.63**

The significance level was examined between cultivars (within columns). The different letters indicate significant difference at P=0.05

The orchard at Nagylapos is also situated in the eastern part of Hungary. A relatively high damage was examined at this location *(Table 10)*. Only cv. Gala Must remained symptomless. The highest damage was detected on cv. Idared. The severity and intensity of the damage and the diameter of the sunburn spots were also the highest for this cultivar. The symptoms were very heavy, the registered values were much higher here compared to the orchard at Derecske.

Table 10. Sunburn damage on apple cultivars grafted on MM106 rootstock (Nagylapos, 2004)

Cultivar	si(%)	ss (%)	sd (mm)	is
Gala Must	0.0 f	0.0 e	0.0 e	0.0 d
Gloster	1.6 d	19.6 c	30.2 b	7.8 b
Golden Reinders	4.9 b	24.3 b	33.1 a	8.5 a
Granny Smith	4.8 b	16.5 d	26.6 c	7.9 b
Idared	8.5 a	28.5 a	34.2 a	8.7 a
Jonagold	3.1 c	25.6 ab	24.8 cd	6.7 c
Mutsu	1.2 de	19.4 c	24.1 cd	7.0 bc
LSD (P=0.05)	**0.44**	**1.53**	**1.48**	**0.38**

The significance level was examined between cultivars (within columns). The different letters indicate significant difference at P=0.05

In the western part of Hungary at Siófok, the symptoms were also strong *(Table 11)*. This is probably due to the geographical and meteorological characteristics: global radiation, sunny hours, the number of hot days are high and the degree of cloudiness is low. Even Gala Must, that showed no symptoms at other locations, was damaged here, though the incidence was very low. Cultivar Braeburn Schneider did not show any symptoms. The highest damage incidence was observed on cv. Idared (and Golden Reinders) also at this location.

Table 11. Sunburn damage on apple cultivars grafted on M9 rootstock (Siófok, 2004)

Cultivar	si(%)	ss (%)	sd (mm)	is
Braeburn Schneider	0.0 e	0.0 d	0.0 c	0.0 e
Gala Must	0.4 d	26.7 ab	25.8 ab	6.1 cd
Golden Reinders	12.3 ab	24.1 b	23.4 b	8.9 ab
Idared	13.1 a	28.7 a	28.7 a	9.5 ab
Jonagored	3.7 c	22.8 bc	27.6 a	7.0 c
LSD (P=0.05)	**1.14**	**2.04**	**1.88**	**0.91**

The significance level was examined between cultivars (within columns). The different letters indicate significant difference at P=0.05

In the orchards at Tornyospálca situated in the northeastern part of Hungary, 40% of the studied cultivars were damaged (42.9% and 40.0% besides a row direction of N-S and E-W, respectively) *(Figures 12–13)*. Due to the relatively low global radiation and low number of hot days characteristic to the location, the high degree of cloudiness and the low plant density, a low damage was registered compared to the other orchards. The highest damage incidence was measured on cv. Idared, while damage severity was the highest for cv. Golden Reinders: 24.6%. (This trend was valid for both orchards with different row directions.) Cvs. Gala Must, Gala Royal, Red Rome Van Well, Summerred, Šampion, Topaz and Watson Jonathan showed no symptoms.

Table 12. Sunburn damage on apple cultivars grafted on MM106 rootstock with a N-S row direction (Tornyospálca, 2004)

Cultivar	si (%)	ss (%)	sd (mm)	is
Gala Must	0.0 f	0.0 d	0.0 d	0.0 d
Gala Royal	0.0 f	0.0 d	0.0 d	0.0 d
Golden Reinders	1.9 b	24.6 a	27.3 b	7.5 a
Granny Smith	1.7 bc	22.6 a	19.5 d	7.3 a
Idared	2.3 a	19.6 b	35.1 a	7.2 a
Jonagold	0.9 c	20.7 b	22.1 c	4.2 c
Mutsu	0.0 f	0.0 d	0.0 d	0.0 d
Pinova	0.4 de	18.3 bc	24.5 bc	4.2 c
Red Rome Van Well	0.0 f	0.0 d	0.0 d	0.0 d
Starking	0.8 d	16.4 bc	23.7 bc	5.5 b
Summerred	0.0 f	0.0 d	0.0 d	0.0 d
Šampion	0.0 f	0.0 d	0.0 d	0.0 d
Topaz	0.0 f	0.0 d	0.0 d	0.0 d
Watson Jonathan	0.0 f	0.0 d	0.0 d	0.0 d
LSD (P=0.05)	**0.59**	**2.42**	**1.87**	**0.38**

The significance level was examined between cultivars (within columns). The different letters indicate significant difference at P=0.05

Table 13. Sunburn damage on apple cultivars grafted on MM106 rootstock with a E-W row direction (Tornyospálca, 2004)

Cultivar	si(%)	ss (%)	sd (mm)	is
Gala Must	0.0 e	0.0 d	0.0 d	0.0 d
Golden Reinders	1.0 b	23.1 a	23.0 b	6.9 a
Granny Smith	0.5 c	20.8 ab	18.1 c	2.7 c
Idared	2.0 a	20.6 ab	35.3 a	6.6 a
Jonagold	0.0 e	0.0 d	0.0 d	0.0 d
Red Rome Van Well	0.0 e	0.0 d	0.0 d	0.0 d
Starking	0.1 cd	15.6 c	22.9 b	5.6 b
Summerred	0.0 e	0.0 d	0.0 d	0.0 d
Šampion	0.0 e	0.0 d	0.0 d	0.0 d
Topaz	0.0 e	0.0 d	0.0 d	0.0 d
LSD (P=0.05)	**0.46**	**1.19**	**2.05**	**0.72**

The significance level was examined between cultivars (within columns). The different letters indicate significant difference at P=0.05

The effect of row direction on the sunburn damage of apple cultivars

The effect of row direction could be studied well at Kálmánháza, Nagylapos and Tornyospálca. The former two orchards are within 10 km from each other with very similar ecological conditions and production technology and the same 7 cultivars can be found in both orchards. At Tornyospálca, 10 cultivars could be compared at the same location. Results are presented in Figures 3–4, where the differences between the N-S and the E-W row directions are shown. The results indicate that in most of the cases, damage incidence, severity and intensity and the diameter of the sunburn spot are higher for the N-S row direction. The reason for this is probably that as the Sun moves from the east to the west, the eastern side of the rows receive sunlight in the morning hours, while the western side of the rows receive sunlight in the afternoon. Therefore, damage may appear on both sides of the tree on a large area. If the row direction is E-W, then sunshine reaches only the top of the canopy and only those fruits are damaged.

At Kálmánháza and Nagylapos, cvs. Gloster and Mutsu were damaged where the row direction was N-S, while they did not show symptoms besides E-W row direction *(Figure 3)*. The greatest differences were measured at different cultivars as follows: the decrease in the incidence and severity of damage was the largest for cv. Idared, while the diameter of the sunburn spot and severity reduced with the most in cv. Golden Reinders. A negative difference was measured only for damage severity at cv. Golden Reinders and for the intensity at cv. Granny Smith, i.e. damage was higher for the E-W row direction.

At Tornyospálca, it was only cv. Jonagold that showed symptoms in the N-S row direction, while it was not damaged in the E-W row direction (*Figure 4*). Cvs. Gala Must, Red Rome Van Well, Summerred, Šampion and Topaz showed no symptoms in either N-S or E-W row direction. The greatest differences were shown in incidence, severity and intensity of sunburn damage for cv. Granny Smith and in the diameter of the sunburn spot for cv. Golden Reinders. The damage was larger in the E-W row direction in three cases only: severity and diameter of the sunburn spot for cv. Idared and intensity for cv. Jonagold.

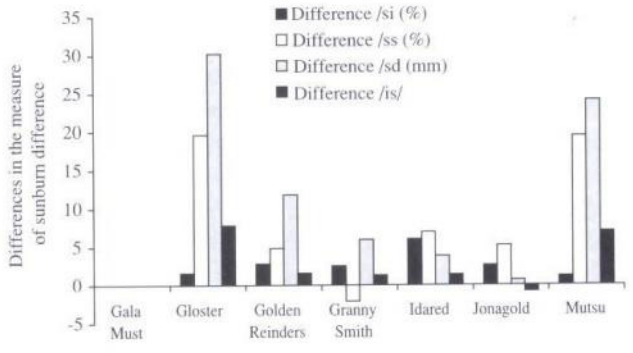


Figure 3. Differences in the measures of sunburn damage (Kálmánháza N-S row direction – Nagylapos E-W row direction)

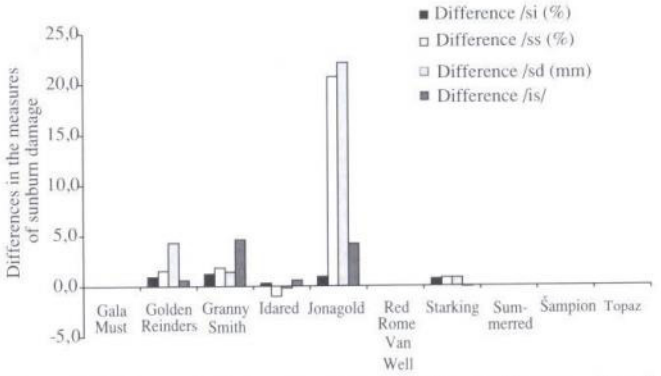


Figure 4. Differences in the measures of sunburn damage (Tornyospálca, N-S row direction -Tornyospálca E-W row direction)

The effect of plant density on the sunburn damage of apple cultivars

For studying the effect of plant density, the data of orchards at Tornyospálca with N-S row direction, conventional management and low density (6.0×4.0 m), at Nagylapos with N-S row direction, intensive management and high density (4.0×0.8 m), at Tornyospálca with E-W row direction, conventional management, low density (6.0×4.0 m) and at Kálmánháza with E-W row direction and high density (4.0×0.9 m) were compared. The results of the comparison are presented in *Figures 5–6*. In this case also, the differences were calculated by subtracting the sunburn measure values of conventional, low-density orchards from those of intensive, high-density orchards. As demonstrated by the figures, in most of the cases N-S row direction brought about higher damage values.

In *Figure 5*, it is shown that cv. Mutsu was damaged in the high-density intensive orchard, while it showed no symptoms in the conventional, low-density orchard. The highest positive differences were observed as follows: the difference in incidence and severity was highest between the high-density and low-density orchards for cv. Idared. The greatest difference in the diameter of the sunburn spot and

the intensity of sunburn damage was registered for cvs. Granny Smith and Jonagold, respectively.

A negative difference was observed in three cases: the severity of sunburn damage was higher for cvs. Golden Reinders and Granny Smith at Tornyospálca than at Nagylapos, while for cv. Idared the diameter of the sunburn spot showed the same tendency.

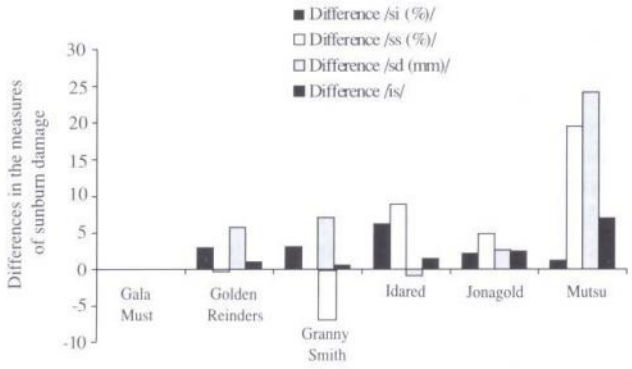


Figure 5. Differences in the measures of sunburn damage (Nagylapos N-S row direction, high density- Tornyospálca, N-S row direction, low density)

As shown in *Figure 6*, cv. Gala Must was damaged in the high-density, intensive orchard, while it showed no symptoms in conventional, low-density orchards. The highest positive differences between high-density and low-density orchards were observed for cv. Granny Smith for incidence. The severity of sunburn damage was higher for cv. Idared in high-density orchards. The difference in the diameter of the sunburn spot and the intensity of symptoms was the greatest for cv. Granny Smith. Negative differences were observed in four cases: for cvs. Golden Reinders and Granny Smith, the severity of sunburn damage was higher at Tornyospálca than at Kálmánháza, while the diameter of the sunburn spot followed the same pattern for cvs. Golden Reinders and Idared.

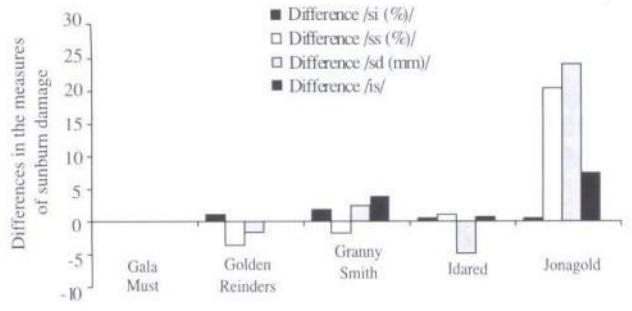


Figure 6. Differences in the measures of sunburn damage (Kálmánháza, E-W row direction, high density – Tornyospálca, E-W row direction, low density)

The effect of rootstock on sunburn damage in apple cultivars

Excellent conditions were provided at Nagykutas for the study of the rootstock effect. During the experiment, a rootstock-specific effect could be observed for the different cultivars. A reduction in the damage could be detected in the following sequence: M9, MM106 and crab apple rootstock (*Figure 7*).

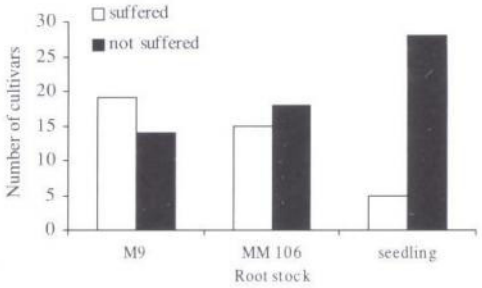


Figure 7. The distribution of the studied 33 apple cultivars according to sunburn injury

The differences in sensitivity are based almost solely on the effect of rootstock influencing the growth and morphology of the tree and the canopy. Consequently, we observed high damage on M9 rootstock, because it has a dwarfing effect, the grafted cultivar has a slow growth rate and the canopy does not become dense enough to protect the fruits from strong sunlight. The size and density of the canopy is greater for MM106 and the highest is for crab apple rootstock. To prove the above statements, we tried to find a correlation between sunburn damage and the canopy density of cultivars/rootstocks. The strongest correlation (-0.71) was found for MM106, while the correlation was -0.68 and -0.37 for M9 and crab apple, respectively. These values demonstrate that canopy density has an effect on sunburn damage, though it is not a primary effect. Tree height and the largest canopy diameter did not have a significant effect on incidence and severity values of sunburn damage.

A stronger correlation with sunburn damage has been found only for the diameter of the upper canopy (*Table 14*).

Table 14. Correlation coefficients between the diameter of the upper canopy and sunburn damage

Correlation coefficients	si	ss	sd	is
on M9 rootstock	-0.81	-0.52	-0.29	-0.55
on MM106 rootstock	-0.76	-0.53	-0.47	-0.49
on seedling rootstock	-0.51	-0.34	-0.21	-0.16

The highest damage was observed on spindle-formed canopies, where the upper canopy consists almost exclusively of the top shoot (only on M9 rootstock e.g. for cvs. Golden Reinders and Novayo), while the cylindrical canopy was less damaged (especially for crab apple rootstock and cvs. Topaz and Pink Lady). In the latter case, the upper canopy is of about the same width and density as the middle or bottom parts. (Of course, it is still in the spindle category). The explanation for this is that sunburn injury occurs only in the upper 1/2–1/3 part of the tree or at the top. Therefore, those cultivars (or rootstocks) that have a thin upper canopy are susceptible to sunburn. Of course, this is just one factor, the sensitivity of fruit surface to sunburn, the

structure of the cuticle, its width etc. are also contributing factors.

A further correlation was revealed between leaf size and sunburn damage (*Table 15*). M9 rootstock has the smallest individual leaf size, while leaf length and width increases in the order of MM106 and crab apple. Though it happens, that in spite of the large individual leaf size, the fruits are not protected completely, because the canopy is thin.

Table 15. Correlation coefficients between individual leaf size and sunburn injury

Correlation coefficients	si	ss	sd	is
on M9 rootstock	-0.46	-0.58	-0.22	-0.37
on MM106 rootstock	-0.62	-0.58	-0.25	-0.44
on seedling rootstock	-0.59	-0.50	-0.31	-0.52

It was found that sunburn damage occurs most frequently on M9 and it decreases in the order of MM106 and crab apple. We have observed that only those cultivars were damaged on MM106 and crab apple rootstocks that were damaged also on M9 rootstock, consequently, it can also be a cultivar effect. Otherwise, other cultivars should have also been damaged on these rootstocks, even if to a smaller extent.

Incidence on M9 is especially high for cvs. Novayo and Golden Reinders (*Table 7*), which indicates that the number of damaged fruits on these cultivars is relatively high. However, this does not necessarily mean that damage is high on the individual fruits. For example, for cv. Boskoop, incidence is low (1.6%), while on individual fruits the damaged surface is 29.3%. The economically significant Gala cultivars had very low incidence values (1.5-1.8%) or showed no symptoms, while Golden cultivars were highly sensitive (3.2-11.0%) except for Golden Rust.

The severity was highest for cv. Smoothee, where 37.1% of the fruit surface was covered by sunburn injury (the highest individual value was 45.3%). Cvs. Boskoop, Gloster and Gala Delbard also showed high values, 29.3%, 29.2% and 27.0%, respectively. The lowest value was measured for cv. Arlet (12.2%).

No lower value was detected, since the sunburn injury could be of such a small extent that it remained latent. A high-intensity damage was detected on cv. Gloster (9.8), where the damaged spot was whitish on the dark purple basic colour. The intensity of damage was also high on for cv. Golden Reinders (8.6%), where the change in the colour was just the opposite, the original yellow colour changed first to white and then to purple. The change of colour was similar at cv. Granny Smith, but here green was the basic colour.

The above statements are related to the number of fruits per tree and the distribution of fruits in the tree. The higher the number of fruits per tree, the higher the damage incidence was at sensitive cultivars. This was the case at cv. Granny Smith, which is sensitive to sunburn damage, but in the experiment the damage incidence was higher in a closed canopy than in a more open canopy. This is because the fruit set of cv. Granny Smith was very low on M9 rootstock (4.6%) compared to that on MM106 rootstock (8.7%) in 2004. Moreover, the fruits were situated in the middle of the canopy and not at the top, so they were protected from strong sunlight.

The lower damage on MM106 rootstock is presented in Table 8. According to the data, the highest damage incidence was only 6.0% (Granny Smith) and many values were below 1%. We have stated previously that only those cultivars were damaged on MM106 that were damaged also on M9. It is important to note that damage incidence was always lower than on M9 rootstock (except for Granny Smith as stated above). The highest reduction was observed on cultivars that did not show any symptoms on MM106. These were the following in decreasing order: Elstar, Jonagored, Arlet, Red Elstar. However, there was not an obvious decrease in the severity of damage compared to M9 rootstock, since there were cultivars the damage severity of which (the size of the damaged spot) decreased (Boskoop, Gala Delbard, Gala Prince, Galaxy, Gloster, Granny Smith, Jonica, Smoothee, Snygold, Summerred and Šampion), did not change (Novayo) and in some cases increased (Golden B, Golden FGA and Golden Reinders).

As regards the intensity of damage, there was a decreasing tendency (except for Golden Reinders and Granny Smith), but the decrease was not too significant. The damaged cultivars showed a similar colour change.

Data on the sunburn damage of cultivars on crab apple rootstock are shown in Table 9. Our data indicate that the rootstock with a strong vegetative production reduced the risk of sunburn damage for each cultivar. We have detected fruit symptoms in only 5 cases, but these values were well below those measured at the two other rootstocks. Cv. Jonica can be mentioned with its high incidence (3.2%). However, the severity of sunburn damage did not show a significant decrease, though it did not exceed 20%. The values indicate that the size of the symptoms did not decrease below a certain level (16.5%). Since a certain potential damaged area is necessary for the appearance of visual symptoms. Accordingly, we have never observed symptoms smaller than 10 mm. The same is valid for the intensity of sunburn damage. Though a decrease was also observed, the intensity of symptoms should have reached a minimum level (4.5) for obvious identification.

The cultivars were grouped into sensitivity categories according to the incidence of sunburn damage. The categories were set up according to the requirements of *Table 16*.

Table 16. Groups of apple cultivars on the basis of sunburn damage incidence

Categories	Incidence of sunburn injury (%)
I. Not sensitive	0.0
II. Moderately sensitive	0.1–2.0
III. Strongly sensitive	2.0<

The results of the grouping are shown in *Table 17*. According to the data, the cultivars on M9 rootstock had the lowest proportion in the "not sensitive" category (*Figure 8*).

This is probably due to the effect of the rootstock to develop a less closed canopy. In the "not sensitive" category, we can find the cultivars of the popular Gala circle (Imperial, Mundial, Royal), Idared or Topaz. Cvs. Šampion, Snygold (Earligold) or Gala Delbard, Gala Prince are of moderate sensitivity. According to our experience, the Gala cultivars and the mutants are generally of low sensitivity or show no symptoms. Among the popular cultivars, Elstar, Gloster, Granny Smith, Jonagored and Golden were greatly sensitive to sunburn damage on M9 rootstock in our experiments.

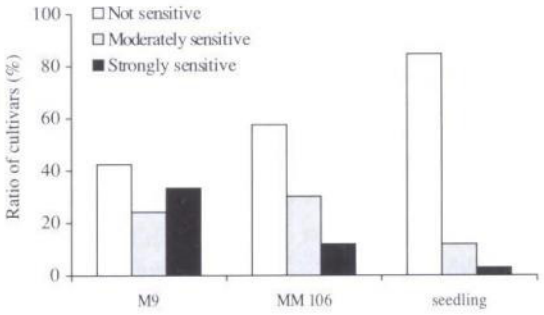
For cultivars on MM106 rootstock, the number of cultivars in the "not sensitive" category increased compared to cultivars on M9 rootstock, cvs. Arlet, Red Elstar and Rubinette from the "moderately sensitive" category and cvs. Elstar and Jonagored from the "sensitive" category were listed in this category. In the moderately sensitive group there was a greater change: from the cultivars that were sensitive on M9, Galaxy, Gloster, Golden FGA, Novayo, Smoothee and Summerred were classified into this group. The number of sensitive cultivars on this rootstock was only 4 (Golden B, Golden Reinders, Granny Smith and Jonica).

Cultivars on crab apple rootstock were of very low sensitivity: 84.8 % of the cultivars belonged to the "not sensitive" category. Only 12.1 % and 3.1 % of the cultivars were moderately sensitive and sensitive, respectively *(Figure 8)*. Only cv. Jonica was sensitive on all three rootstocks.

Table 17. Sensitivity of apple cultivars to sunburn damage on different rootstocks

Categories	Rootstock		
	M9	MM106	seedling
I. Not sensitive	Braeburn Hillwell Braeburn Schneider Gala Imperial Gala Mundial Gala Royal Golden Rust Green Sliws Idared Mollie's Delicious Pink Lady Prima Topaz Vista Bella	Arlet Braeburn Hillwell Braeburn Schneider Elstar Gala Imperial Gala Mundial Gala Royal Golden Rust Green Sliws Idared Jonagored Mollie's Delicious Pink Lady Prima Red Elstar Rubinette Topaz Vista Bella	Arlet Boskoop Braeburn Hillwell Braeburn Schneider Elstar Gala Delbard Gala Imperial Gala Mundial Gala Prince Gala Royal Galaxy Gloster Golden FGA Golden Rust Granny Smith Green Sliws Idared Jonagored Mollie's Delicious Pink Lady Prima Red Elstar Rubinette Smoothee Snygold (Earligold) Summerred Topaz Vista Bella
II. Moderately sensitive	Arlet Boskoop Gala Delbard Gala Prince Red Elstar Rubinette Snygold (Earligold) Šampion	Boskoop Gala Delbard Gala Prince Galaxy Gloster Golden FGA Novayo Smoothee Snygold (Earligold) Summerred Šampion	Golden B Golden Reinders Novayo Šampion
III. Strongly sensitive	Elstar Galaxy Gloster Golden B Golden FGA Golden Reinders Granny Smith Jonagored Jonica Novayo Smoothee Summerred	Golden B Golden Reinders Granny Smith Jonica	Jonica

Figure 8. The distribution of apple cultivars according to their sensitivity to sunburn damage.



We also analysed the relationship between damage incidence and severity and fruit quality parameters. We have studied the relationship between fruit size (weight) and colouration, and the incidence and intensity of sunburn damage. According to our results, the higher the fruit weight is, the higher the probability of sunburn damage is. A significant relationship was found for cvs. Boskoop, Gloster, Golden B, Jonica and Šampion. This relationship seems to be independent from the type of rootstock in most cases, since it was not significant for cv. Boskoop only for MM106 rootstock.

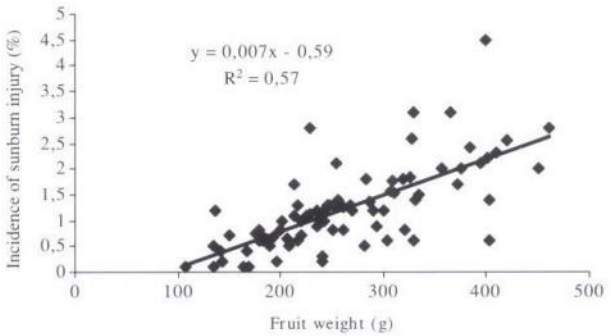


Figure 9. The relationship between fruit weight and sunburn damage incidence on M9 rootstock

The above statement is true in general: on cultivars with smaller fruit size and weight, sunburn damage occurs rarely, that is fruits showing sunburn damage are of bigger size (*Figure 9*).

Besides fruit size, colouration showed a tight correlation with damage incidence as presented in *Figure 10*. According to the figure, the higher the colouration of the fruit is, the higher the probabilty of a sunburn spot is. The reason for this is that the fruits with a high colouration can be found in the outer parts of the canopy, therefore, they receive a high dosage of damaging sunlight. The above statement is cultivar-specific, that is for cv. Šampion, the incidence of a sunburn damage increases only at 50% red colouration, while for cv. Granny Smith (where 5–8% red colouration is considered high), the symptoms appear already at 2–3% colouration.

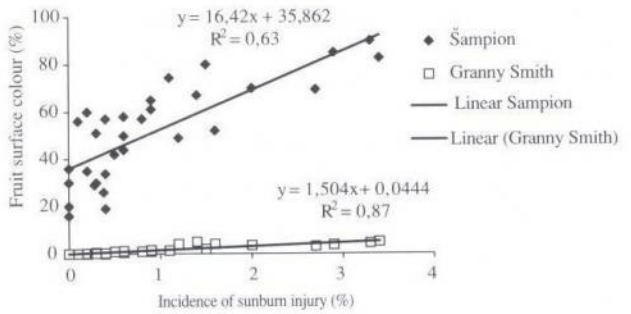


Figure 10. The relationship between colouration and sunburn damage incidence on cvs. Sampion and Granny Smith on M9 rootstock

Sunburn damage of the different cultivars

On the basis of the damage incidence of the different cultivars, a combined table was constructed (considering the complex effect of location, row direction, plant density and rootstock) (*Table 18*). According to the table, cvs. Golden B. Golden Reinders, Granny Smith, Jonica, Novayo, Pinova and Starking are very sensitive to sunburn injury (in black). While cvs. Braeburn Hillwell, Braeburn Schneider, Gala Imperial, Gala Mundial, Golden Rust, Green Sliws, Jonathan Csány 1, Mollie's Delicious, Pink Lady, Prima, Red Rome Van Well, Topaz, Vista Bella and Watson Jonathan showed no symptoms under the experimental conditions. Other examined cultivars were damaged to a smaller or greater extent between these two extremes.

Table 18. Total results of sunburn sensitivity of studied apple cultivars

Cultivar	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*Summary*
Arlet	-	-	●	☺	☺	-	-	-	-	
Boskoop	-	-	●	●	☺	-	-	-	-	
Braeburn Hillwell	-	-	☺	☺	☺	-	-	-	-	
Braeburn Schneider	☺	-	☺	☺	☺	-	☺	-	-	
Elstar	●	●	●	☺	☺	-	-	-	-	
Gala Delbard	-	-	●	●	☺	-	-	-	-	
Gala Imperial	-	-	☺	☺	☺	-	-	-	-	
Gala Mundial	-	-	☺	☺	☺	-	-	-	-	
Gala Must	☺	☺	-	-	-	☺	●	☺	☺	
Gala Prince	-	-	●	●	☺	-	-	-	-	
Gala Royal	-	●	☺	☺	☺	-	-	☺	-	
Galaxy	-	-	●	●	☺	-	-	-	-	
Gloster	-	☺	●	●	☺	●	-	-	-	
Golden B	-	-	●	●	●	-	-	-	-	
Golden FGA	-	-	●	●	☺	-	-	-	-	
Golden Reinders	●	●	●	●	●	●	●	●	●	
Golden Rust	-	-	☺	☺	☺	-	-	-	-	
Granny Smith	●	●	●	●	☺	●	-	●	●	
Green Sliws	-	-	☺	☺	☺	-	-	-	-	
Idared	●	●	☺	☺	☺	●	●	●	●	
Jonagold	●	●	-	-	-	●	-	●	☺	
Jonagored	-	●	●	☺	☺	-	●	-	-	
Jonathan Csány 1	-	☺	-	-	-	-	-	-	-	
Jonica	-	-	●	●	●	-	-	-	-	
Mollie's Delicious	-	-	☺	☺	☺	-	-	-	-	
Mutsu	●	☺	-	-	-	●	-	☺	-	
Novayo	-	-	●	●	●	-	-	-	-	
Pink Lady	-	-	☺	☺	☺	-	-	-	-	
Pinova	●	-	-	-	-	-	-	●	-	
Prima	-	-	☺	☺	☺	-	-	-	-	
Red Elstar	-	-	●	☺	☺	-	-	-	-	
Red Rome Van Well	-	-	-	-	-	-	-	☺	☺	
Rubinette	-	-	●	☺	☺	-	-	-	-	
Smoothee	-	-	●	●	☺	-	-	-	-	
Snygold (Earligold)	☺	-	●	●	☺	-	-	-	-	
Starking	-	-	-	-	-	-	-	●	●	
Summerred	●	-	●	●	☺	-	-	☺	☺	
Sampion	-	-	●	●	●	-	-	☺	☺	
Topaz	☺	-	☺	☺	☺	-	-	☺	☺	
Vista Bella	-	-	☺	☺	☺	-	-	-	-	
Watson Jonathan	-	-	-	-	-	-	-	☺	-	

Note: ☺ = not suffered, ● = suffered; the colour is the darker, the sensitivity is stronger
A= Derecske (intensive, N-S row direction, M9 rootstock); B= Kálmánháza (intensive, E-W row direction, MM106 rootstock); C= Nagykutas (intensive, N-S row direction, M9 rootstock); D= Nagykutas (intensive, N-S row direction, MM106 rootstock); E= Nagykutas (intensive, N-S row direction, seedling rootstock); F= Nagylapos (intensive, N-S, MM106 rootstock); G= Siófok (intensive, N-S row direction, M9 rootstock); H= Tornyospálca (conventional, N-S row direction, MM106 rootstock); I= Tornyospálca (conventional, E-W row direction, MM106 rootstock)

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