African Journal of Biotechnology Vol. 10(41), pp. 7998-8006, 3 August, 2011
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB10.2538
ISSN 1684–5315 © 2011 Academic Journals

Full Length Research Paper

Impact of UV radiation on the physical properties of polypropylene floating row covers

Andrej Demšar[1], Dragan Žnidarčič[2]* and Diana Gregor Svetec[1]

[1]University of Ljubljana, Faculty of Natural Sciences and Engineering, Department of Textiles, Aškerčeva 12, 1000 Ljubljana, Slovenia.
[2]University of Ljubljana, Biotechnical Faculty, Department of Agronomy, Jamnikarjeva 101, 1000 Ljubljana, Slovenia.

Accepted 8 April, 2011

In the intensive horticulture, various ways of protected area are used for the growth of seedlings and the cultivation of vegetables in all seasons. The easiest and the cheapest form of protected area is agrotextile, which can be laid directly over vegetable crops (row cover). Agrotextiles are nonwovens which are manufactured from textile fibres which are usually of chemical origin. Textiles, used as agrotextiles require suitable tensile strength and good permeability characteristics with no significant deterioration under the influence of weather changes and UV radiation. Properties of agrotextiles depend on the fibres made of and on the type and conditions of production. The purpose of this study was to analyse the influence of simulated sun light radiation (xenon lamp) on physical properties of polypropylene (PP) nonwoven material, which is used for the production of agrotextiles. The research showed that the properties of row cover change when radiated with UV light. Tensile, tearing and bursting properties worsen after radiation and air permeability and water vapour show little increase. The changes in the properties are a consequence of changes in fibres, molecular and supermolecular structure which is exhibited in changed fibres and consequently also nonwoven properties.

Key words: Agrotextile, polypropylene, nonwovens, UV radiation, properties.

INTRODUCTION

Many studies have been conducted to increase the yield and quality of fruits or vegetables (Trdan et al., 2007; Usenik et al., 2009; Veberič et al., 2010; Kacjan-Maršić et al., 2010). Follow these trends in horticultural practice, growers have employed row covers, as a low-cost technique to protect both cool-season and warm-season vegetable crops (Gimenez et al., 2002). The most often used plants cover is the floating row covers made of spun bonded polypropylene (PP) (Demšar et al., 2009). In the manufacturing process of spun bonded PP nonwoven, the PP melt is extruded or spun onto a collection belt. The small-diameter filaments are then heat and pressure treated to form a thin, whitish sheet of porous fabric (Vaughn, 1992). Spun bonded row cover is extremely lightweight (10 to 50 g/m^2), transmits enough light (80 to 94%) and can be placed directly over crops without the use of hoops for support (Wells and Loy, 1985a).

According to many authors, row covers create a specific microenvironmental condition around the crops. Abdalla and Verkerk (1968) showed that, temperature under PP nonwoven row covers can be several degrees higher that ambient ones and time between flowering and fruit development is much shorter at high rather than moderate temperatures. Wells and Loy (1985b) reported that, row covers contribute to moderate low temperature extremes in root-zone. In addition, row covers reduce solar radiation (Benoit and Ceustermans, 1987), wind influences (Mermier et al., 1995) and evaporation rates (Choukr-Allah et al., 1994), while increasing air humidity (Hemphill, 1989) as well as the soil humidity (Wolfe et al., 1989).

Many studies report about positive effects of the PP nonwovens on production of vegetables. In cold spring, Wadas et al. (2004) with covering potatoes (*Solanum*

*Corresponding author. E-mail: dragan.znidarcic@bf.uni-lj.si Tel: + 386 1 320 32 27. Fax: + 386 1 42310 88.

tuberosum L.) achieved twice the yield of tubers with more dry matter and starch than with the uncovered plants. Similar results were achieved by Sawicka and Mikos-Bielak (2000) and Lachman et al. (2000) with forcing potatoes under row covers. Higher yields under row covers were achieved also by a number of other plants, that is, sweet potato (Brown et al., 1998), okra (Brown and Channell-Butcher, 2000), muskmelon (Ibarra et al., 2001), tomatoes (Žnidarčič et al., 2003), Chinese cabbage (Hernandez et al., 2004), leek (Kołota and Adamczewska-Sowińska, 2007), kohlrabi (Biesiada, 2008), peppermint, bergamot mint, melissa (Carron et al., 2008) and lettuce (Salas et al., 2008).

The row covers affects not only plant growth, development and yields but also protects crops from high intensity rainfall (Benoit and Ceustermans, 1987) and the behaviour of insects that visit the plants. Costa et al. (1994) found out that, mean densities of silverleaf whitefly (*Bemisia tabaci* Gennadius) and aphid (*Aphis gossypii* Glover) were significantly lower in row cover treated zucchini compared with untreated plots. Similar trend has been reported by Qureshi et al. (2007) who have shown that the use of row covers until flowering has been effective method in reducing the number of silverleaf whitefly in zucchini. In another study which was carried out in a dry tropic region of Mexico, aphids, silverleaf whitefly and leafminer (*Lyriomyza sativa* Blanchard) were completely excluded by floating row cover, while the plots were covered (Orozco-Santos, 1995).

PP is a thermoplastic polymer which is liable to chain degradation when exposed to UV radiation which is a part of a solar electromagnetic radiation. Polymer degradation is an irreversible chemical reaction which leads to cleavage of chemical bonds, decomposition of polymer matter, reduction of molecular mass, change in functional groups of polymer and originating of low molecular decomposition products. Consequences of changes in polymer caused by UV radiation are changes in solvability, melting and mechanical properties (tenacity and extension). Because of the degradation of PP polymer (fibres), the degree of polymerisation is lower than the consequence which is worsening of mechanical properties (tenacity). As a consequence of cross linking, the extension, dynamic modulus and density of PP fibres at the beginning of degradation process is higher (Demšaret et al., 2009). Longer exposure to UV radiation leads to brittleness and appearance of regularly repeating surface cracks which are oriented perpendicularly to the fibre axis and decrease of all mechanical properties (La Mantia et al., 1985). The reasons for all these changes are morphological changes which activate the accelerated degradation on the places where cracks appear (McKellr and Allen, 1979).

Because standard nonwoven material degrades quickly under the influence of light (UV radiation) and it loses required mechanical properties, the need for more durable product with the life expectancy longer than one growing season come in site. The purpose of this study was to analyse the influence of simulated sun light radiation (xenon lamp) on physical properties of nonwoven material.

MATERIALS AND METHODS

In the research nonwoven fabric produced out of fibre mixture of 70% of PP fibres FiberVisions® HY-Comfort and 30% of UV-stabilised PP fibres Trevon® (produced by Tosama Domžale, Slovenia) has been analysed. The fibres properties are presented else where (Demšar et al., 2009).

The nonwoven fabric has been exposed to Xenon light on the Xenotest 150 (Original Hanau), whereas source of light xenon lamp Xe 1500 has been used. Xenon lamp Xe 1500 is in the visible (400 to 700 nm) and UV (300 to 400 nm) region of electromagnetic spectrum very similar to electromagnetic spectrum emitted by sun. To analyse the effect of sun light on the physical and mechanical properties of nonwoven fabric, the fabric has been exposed to xenon light for different time intervals. Three different samples of fabrics have been thus generated. First sample is a control sample which has not been exposed to xenon light (designation of sample – nonwoven 0). Second sample is nonwoven fabric illuminated with xenon light for 5 days which is equivalent to 50 days in nature considering the average weather conditions and the alternation of day and night (designation of sample – nonwoven 5). Third sample is nonwoven fabric illuminated with xenon light for 8 days which is equivalent to 80 days in natural conditions (designation of sample – nonwoven 8).

Tensile properties were measured on the universal electronic dynamometer Instron 6022 (SIST EN ISO 13934-1, 1999). Results were analysed using computer program DINARA (Bukošek, 1989) which enables us to calculate stress, strain, first, second and third derivate and integral of the stress strain curve in the whole region of material deformation. It enables us to draw stress strain curve, the derivates (first, second and third) and integral of stress strain curve. From the derivate curve the elastic modulus was obtained.

Tearing strength has been measured on the dynamometer Instron 6022 according standard SIST EN ISO 9073-4 (1997):

$$F = \frac{W}{2l} \quad \text{(N)} \qquad (1)$$

Where, F is the tearing strength (N); W is the tearing energy (N·cm) and l is the tearing length (cm).

Bursting strength has been measured and calculated according to standard SIST EN ISO 13938-2 (1999):

$$K = p \cdot \frac{(r^2 + h^2)}{4 \cdot h} \quad \text{(daN/cm)} \qquad (2)$$

$$\varepsilon = \left[\frac{\left(r^2 + h^2\right) \cdot \pi \cdot \alpha}{360 \cdot h \cdot r} - 1 \right] \cdot 100 \quad (\%) \qquad (3)$$

$$K_0 = K \cdot \frac{100 + \varepsilon}{100} \quad \text{(daN/cm)} \qquad (4)$$

Where, K is the linear bursting strength (daN/cm); K_o is the linear bursting strength in no elongated state (daN/cm); p is the bursting pressure (kg/cm^2); h is the bursting height (mm); r is the sample radius (mm) and ε is the strain (%).

Air permeability and the quantity of air which passes the testing fabric at selected pressure has been measured and calculated according to standard SIST EN ISO 9237 (1995):

$$Q = \frac{q}{F} \quad (m^3/min \cdot m^2) \qquad (5)$$

Where, Q is the quantity of sucked air ($m^3/min \cdot m^2$) at selected pressure; q is the quantity of air which passes through the sample (l/h) and F is the testing area (cm^2).

Thermal conductivity has been measured using apparatus E. Scgiltkneiht ing., M-280 and calculated:

$$\lambda_x = \lambda_n \cdot \frac{d_x}{d_n} \cdot \frac{(T_4 - T_3)}{(T_3 - T_2)} \quad (W/m \cdot K) \qquad (6)$$

Where, λ_x is the thermal conductivity of tested sample; λ_n is the thermal conductivity of reference glass plate (λ_n = 1,0319 W/m·K); d is the thickness of tested sample (mm); d_n is the thickness of reference glass plate (d_n = 4 mm); T_2 is the temperature of colder thicker copper plate (℃); T_3 is the temperature of middle thinner copper plate (℃) and T_4 is the temperature of warmer thicker copper plate (℃).

Water vapour diffusion has been measured and calculated using modified gravimetric method (SIST EN ISO 14268, 2002):

$$K = (G_0 - G_1) \cdot k \quad (g/h \cdot m^2) \qquad (7)$$

Where, K is the quantity of water vapour diffused through the sample ($g/h \cdot m^2$); G_0 is the mass of full water pot at the beginning (g); G_1 is the mass of water pot after 20 h (g) and k is the calculated constant 70.7355 ($h^{-1}m^{-2}$).

RESULTS AND DISCUSSION

The materials are influenced by UV light in different ways. For PP, it is characteristically that if not UV stabilised, it degrades and decomposes very quickly. In this study, PP nonwoven made of mixture of regular and UV stabilised PP fibres is presented. To compare properties of nonwoven made just of regular PP fibres and nonwoven made of mixture of regular and UV stabilised PP fibres after radiation with xenon light, in Table 1 some mechanical properties of regular nonwoven made just of regular PP fibres (100% PP fibres FiberVisions ® HY-COMFORT, 20 g/m^2) are presented.

Tensile properties

According to the tensile test results (Tables 1 and 2) it can be clearly seen that exposure to sunlight worsens tensile properties (force – F and stress – σ are lower) of PP nonwoven fabric in both directions (longitudinally and perpendicular to the nonwoven production direction). Breaking force (F_{br-L}) of the samples taken longitudinally which have been exposed to xenon light for five days is lower for 21.3% and at sample exposed for eight days 30.4% (Table 2). Also, breaking stress (σ_{br}) is lower, after five days of exposure it lowers for 24% and it has the same value also after eight days of exposure to xenon light.

At samples taken in the perpendicular direction and exposed to xenon light for 5 days breaking force stays unchanged, whereas breaking stress rises compared with non a exposed sample which is a consequence of lower thickness and mass of nonwoven. After eight days of exposure, the 29% decrease of breaking force can be seen. Coefficient of variation of perpendicularly taken samples is higher compared to samples taken longitudinally which is an intrinsic property of nonwovens because of the anisotropy of the structure (composition) of the nonwovens (Table 2). Higher decrease of tensile properties in longitudinal direction is linked with orientation of fibres in the nonwoven. Great majority of fibres are oriented in longitudinal direction connected together through chemical bonds. Since UV radiation causes the cleavage of molecular bonds prior to breakage of the fibre, the decrease is mainly seen in the longitudinal direction, were mainly the bonds between fibres break. In the perpendicular direction, fibres are more randomly oriented and less tightly bonded together. The cleavage due to the UV radiation is less pronounced in such more randomly distributed structure than in longitudinal direction where more bonds and fibres are affected.

From Tables 1 and 2, is also clearly seen that the decrease of tensile properties after radiation with xenon light is much more intense at nonwoven composed of regular PP fibres which are not UV protected.

In Figure 1, the behaviour of breaking strain after exposure to xenon light is presented. As it can be seen the behaviour is very similar to behaviour of breaking force. Breaking strain is after exposure lower at samples taken in both directions. Decrease of breaking strain is higher in the longitudinal direction where it decreases from 45% at control sample to 33% at sample nonwoven 5 and to 25% at sample nonwoven 8. At samples taken in the perpendicular direction, the breaking strain at sample exposed to xenon light for 5 days is even a little higher and after eight days of exposure decreases for 27%.

Figures 2 and 3 are presenting force/strain curves of all samples before and after exposure to xenon light. The shape of all curves is similar although, the difference between the longitudinally and perpendicularly taken samples is clearly visible. Strain is relatively evenly increasing with the load.

At samples taken longitudinally (Figure 2), the increase in load is higher on the whole deformation range, meaning that more force is needed to elongate the nonwoven in longitudinal direction than in perpendicular direction. The differences between non exposed and exposed samples are more clearly seen at samples taken longitudinally. Comparing the curves of samples taken perpendicularly (Figure 3), it can be seen that the differences between samples are very small. At the curve of five days exposed, nonwoven the difference compared with curve of nonwoven 0 only a small difference can be

Table 1. Area mass, breaking force longitudinally; F_{br-L}, breaking strain longitudinally; ε_{br-L}, breaking force perpendicularly; F_{br-P}, breaking strain perpendicularly; ε_{br-P} of sample made just of regular PP fibres (100 % PP fibres FiberVisions ® HY-COMFORT, 20 g/m^2).

Property	Day of radiation					
	0	1	2	3	6	9
Area mass (g/m^2)	18.92	18.91	19.01	18.12	11.61	Decomposition
F_{br-L} (N)	31.51	31.48	31.21	30.01	13.92	Decomposition
ε_{br-L} (%)	40.60	42.31	44.01	43.21	25.41	Decomposition
F_{br-P} (N)	7.94	7.91	7.42	6.59	3.69	Decomposition
ε_{br-P} (%)	63.01	62.65	61.25	60.01	11.81	Decomposition

Table 2. Breaking force (F_{br}), coefficient of variation (CV) and breaking stress (σ_{br}).

Sample	F_{br} (N)	CV (%)	σ_{br} (MPa)
Longitudinally taken samples			
Nonwoven 0	40.93 ± 3.14	7.81	5.28
Nonwoven 5	32.23 ± 2.51	7.91	4.02
Nonwoven 8	28.48 ± 4.64	16.61	4.01
Perpendicularly taken samples			
Nonwoven 0	8.76 ± 0.82	13.46	0.99
Nonwoven 5	8.79 ± 0.88	14.50	1.11
Nonwoven 8	6.22 ± 1.20	27.80	0.99

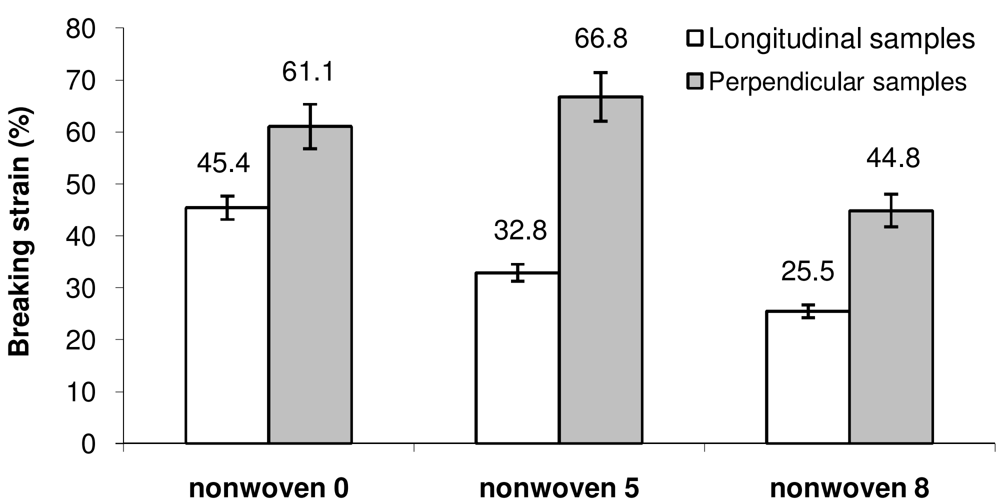

Figure 1. Breaking strain (ε_{br}) at longitudinally and perpendicularly taken samples.

seen after 20% strain. The difference at curve of sample nonwoven 8 (longer exposed non-woven) can be seen already after yield point which is at 5% strain, though,also this difference is very small. This is important because nonwoven fabric is much weaker in perpendicular direction and with higher loss in strength the use of such fabric could be problematic. The loss in strength after UV radiation in longitudinal direction is higher, but because the force needed to elongate and break the nonwoven fabric is high, this weakening does not influence the use of such nonwoven fabric.

Elastic modulus E_0 has been defined at maximum of

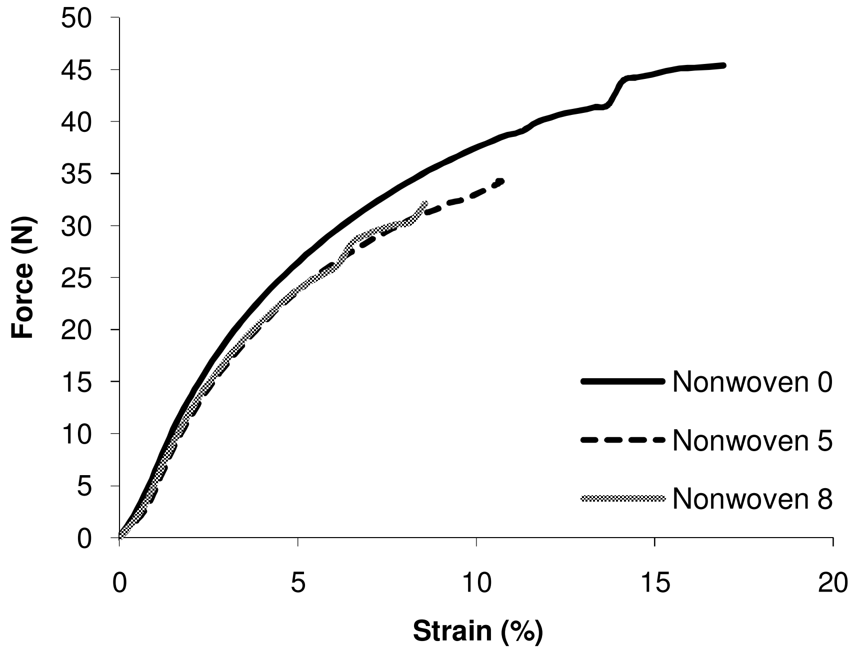

Figure 2. Force/strain curves of longitudinally taken samples.

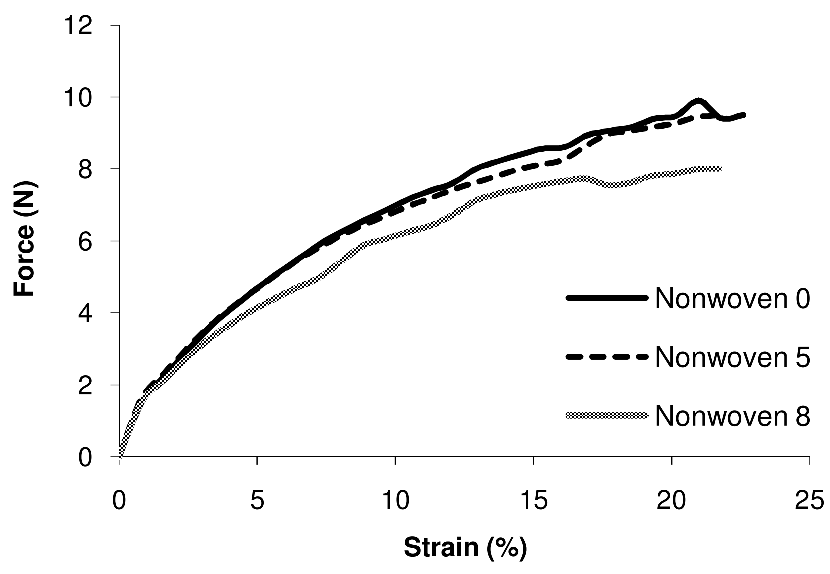

Figure 3. Force/strain curves of perpendicularly taken samples.

first derivate of the force/strain curve. It is important property of fabrics as it determines the force needed to deform the fabric prior the permanent deformation takes place. The E_0 of longitudinally taken samples has been determinate at strains around 1% and at perpendicularly taken samples at around 3.6%. Additionally, when applying force on the nonwoven in the perpendicular direction the fibres firstly re-orient in the direction of force and the maximum increase of force is reached after the re-orientation of the fibres.

Values of E_0 at longitudinally taken samples are approximately three times higher as at perpendicularly taken samples (Figure 4) which is again a consequence of longitudinal orientation of the fibres in the nonwoven. The E_0 module increase with the time of exposure to xenon light although, the increase is relatively low. The increase of E_0 modulus of samples exposed to xenon light is a consequence of decomposition and deploy-merisation in the inner fibre structure which results in larger number of shorter molecules in the fibres which

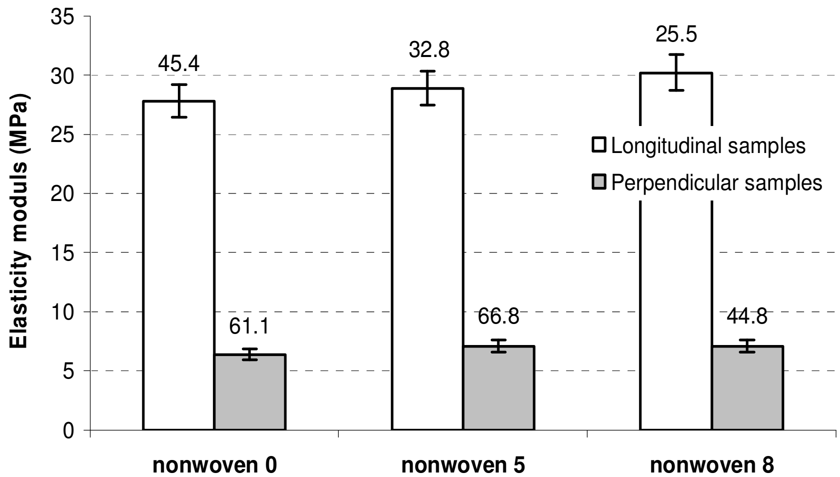

Figure 4. Breaking strain (ε_{br}) at longitudinally and perpendicularly taken samples.

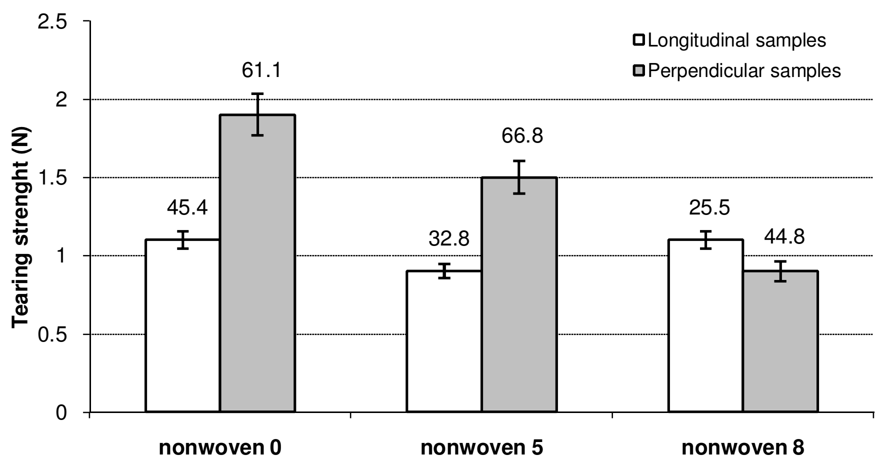

Figure 5. Tearing strength (F_{tr}) of all samples.

form more intermolecular bonds, consequence of which is higher E_0 module. But it is anticipated that module E_0 would decrease at higher exposure times.

Tearing strength

The results of the tearing strength analysis are presented in Figure 5. It should be pointed out that, when the samples for the tearing analysis are taken in longitudinal direction, the direction of tearing is perpendicular and when the samples are taken perpendicularly the tearing direction is longitudinal. As it can be seen from Figure 5, higher tearing strength has perpendicularly taken samples (direction of tearing is longitudinal). It can also be seen that the exposure to the xenon light is mainly seen at samples taken perpendicularly where at samples taken longitudinally the effect of xenon light is not so evident. Again this is in accordance with tensile analysis where it has been seen that nonwovens have higher tensile strength in longitudinal direction and this direction is more sensible on the modification of fibre properties which is the case with the sunlight (xenon) radiation.

Bursting strength

Bursting strength is the strength when certain area of the

Material (nonwoven) is loaded from all directions. This can be done by loading certain area of nonwoven with compressed air in the perpendicular direction to the surface of the nonwoven.

The strength which is needed to break the sample and the height of the nonwoven imposed by compressed air is measured. Linear bursting strength (K) is a

Table 3. Linear bursting strength (K) of strained sample, strain (ε) and linear bursting strength (K_0) of unstrained sample.

Sample	K (N/cm)	ε (%)	K_0 (N/cm)
Nonwoven 0	23.3	10.84	25.8
Nonwoven 5	22.9	7.88	24.7
Nonwoven 8	20.7	6.70	22.1

Table 4. Quantity of sucked air (q), coefficient of variation (CV), air permeability through five layers of nonwoven (Q_5) and through one layer (Q_1).

Sample	Q (l/h)	CV_Q (%)	Q_5 ($m^3/min{\cdot}m^2$)	Q_1($m^3/min{\cdot}m^2$)
Nonwoven 0	4112 ± 62.8	3.49	68.54	342.72
Nonwoven 5	4160 ± 60.5	3.32	69.33	346.74
Nonwoven 8	4176 ± 61.8	3.38	69.61	348.13

Table 5. Thermal conductivity coefficient (λ).

Sample	λ (mW/m·K)
Nonwoven 0	78.77
Nonwoven 5	89.51
Nonwoven 8	94.74

measure of strength of material (nonwoven in our case) when it is loaded in all directions. Control sample (nonwoven 0) has linear bursting strength of 23.3 N/cm and it has 10.84% strain. The coefficient of variation (CV) has not exceeded 11%. The measured values are suitable for the floating row covers nonwovens. From Table 3, it can be seen that the linear bursting strength and strain are decreasing with longer radiation times. The linear bursting strength of samples exposed to xenon light for five days is 2% lower and at samples exposed 8 days only 12% lower. The strain is after five days of radiation lower for 27% and after eight days, 38% lower. According to the bursting strength analysis, it has been clearly confirmed that sunlight (xenon light) influences the tensile properties of nonwoven fabric in such a way that it decreases its strength.

Air permeability

From the air permeability results, the porosity and isolation properties of the material can be anticipated. The air permeability results are presented in Table 4. Air permeability of control sample is 342.72 $m^3/min{\cdot}m^2$ which is relatively high. From this result, high porosity of the material can be anticipated. It also means that, relatively high quantity of air passes through the nonwoven. After radiation of samples with xenon light relatively small increase of air permeability of samples can be seen. Higher air permeability can be linked with lower area mass of nonwoven.

Thermal conductivity

Thermal conductivity is a property which enables us to anticipate the isolation properties of material. It depends on the material, structure and thickness of the nonwoven. Less air pockets means higher thermal conductivity and similarly higher thickness means higher thermal conductivity. The thermal conductivity of samples is presented in Table 5. It can be seen that, thermal conductivity of nonwovens with exposure to xenon light increases. After five days of exposure, it increases for 13.6% and after eight days of exposure, further higher for 5.8%. Highest influence on the increase of the thermal conductivity has the thickness of the nonwovens which is decreasing with increasing exposure to xenon light. The electromagnetic radiation of nonwovens influences the supermolecular structure of fibres which degrade in certain extent, which has a consequence worse bending properties, higher compressibility and lower thickness.

Water vapour permeability

Water vapour permeability is an important property of nonwoven which gives us information also about applicability of nonwoven in agricultural applications. Values of water vapour permeability above 21 g/m^2h characterise materials with good water vapour permeability properties. Water vapour permeability of control nonwoven (Nonwoven 0) is 61 g/m^2h which indicate the material with very good water permeability properties (Table 6). From the results presented in Table

Table 6. Quantity of water vapour which passes through certain area of nonwoven – U, evaporation share.

Sample	U (g/m^2h)	% evaporation
Nonwoven 0	60.83	57.33
Nonwoven 5	62.95	59.33
Nonwoven 8	64.37	60.67

6, it can be seen that water vapour permeability with the time of xenon light radiation increases. At samples exposed to xenon light for five days the quantity of evaporated water is 2% and at samples exposed for eight days 3.3%, which was higher compared with control sample. The results are in accordance with air permeability results where samples exposed to xenon light exhibit higher air permeability. Also, this results are a consequence of changes in fibres molecular and supermolecular structure which is exhibited in changed fibres and consequently also nonwoven properties.

Conclusions

In this study, the dependence of some physical properties of row covers on the UV radiation has been investigated. The research showed that the properties of row covers change when radiated with UV light and that the changes are lower when in nonwovens UV stabilised fibres are used. It has been shown that tensile, tearing and bursting prla mantiaoperties worsen to some extend after radiation and that air permeability and water vapour show little increase. The properties in the longitudinal and perpendicular direction of the nonwoven are different which is a consequence of the longitudinal fibres orientation in the nonwoven. Because of this, it is important in which direction the row covers laid. The changes in the properties after UV radiation are the consequence of changes in the fibre molecular and supermolecular structure, cleavage of bond between fibres which is then exhibited in the changed fibres and consequently, also in the nonwoven fabric properties. As most of the change affect mechanical properties in the longitudinal direction where the nonwoven fabric is strong enough, these does not limits the usage of nonwoven fabric as row cover for longer period.

REFERENCES

Abdalla AA, Verkerk K (1968). Growth, flowering and fiuit-set of the tomato at high temperature. Neth. J. Agric. Sci., 16: 71-76.
Benoit F, Ceustermans N (1987). Advancing the harvest of bolt-sensitive endives by means of temporary single and double direct crop covering. Plasticulture 7: 4-8.
Biesiada A (2008). Effect of flat covers and plant density on yielding and quality of kohlrabi. J. Elementol., 13(2): 167-173.
Brown JE, Woods FM, Channell-Butcher C (1998). Effects of black plastic mulch and row cover on sweet potato production. J. Veg. Crop Prod., 4(1): 49-54.
Brown JE, Woods FM, Channell-Butcher C (2000). Effect of three row covers and black plastic mulch on the growth and yield of 'Clemson Spineless' okra. J. Veg. Crop Prod., 5(2): 67-71.
Bukošek V (1989). Računalniško vrednotenje visokoelastičnih lastnosti vlaken, filamentov, prej, tkanin, trakov, folij in ploskih izdelkov iz nateznih in tlačnih poskusov. Razvoj metode in programske opreme DINARA©, Ljubljana, 55 p. (in Slovene)
Carron CA, Baroffio C, Carlen Ch (2008). Influence of agrotextile cover on the yield and the quality of three species of aromatic plants. Rev. Suisse Vitic. Arbor. Hortic., 40(2): 125-130.
Choukr-Allah R, Hafidi B, Reyd G, Hamdy A (1994). Influence of non-wovens on outdoor crops: Moroccan experience. Proceed. of 13th ICPA, Verona, Italy. 13 p.
Costa HS, Johnson MW, Ullman DE (1994). Row covers effect on sweetpotato whitefly (Homoptera: Aleyrodidae) densities, incidence of silverleaf, and crop yield in zucchini. J. Econ. Ent., 87(6): 1616-1626.
Demšar A, Žnidarčič D, Gregor-Svetec D (2009). The comparison of properties of polypropylene fibres intended for the production of agrotextiles. Acta Agric. Slov., 93(2): 211-217.
Gimenez C, Otto RF, Castilla N (2002). Productivity of leaf and root vegetable crops under direct cover. Sci. Hort. 94: 1-11.
Hemphill DD (1989). Tomato, cucurbit, and sweet corn growth under agriplastics as a function of heat unit accumulation. Proceed. of 21st NAPC, Orlando, Florida, pp. 276-282.
Hernandez J, Soriano T, Morales M, Castilla N (2004). Row covers for quality improvement of Chinese cabbage (*Brassica rapa* subsp. *pekinensis*). New Zeal. J. Crop. Hortic., 32(4): 379-388.
Ibarra L, Flores J, Diaz-Perez JC (2001). Growth and yield of muskmelon in response to plastic mulch and row covers. Sci. Hortic., 87: 139-145.
Kacjan-Maršić N, Šircelj H, Kastelec D (2010). Lipophilic antioxidants and some carpometric characteristics of fruits of ten processing tomato

varieties, grown in different climatic conditions. J. Agric. Food Chem., 58: 185-192.
Kołota E, Adamczewska-Sowińska K (2007). The effects of flat covers on overwintering and nutritional values of leeks. Veget. Crops Res. Bull., 66: 11-16.
McKellr JF, Allen NS (1979). Photochemistry of Man-made polymers. Applied Science Publishers, London, UK, pp. 33-34.
Mermier M, Reyd G, Simon JC, Boulard T (1995). The microclimate under Agril P17 for growing lettuce. Plasticulture, 107: 4-12.
Lachman J, Hamouz K, Hejtmankova A, Dudjak J, Orsak M, Pivec V (2003). Effect of white fleece on the selected quality parameters of early potato (*Solanum tuberosum* L.) tubers. Plant Soil Environ., 49(8): 370-377.
La Mantia FP, Spadaro G, Acierno D (1985). Effect of morphology on the photooxidation of polypropylene films. Polym. Photochem., 6(6): 425-435.
Orozco-Santos M, Perez-Zamora O, Lopez-Arriaga O (1995). Floating row cover and transparent mulch to reduce insect populations, virus diseases and increase yield in cantaloupe. Florida Entomol., 78(3): 493-501.
Qureshi MS, Midmore DJ, Syeda SS, Playford CL (2007). Floating row covers and pyriproxyfen help control silverleaf whitefly *Bemisia tabaci* (Gennadius) Biotype B (Homoptera: Aleyrodidae) in zucchini. Aust. J. Ent., 46(4): 313-319.
Salas FJS, Moraes CAP, Garcia S, Sabundjian TT (2008). Evaluation of lettuce crop protected with floating row cover and its performance

in different types of applications. Arq. Inst. Biol. São Paulo, 75(4): 437-442.
Sawicka B, Mikos-Bielak M (2000). Wpływ nawoŜenia azotem i uprawy pod osłonami na wartość konsumpcyjną bulw ziemniaka. Konf. Nauk. "Ziemniak spoŜywczy i przemysłowy oraz jego przetwarzanie". AR Wrocław, Polanica Zdrój: pp. 132-133. (in Polish)
SIST EN ISO 9237 (1995). Textiles. Determination of the permeability of fabrics to air.
SIST EN ISO 9073-4 (1997). Textiles. Test methods for nonwovens. Determination of tear resistance.
SIST EN ISO 13934-1 (1999). Textiles. Tensile properties of fabrics. Determination of maximum force and elongation at maximum force using the strip method.
SIST EN ISO 13938-2 (1999). Textiles. Bursting properties of fabrics. Pneumatic method for determination of bursting strength and bursting distension.
SIST EN ISO 14268 (2002). Leather. Physical and mechanical tests. Determination of water vapour permeability.
Trdan S, Cirar A, Bergant K, Anđus Lj, Kač M, Vidrih M, Rozman L (2007). Effect of temperature on efficacy of three natural substances to Colorado potato beetle, *Leptinotarsa decemlineata (*Coleoptera: Chrysomelidae). Acta Agric. Scand., B Soil Plant. Sci., 57(4): 293-296.
Usenik V, Štampar F, Veberič R (2009). Anthocyanins and fruit colour in plums (*Prunus domestica* L.) during ripening. Food Chem., 114(2): 529-534.
Vaughn EA (1992). Nonwoven Fabric Primer and Reference Sampler, INDA.
Veberič R, Jurhar R, Mikulič-Petkovšek M, Štampar F, Schmitzer V (2010). Comparative study of primary and secondary metabolites in 11 cultivars of persimmon fruit (*Diospyros kaki* L.). Food Chem., 119(2): 477-483.
Wadas R, Jabłońska-Ceglarek R, Kosterna E (2004). Effect of plastic covering and nitrogen fertilization on yield and quality of early potatoes. Folia Hortic., 16(2): 41-48.
Wells OS, Loy JB (1985a). Intensive vegetable production with row covers. HortScience, 20(5): 822-826.
Wells OS, Loy JB (1985b). Row cover and high tunnels enhance crop production in the northeastern United States. HortTechnology, 3: 92-95.
Wolfe DW, Albright LD, Wyland J (1989). Modelling row cover effects on microclimate and yield. I. Growth response of tomato and cucumber. JASHS, 114(4): 562-568.
Žnidarčič D, Trdan S, Zlatič E (2003). Impact of various growing methods on tomato (*Lycopersicon esculentum* Mill.) yield and sensory quality. Res. Rep., Biotech. Fac., Univ. Ljublj. 81: 341-348.