Protected Horticulture and Plant Factory, Vol. 23, No. 4:314-320, December (2014)
DOI http://dx.doi.org/10.12791/KSBEC.2014.23.4.314

pISSN 2288-0992
eISSN 2288-100X

Optical Characteristics of Two New Functional Films and Their Effect on Leaf Vegetables Growth and Yield

Joon Kook Kwon*, Bekhzod Khoshimkhujaev, Kyoung Sub Park, Hyo Gil Choi, Jae-Han Lee, and In Ho Yu

Protected Horticulture Research Station, National Institute of Horticultural and Herbal Science, Haman 637-812, Korea

Abstract. Three leaf vegetables, namely green lettuce, red lettuce (*Lactuca sativa*) and red-veined chicory (*Cichorium intybus*) were grown in minigreenhouses covered with two new functional films and conventional polyethylene film (PE). Seedlings of leaf vegetables were transplanted in a plastic troughs filled with soil-perlite mixture. Two functional films were made from polyolefin (PO) material. Measurement of optical characteristics showed that polyolefin films have better transmittance for the photosynthetic active radiation (PAR, 400-700nm) and higher absorptance for the ultraviolet radiation (UV, 300-400nm) in comparison with the conventional PE film. After three months of utilization higher loss in PAR transmittance was observed for conventional PE film. Leaf vegetables growth was enhanced and yield was increased in greenhouses covered by new functional films.

Additional key words : cover, greenhouse, microclimate, PAR transmittance, polyethylene, polyolefin

Introduction

Leaf vegetables such as lettuce, chicory, spinach, perilla are highly consumed by Korean people as a side dish due to their high content of health related phytochemicals. In Korea leaf vegetables as other horticultural crops are mostly grown in protected horticulture constructions such as low and high tunnels, greenhouses. Transparent plastic materials are extensively used as a greenhouse covers due to their low price and good physical and mechanical properties.

Selection of a proper cover material is essential because it directly affects plant growth and development through changing microclimatic parameters within the cultivation area. Light quantity and quantity have a profound effect on plant growth and development. In addition, the microclimatic factors (air humidity or carbon dioxide concentration) are affected indirectly by the covering system (Giacomelli and Roberts, 1993).

In Korea 83% of protected horticulture constructions were covered by polyethylene film (MAFRA, 2011). Dominance of polyethylene film as the cover material can be explained by its low price, fairly good transmittance for solar PAR and plasticity. However, main drawback of PE film is its short useful life. After one to two seasons farmers have to change plastic covering which is labor intensive and time consuming. Owing to the current plastic industry development more and more new types of covering materials are now available in the market. For instance, so-called polyolefin plastic covering materials is becoming popular among Korean greenhouse producers because of their superior optical and mechanical characteristics compared to conventional cover films based on PE.

Polyolefins are polymers produced from simple olefin (also called an *alkene*) as a monomer (Wikipedia, 2014). Antioxidants, UV-stabilizers and other protective additives have in the past been developed to improve the long term durability of polyolefins, particularly for out-door environment (Wiles and Scott, 2006). Previous reports showed that PO film with a 0.1mm thickness had better mechanical properties in comparison with ethylene vinyl acetate co-polymer (EVA) film (Kwon et al, 2012; Kwon et al, 2001). Authors reported that crop growth and yield were enhanced in greenhouses covered by PO film compared to EVA film. According to these results it can be summarized that growth and yield of experimental crops were enhanced because of higher light transmittance and relatively higher mean air temperatures which were created under PO film cover.

Light is essential for plant growth and development especially in cold seasons of the year when light is limiting factor for photosynthesis. Therefore covering materials must have high light transmittance and retain this property during

*Corresponding author: kjk0412@korea.kr
Received August 12, 2014; Revised September 3, 2014; Accepted November 11, 2014

the whole utilization period. Increasing popularity and farmer's demand for films with a high light transmission and long useful life led Korean manufactures of polymer materials to develop and produce PO films locally. In this experiment the effect of two locally produced PO covering films on the growth and yield of leaf vegetables were studied in comparison with conventional PE film.

Materials and methods

1. Experimental site

The experiment was conducted in the minigreenhouses at the Protected Horticulture Research Station, Busan, Korea (35°N and 128°E) during March-May in 2014. The greenhouses were north-south oriented, arch roofed, with the dimensions of 6.5×2.7×2.3 m (L×W×H). Ventilation was carried out automatically, through the side wall openings using roll-up mechanisms. The influence of two newly developed polyolefin films marked optionally as TKP (75μm) and TKN (0.015mm) (Taekwang Newtec Co., Ltd.) in comparison with conventional polyethylene film (PE, 0.015mm) on leaf vegetables growth and yield was investigated in these minigreenhouses.

2. Plant material and cultural practices

Young seedlings of red and green lettuce as well as chicory were transplanted in plastic trapezoid shaped troughs with approximate volume of 36l liters filled with soil-perlite mixture on 3 March, 2014. Plants were periodically irrigated and fertilized with drip irrigation system. Plants was covered with the black, spun-bonded, non-woven polypropylene fabric during night and early morning hours in the initial growth period to protect young plants from extreme low temperatures.

3. Environmental conditions in minigreenhouses and plastic film characteristics

Air temperature and relative humidity were measured and recorded using TR-72U dataloggers (T&D Corp., Nagano, Japan), soil temperature was measured and recorded at 30 min interval using HOBO Pro v2 dataloggers (Onset Computer Corp., ME, USA) with embedded temperature sensors. Air temp/RH sensors were installed in the center of each greenhouse at the plant level and soil temperature sensors was buried at the depth of 10cm.

Solar radiation spectral distribution in the 300-1100nm waveband in minigreenhouses covered by three plastic films was analyzed by means of LI-1800 spectroradiometer (Licor, Lincoln, NE, USA) with the standard cosine receptor on a clear day at solar noon (12:00 - 13:00). External integrating sphere (model - 1800-12) connected to spectroradiometer via quartz fiber optic probe (model - 1800-10) was utilized to investigate the optical characteristics of three cover materials. Optical characteristics were analyzed for the new plastic films and after three months of utilization period as a greenhouse covering (March, April, and May). Relative loss in transmittance was determined as (Geoola et al, 1998):

$$\text{Relative loss in transmittance} = (T_{new} - T)*100/T_{new}$$

where T_{new} is he PAR transmittance of new material, and T is the PAR transmittance after certain utilization period.

4. Plant growth characteristics

Gas exchange parameters such as net CO_2 assimilation rate, stomatal conductance and transpiration rates were measured by means of LI-6400 portable photosynthesis system (Licor, Lincoln, NE, USA). During gas exchange measurement in green lettuce, red lettuce and chicory the leaf temperature, relative humidity and CO_2 levels within the leaf chamber were set at 26°C, 70±5%, and 400μmol·mol^{-1}, respectively.

Four consecutive harvests were carried out on the three crops to assess crop growth and development. Plant characteristics such as leaf width, leaf length and fresh weights of upper part and roots were measured. On those plants, leaf number was counted for each plant and its area was determined by using LI-3100 area meter (Licor, Lincoln, NE, USA). After fresh weight measurements, plant parts were dried in an oven at 70°C for 4 days. Then dry weights of plants were measured with CUX - 420H electronic scale (CAS Corp., Korea).

5. Statistical analysis

Experiment was arranged in a completely randomized design with four replications. Data were subjected to analysis of variance (ANOVA) and means of treatments were separated by Duncan's multiple range test at $p \leq 0.05$ in the SAS 9.1 software (SAS Institute Inc. Cary, NC, USA).

Results & Discussion

Visually functional PO films were colorless, whereas PE film had a bluish tint and all experimental films were transparent for light. Analysis of optical characteristics of three plastic films showed that there were significant differences in transmittance, reflectance and absorptance between two functional and conventional films (Table 1). The total transmittance for the PAR region (400-700nm) was the highest in TKP film (88.0%), followed by TKN (87.2%). The lowest value showed PE film (85.2%). Transmittance for UV range was the lowest in TKP and TKN films compared to PE film. Transmittance for NIR (near-infrared radiation, 700-1100nm) was almost similar for all covering films. After three months of utilization optical characteristics were again analyzed. Analysis of optical characteristics of plastic coverings showed that reduction in transmittance was similar for the whole spectrum and this reduction in light transmittance was due to increased absorptance for light. Analysis also showed that transmittance values for PAR were decreased in all films without exclusion (Table 2). However higher decrease in transmittance for PAR was observed in PE film compared to TKP and TKN films. After three months of utilization relative loss in PAR transmittance was 5.7%, 5.1% and 4.5% for PE, TKN and TKP covering films, respectively. In our opinion, the most prominent factor for decreasing transmittance of covering films was a dust and dirt accumulation on the polymer's outer surface.

Spectral transmittance curves of TKP and TKN covering films were relatively flat for the 400-1100nm waveband, whereas PE had a slightly higher absorption in orange-red region (Fig. 1), which is crucial for plant photosynthesis and consequently for its productivity.

Field spectroradiometric measurement results were consistent to those measured in laboratory conditions. Similar to spectral transmittance data, more prominent difference between plastic films was in orange-red-far red

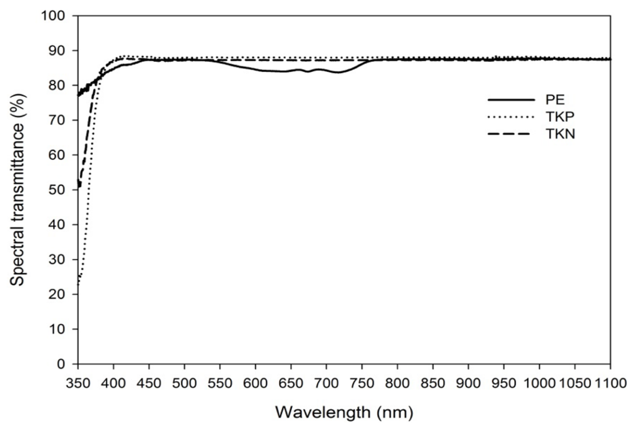

Fig. 1. Transmittance spectra of three covering materials.

Table 1. Optical characteristics of three plastic covering films before the utilization.

Covering film	Transmittance			Reflectance			Absorptance		
	UV[z]	PAR[y]	NIR[x]	UV	PAR	NIR	UV	PAR	NIR
PE	81.4	85.3	86.9	8.7	8.0	7.9	10.0	6.7	5.2
TKP	66.1	88.0	88.0	6.1	7.8	7.4	27.8	4.2	4.5
TKN	75.9	87.2	87.3	8.3	8.9	8.3	15.9	3.9	4.4

[z]UV - Ultraviolet radiation , here 330-400nm
[y]PAR - Photosynthetic active radiation, 400-700nm
[x]NIR - Near infra-red radiation, 700-1100nm

Table 2. Optical characteristics of three plastic covering films after the ~~3~~three months of utilization.

Covering film	Transmittance			Reflectance			Absorptance		
	UV[z]	PAR[y]	NIR[x]	UV	PAR	NIR	UV	PAR	NIR
PE	75.8	80.4	83.2	8.3	8.3	8.2	15.9	11.3	8.6
TKP	62.5	84.0	85.3	6.6	8.0	7.6	30.9	8.0	7.1
TKN	69.8	82.7	84.2	8.5	8.8	8.2	21.7	8.5	7.6

[z]UV - Ultraviolet radiation , here 330-400nm
[y]PAR - Photosynthetic active radiation, 400-700nm
[x]NIR - Near infra-red radiation, 700-1100nm

region. Solar radiation distribution data showed that both TKP and TKN allowed more photons to penetrate in 580-740nm waveband compared to PE. Also TKP and TKN films restricted penetration of photon flux in 300-380nm wavelength range, whereas PE film was more transparent for this wavelength range (Fig. 2).

Mean diurnal and nocturnal air and soil temperatures under all examined cover films were higher than outside (no cover). Slightly warmer temperatures among tested covering films were observed in TKP and TKN films compared to PE film (Table 3, Fig. 3A). Diurnal air humidity was lower in greenhouses covered with plastic films compared to this outside due to good ventilation and

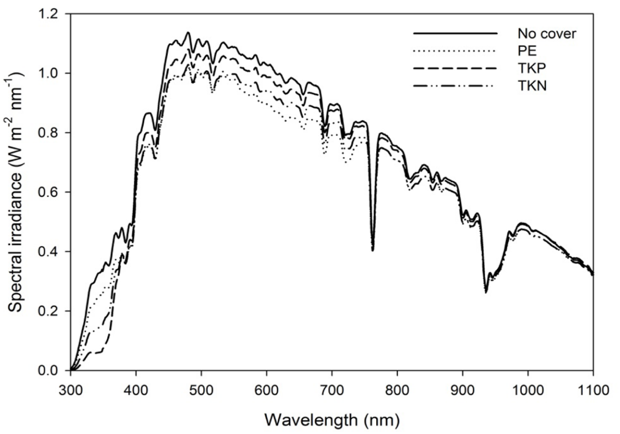

Fig. 2. Sun radiation spectral distribution under three plastic covering materials measured on a clear sky day at solar noon (12:00-13:00 pm).

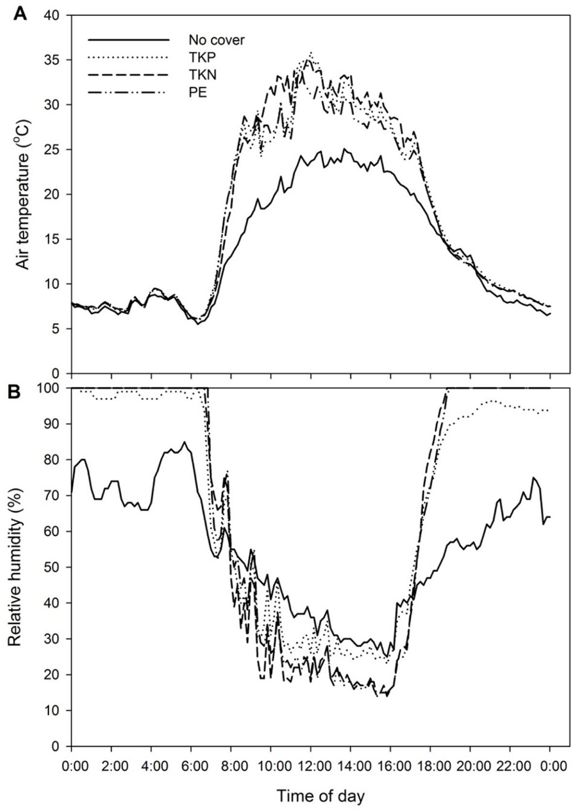

Fig. 3. Diurnal course of air temperature and relative humidity in greenhouses covered by three plastic materials.

Table 3. Air and soil temperature, relative humidity under three plastic covering materials (measured from March to May, 2014)

Covering film	Air temperature (°C)			Soil temperature (°C)			Air humidity (%)		
	Mean	Day	Night	Mean	Day	Night	Mean	Day	Night
No cover	9.3	14.0	3.8	12.1	13.6	11.0	73.3	55.4	86.3
PE	12.2	21.3	5.6	15.4	17.9	13.4	77.9	50.9	97.5
TKP	12.6	21.9	5.8	15.8	18.4	13.9	79.1	50.6	97.0
TKN	12.4	21.7	5.7	15.7	18.2	13.7	77.8	50.1	98.0

Table 4. Leaf gas exchange parameters of chicory, red and green lettuce grown under three plastic covering materials.

Covering film	Chicory			Red lettuce			Green lettuce		
	A_n[z]	g_s[y]	Tr[x]	A_n	g_s	Tr	A_n	g_s	Tr
PE	18.9 a[w]	0.635 a	4.757 a	10.6 a	0.209 a	2.197 a	15.0 b	0.334 a	2.973 a
TKP	19.6 a	0.791 a	5.033 a	11.8 a	0.259 a	2.490 a	19.5 a	0.591 a	4.030 a
TKN	19.8 a	0.756 a	4.957 a	8.9 a	0.221 a	2.270 a	17.6 ab	0.471 a	3.653 a

[z]A_n is the net CO_2 assimilation rate in mmol $m^{-2}\cdot s^{-1}$
[y]g_s is the stomatal conductance in mol $m^{-2}\cdot s^{-1}$
[x]Tr is the transpiration rate in mmol $m^{-2}\cdot s^{-1}$
[w]Mean separation within columns by Duncan's multiple range test at $p \leq 0.05$

higher air temperatures; however at night time, when side openings were closed, air humidity was higher than outside and was close to saturation (Fig. 3B).

Gas exchange parameters were not significantly different in examined crops due to different plastic coverings, except in green lettuce (Table 4). Net CO_2 assimilation rate in green lettuce grown under TKP was higher compared to those grown under TKN and PE covering films, but stomatal conductance and transpiration rate were similar.

The growth parameters of leaf vegetables grown under three covering materials were shown in Table 5. Leaf vegetables growth characteristics were significantly affected due to different plastic covering materials. The plants grown in TKP showed relatively better growth; leaf weight, root weight and total leaf area per plant were higher than those of the plants grown in conventional PE covered greenhouses.

Yield of leaf vegetables grown under three covering materials were expressed as a number of leaves per plant and accumulated leaf weight from four consecutive harvests (Table 6). There was a significant difference in yield of leaf vegetables grown under two PO and PE films. Number of leaves per plant and accumulated leaf fresh weight were higher in plants grown under TKP and TKN compared to PE film. Yield of leaf vegetable was not significantly different between TKP and TKN treatments.

Effects of greenhouse covering materials on microclimate parameters were extensively studied by several research groups (Baytorun et al., 1994; Papadopoulos and Hao, 1997 a,b; Nishimura et al., 2009; Cemec et al., 2005; Kittas et al., 2006.). These authors showed that plastic covers with different properties can significantly alter microclimatic parameters of greenhouses such as light intensity and quality, temperature of air as well as soil and relative humidity. However, it should be noted, that in aforementioned reports experimental cover materials included such materials as glass, rigid polymer panels, double inflated plastic films which is not comparable with our results. In our experiments we compared newly developed polyolefin based functional films with conventional polyethylene greenhouse films.

During the three months of usage all covering films were subjected to different environmental factors (high and low air temperatures, high solar radiation, strong rain and wind

Table 6. Yield of chicory, red and green lettuce grown under three plastic covering materials.

Crop	Covering film	No. of leaves (ea plant^{-1})	Accumulated leaf weight (g plant^{-1})
Green lettuce	PE	39.4 b^{z}	163.3 b
	TKP	45.7 a	186.1 a
	TKN	44.1 a	192.4 a
Red lettuce	PE	28.4 b	149.4 b
	TKP	32.8 a	158.7 a
	TKN	31.1 a	155.8 a
Chicory	PE	29.1 b	86.9 b
	TKP	34.6 a	93.8 a
	TKN	34.3 a	92.7 a

^{z} Mean separation within columns by Duncan's multiple range test at $p \le 0.05$

Table 5. Plant growth characteristics of chicory, red and green lettuce grown under three plastic covering materials.

Crop	Covering film	Leaf weight (g plant^{-1})		Root weight (g plant^{-1})		Leaf area (cm^2 plant^{-1})
		Fresh	Dry	Fresh	Dry	
Green lettuce	PE	19.4 b^{z}	0.98 b	1.6 b	0.10 b	359.6 b
	TKP	28.4 a	1.37 a	2.2 a	0.13 a	465.3 a
	TKN	20.5 b	1.10 b	1.9 b	0.11 b	366.2 b
Red lettuce	PE	22.0 b	1.23 b	2.0 b	0.13 b	469.2 b
	TKP	25.2 a	1.45 a	2.7 a	0.15 a	528.3 a
	TKN	23.0 b	1.30 b	2.1 b	0.13 b	485.7 b
Chicory	PE	11.3 b	0.96 b	1.8 a	0.12 a	226.0 b
	TKP	13.1 a	0.99 a	1.9 a	0.13 a	258.4 a
	TKN	11.7 b	0.97 b	1.8 a	0.12 a	228.7 b

^{z} Mean separation within columns by Duncan's multiple range test at $p \le 0.05$

as well as dust). Dust can be a serious problem in arid, dusty areas as well as in highly industrialized zones, since dust accumulation on the outer surface of greenhouse cover can notably decrease its light transmission and consequently lower the crop yield and its quality (Jaffrin an Morisot, 1994; Geoola, 1998). Dust and dirt are strongly attached to the plastic surface and even strong precipitations cannot remove the dirt. Hasson (2008) reported that dust accumulation over 22 week period reduced light transmittance of plastic cover film with the thickness of 0.18mm by 60%. According to the author this reduction in light transmittance highly lowered capsicum plant growth and decreased its yield by 33%. Measurement of optical characteristics of 3 covering films after 3 month of utilization also showed that dust accumulation was the main source for decreasing light transmittance. Even after heavy rain which was occurred several times during the testing period dust and dirt were not completely removed from the plastic film surface. Loss in transmittance was observed for all examined cover films, however higher loss in transmittance due to dust and dirt accumulation was observed for conventional PE film compared to TKN and TKP films.

In our previous report (Kwon et al., 2012) we observed that light intensity and temperature inside the cultivation area were altered due to different cover materials. When compared to conventional cover material mean, daily and night air temperatures in greenhouses covered by PO based plastic film were significantly higher. However, present experiments showed that air temperature differences in greenhouses covered by two PO and PE were not so large.

Leaf net CO_2 assimilation rate, stomatal conductance and transpiration values were not affected by covering film, except green lettuce which had significantly higher CO_2 assimilation rate under TKP film compared to those grown under TKN and PE films. These differences in gas exchange parameters can be explained by the specific light requirements of the examined crops.

Growth and yield of all leaf vegetables without exclusion were enhanced under two polyolefin greenhouses compare to those under PE. This is consistent with our previous reports (Kwon et al., 2012), where lettuce and cucumber yield was also increased in greenhouses covered by PO plastic film. Better growth and increased yield of leaf vegetables in greenhouses covered by TKP and TKN films can be explained by better light conditions, which is crucial in early spring season. Moreover TKP and TKN films have a lower transmittance to solar ultra violet radiation. As shown by several reports related to UV's biological effect (Krizek et al., 1997, 1998; Kittas et al., 2006), plant growth and development were enhanced in cultivation areas with the exclusion of UV-B and UV-A radiation.

Results of this and previously conducted experiments clearly show that PO based newly developed functional films have better mechanical and optical characteristics than conventional polyethylene films. Growth and yield of leaf vegetables was increased in greenhouses covered by PO based films. In our opinion this increase in yield was due to combined effect of higher transmittance for PAR and lower transmittance for solar UV radiation of TKP and TKN films. Despite their low prices, PE based films have relatively short useful life, and after certain period of time they must be replaced, which is time consuming and labor intensive operation. Moreover PE films are more prone to accumulation of dust and dirt on their outer surface, which is one of the main factors for decreasing PAR transmittance. According to results of present study we can conclude that TKP and TNK plastic films can be a good alternative to the conventional PE films as a greenhouse cover.

Literature Cited

Baytorun, N., K. Abak, H. Tokgöz and Ö. Altuntas. 1994. Effect of different greenhouse covering materials on inside climate and on the development of tomato plants. Acta Hort. 366:125-132.

Cemec, B., Y. Demir and S. Uzun. 2005. Effects of greenhouse covers on growth and yield of Aubergine. Europ. J. Hort.Sci. 70:16-22.

Geoola, F., Y. Kashti and U.M. Peiper. 1998. A model greenhouse for testing the role of condensation, dust and dirt on the solar radiation transmissivity of greenhouse cladding materials. Journal of Agricultural Engineering research. 71:339-346.

Giacomelli, G.A. and W.J. Roberts. 1993. Greenhouse covering systems. HortTechnology. 3:50-58.

Hasson, A. 2008. Atmospheric dust properties and its effect on light transmission and crop-soil productivity. J. Agri. Food and Environ. Sci. 2.

Jaffrin, A. and A. Morisot. 1994. Role of structure, dirt and condensation on the light transmission of greenhouse covers. Plasticulture. 94:33-44.

Kittas, C., M. Tchamitchian, N. Katsoulas, P. Karaiskou and Ch. Papaioannou. 2006. Effect of two UV-absorbing greenhouse-covering films on growth and yield of an eggplant soilless crop. Sci.Hort. 110:30-37.

Krizek, D.T., R.M. Mirecki, and S.J. Britz. 1997. Inhibitory effects of ambient levels of solar UV-A and UV-B radiation on growth of cucumber. Physiol.Plant. 100:886-893.

Krizek, D.T., R.M. Mirecki, and S.J. Britz. 1998. Inhibitory effects of ambient levels of solar UV-A and UV-B radiation on growth of New Red Fire lettuce. Physiol.Plant. 103:1-7.

Kwon, J.K., K.S. Park, H.G. Choi, S.Y. Lee, K. Bekhzod and N.J. Kang. 2012. Effect of polyolefin greenhouse covering film on growth of lettuce and cucumber in cool season cultivation. Journal of Bio-environmental control. 21:312-316.

Kwon, J.K. Y.H. Choi, D.K. Park, J.H. Lee, Y.C. Um, and J.C. Park. 2001. Optical and physical properties of covering materials. J. Bio-Env. Con. 10(3):141-147 (in Korean).

Nishimura, Y., Y. Fukumoto, H. Agura and Y. Shimoi. 2009. Growth and developmental characteristics of vegetables grown under spectrum conversion film. Hort. Environ. Biotechnol. 50:416-421.

MAFRA. 2011. Statistics. www.mafra.go.kr/main.jsp.

Papadopoulos, A. and X. Hao. 1997a. Effect of greenhouse covers on seedless cucumber growth, productivity, and energy use. Sci.Hort. 68:113-123.

Papadopoulos, A. and X. Hao. 1997b. Effects of three greenhouse cover materials on tomato growth, productivity, and energy use. Sci.Hort. 70:165-178.

Wikipedia. 2014. Polyolefin. https://en.wikipedia.org/wiki/Polyolefin.

Wiles, D.M. and G. Scott. 2006. Polyolefins with controlled environmental degradability. Polymer degradation and stability. 91:1581-1592.

2종류의 기능성필름이 광학특성과 엽채류 생육과 수량에 미치는 영향

권준국*·벡조드·박경섭·최효길·이재한·유인호

국립원예특작과학원 시설원예시험장

적 요. 소형 비닐하우스에 2종류의 기능성 필름과 관행의 PE 필름을 피복하고 청치마, 적치마, 치커리 등 3종의 엽채류를 재배하여 기능성필름의 특성을 검토하였다. 2종류의 기능성 필름은 PO(polyorefine)계 수지로 만들어졌으며, 엽채류는 흙과 펄라이트를 혼합한 배지에서 육묘하였다. 필름의 광학적 특성에 있어서 기능성 필름은 관행의 PE 필름과 비교하여 광합성 유효광(400-700nm)의 투과율이 높고 자외선(300-400nm)의 흡수율이 높았다. 피복 3개월 후의 광합성 유효광 투과율의 감소 수준은 기능성필름이 PE필름보다 작았다. 이 같은 요인으로 인해 엽채류의 생육과 수량이 기능성 필름을 피복한 하우스에서 높았다.

추가주요어 : 피복재, 온실, 미기상, 광합성유효광, 폴리에칠렌, 폴리오레핀