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Photometric Analysis of Low-Density Polyethylene for Enhanced Greenhouse Films

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Abstract
Low-density polyethylene (LDPE) has emerged as a versatile material for greenhouse coverings, offering sustainable solutions to enhance agricultural productivity. Light transmission and diffuse reflection are crucial considerations when selecting greenhouse covering materials. High light transmission is desirable to facilitate photosynthesis and healthy plant growth by allowing ample sunlight to reach plants. Conversely, diffuse reflection scatters light evenly, reduces shadow formation, and ensures uniform light distribution across plants, promoting optimal growth. Certain greenhouse coverings are engineered to possess specific levels of diffuse reflection, further enhancing plant growth and yield. This paper investigates the role of LDPE in optimizing environmental conditions and improving crop performance in greenhouse systems. It emphasizes the potential of LDPE as a sustainable solution for maximizing crop production by measuring its optical properties as diffuse reflection and the ultraviolet protection factor (UPF). Where excessive exposure to UV radiation can lead to sunburn, reduced photosynthesis, and damage to plant tissues.

Keywords: Diffused Reflectance, Transmittance, Polyethylene, Greenhouse Covering, Ultraviolet Protection Factor (UPF)

1. Introduction

Greenhouse agriculture has revolutionized food production by enabling year-round cultivation and protection of crops from adverse environmental conditions. The selection of appropriate materials for greenhouse coverings plays a critical role in optimizing environmental conditions for plant growth and cultivation [1, 2]. Among the diverse range of materials available, Polyethylene (PE) has gained widespread popularity as a greenhouse covering material due to its favorable properties, including flexibility, optical clarity, thermal insulation, and chemical resistance [3, 4]. Polyethylene films used as greenhouse coverings are typically manufactured through extrusion processes, resulting in thin, flexible sheets with varying thicknesses [5]. The molecular structure of polyethylene imparts remarkable mechanical properties, including high tensile strength, tear resistance, and flexibility [6]. These structural characteristics allow polyethylene films to withstand environmental stresses such as wind, snow loads, and hail impact, ensuring durability and longevity in greenhouse applications [7, 8]. These properties and benefits make LDPE films suitable for applications such as packaging (including food packaging), agriculture (greenhouse covers, mulch films), medical products (medical packaging, disposable gloves), construction (vapor barriers), and many other industries where their unique combination of properties is advantageous [9, 10]. One of the key functions of greenhouse coverings is to regulate the internal microclimate by controlling the transmission and retention of solar radiation [11]. Polyethylene films exhibit favorable thermal properties, including low thermal conductivity and infrared-transmitting capabilities. These properties facilitate the absorption of solar radiation within the greenhouse while minimizing heat loss to the external environment [12, 13]. Additionally, polyethylene films possess insulating properties, which help maintain stable temperature levels conducive to plant growth and development [14].

The optical clarity of greenhouse coverings influences the transmission of sunlight and the distribution of photosynthetically active radiation (PAR) within the greenhouse. Polyethylene films exhibit high optical clarity, allowing for efficient transmission of sunlight across a broad spectrum of wavelengths [15-17]. This enables uniform distribution of light within the greenhouse, promoting optimal conditions for photosynthesis and plant growth. Furthermore, polyethylene films can be tailored to modify light transmission properties, such as diffusing or blocking specific wavelengths, to suit the requirements of different crops and growing conditions [18, 19]. This paper aims to provide a comprehensive overview of the utilization of colored polyethylene in greenhouse applications, covering its optical properties. Using different colors of low-density polyethylene (LDPE) films in greenhouses can serve multiple purposes and address specific needs in agricultural practices. For that purpose, the optical properties of four colored samples were measured, additionally, the ultraviolet protection factor (UPF) was determined to assess which samples have good UV protection.

2. Experimental Materials

The Cary 5000 spectrophotometer was used to measure the reflection of four samples against a white and black background. Reflection comprises two components: Specular and diffuse. Specular reflectance is the mirror-like reflection off a sample surface while diffuse reflectance occurs when the surface reflects light in many different directions, giving the surface a matt finish. Traditionally, the accessory used to measure diffuse reflectance is the integrating sphere. Cary 5000 spectrophotometer is attached with a diffuse reflectance accessory consisting of a 73 mm diameter integrating sphere. The sphere is easily installed in the sample compartment of the instrument and features an in-built high-performance photomultiplier. The interior of the sphere is coated with highly reflective barium sulfate paint or PTFE. These paints have a reflectivity greater than 0.98 over most of the UV-visible region, maintaining a high signal-to-noise ratio and enabling the operation of the accessory from 200 to 800 nm. Fig.1 shows the spectrophotometer model Cary 5000.

Fig 1: Spectrophotometer Cary 5000

When measuring diffuse reflection, white and black backgrounds are often used whereas a white background is typically used because it reflects light uniformly in all directions. This allows for accurate measurement of the diffuse reflection from the sample, without interference from the background itself. The white background helps to minimize any variations or unevenness in the reflected light, ensuring more reliable measurement results. A black background is used to measure the total reflection, which includes both the specular and diffuse reflection components. The black background absorbs the secularly reflected light, preventing it from interfering with the measurement of the diffuse reflection. This helps to isolate and measure only the diffusely reflected light, providing a more accurate characterization of the sample. By using white and black backgrounds, the measurement of diffuse reflection can be performed with greater accuracy and precision, ensuring that the obtained results are representative of the sample's diffuse reflection properties. Fig.2 shows a diagram of four different colored Polyethylene samples.

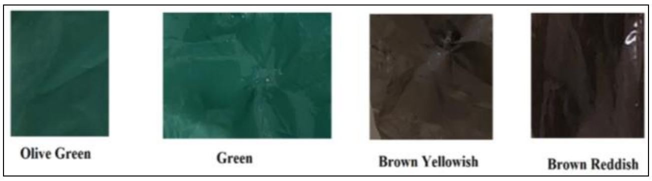

Fig 2: Schematic diagram of four different colored Polyethylene samples

3. Results and discussion

By selecting specific colors, growers can modify the quality and quantity of light that plants receive, influencing their growth and development [20, 21]. The transparent or clear LDPE films allow maximum light transmission, while colored films can selectively filter or block certain wavelengths of light. This can be advantageous for light-sensitive crops or when specific light conditions are desired. On the other hand, some LDPE films are designed with light-diffusing properties [22]. These films help scatter and distribute light more evenly throughout the greenhouse, reducing the formation of shadows and minimizing the risk of plant sunburn. Additionally, the color of LDPE films can influence their heat absorption and reflection properties. Dark-colored LDPE films, such as black or dark green, tend to absorb more heat from sunlight, which can be beneficial in cooler climates or during colder seasons by providing additional warmth to the greenhouse. On the other hand, lighter-colored films, such as white or light green, reflect more sunlight and heat, helping to maintain cooler temperatures inside the greenhouse during hot weather conditions. Additionally, colored LDPE films can be used to manage pests in greenhouse environments. Certain colors, such as yellow or blue, can attract specific insect pests, serving as a trap for them. By strategically placing LDPE films of specific colors, growers can lure and capture pests, helping to protect crops and reduce the need for chemical pesticides. It's important to note that the selection of LDPE film color for greenhouse applications should consider the specific needs of the crops being cultivated, the local climate conditions, and the goals of the grower.

Figs. 3,4, show the diffused reflectance spectra over wavelength for the green and olive-green samples measured in white and dark backgrounds. When the difference between the two curves is small, it remains opaque, and when the difference is large, it remains more transparent where the color difference indicates the transmittance.

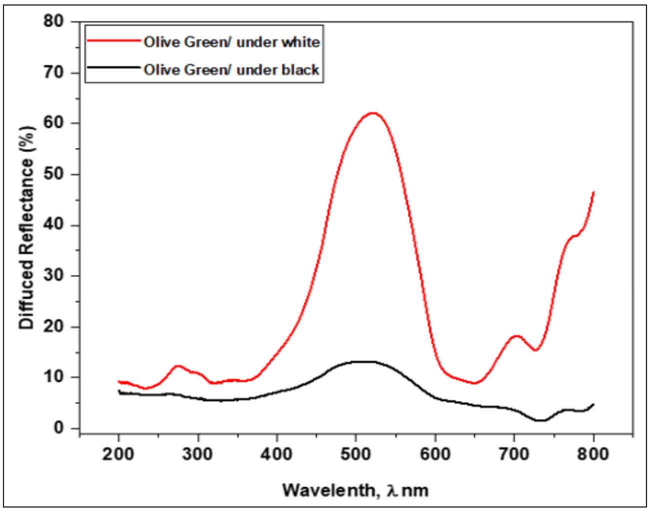

Fig 3: Diffused reflectance spectra over wavelength for the Olive-green sample

Transparent samples of Low-Density Polyethylene (LDPE), such as green and olive-green varieties, permit light to pass through, providing clarity and visibility of objects or contents behind them. While LDPE is commonly opaque or semi-opaque, transparent forms can be produced based on specific formulations and processing methods. Transparent LDPE facilitates high levels of light transmission, ensuring plants receive sufficient sunlight for photosynthesis. This feature is particularly advantageous in regions with limited natural light or during periods of low sunlight, such as winter months. Transparent LDPE coverings optimize sunlight exposure, enhancing plant growth and productivity. Moreover, they contribute to efficient solar heat gain within the greenhouse. Transparent LDPE can enhance the visual appeal of the greenhouse and the plants within. It allows customers or visitors to see the vibrant colors, shapes, and overall quality of the cultivated crops. Additionally, transparent LDPE can provide an attractive display for retail greenhouses, making the plants more appealing to potential buyers.

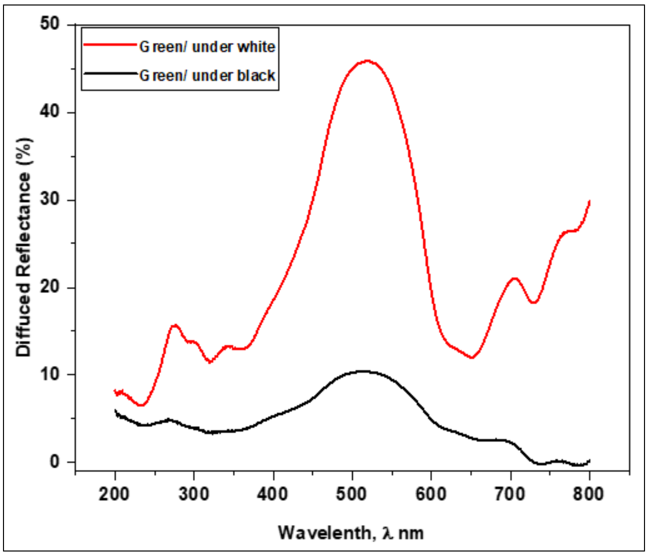

Fig 4: Diffused reflectance spectra over wavelength for green sample

Figs. 5, 6, show the diffused reflectance spectra over wavelength for brown-yellowish and brown-reddish samples measured in white and dark backgrounds. The opaque or semi-opaque samples of Low-Density Polyethylene (LDPE), like the brown-yellowish and reddish, indicate that the material does not transmit light, resulting in a lack of transparency.

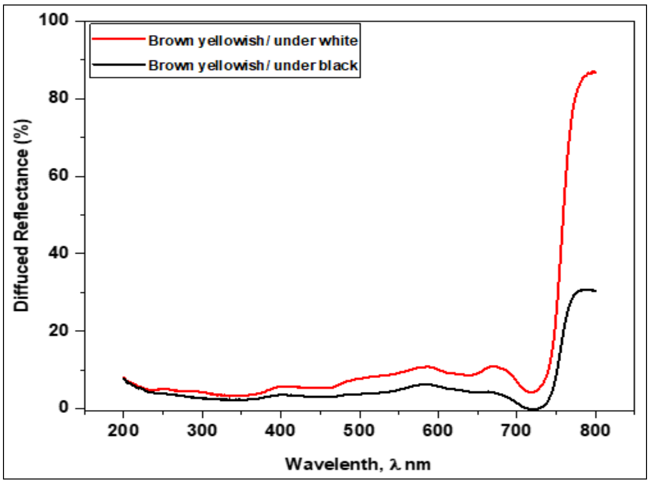

Fig 5: Diffused reflectance spectra over wavelength for the Brown yellowish sample

This opacity proves beneficial in scenarios where light exposure needs to be restricted, or a non-transparent appearance is preferred. Additionally, it aids in diffusing sunlight entering the greenhouse, promoting uniform light distribution across the growing area [8]. This diffusion minimizes the formation of hotspots and reduces the risk of plant damage from excessive heat or light exposure, fostering more consistent growth. The opaque LDPE helps to filter and reduce the intensity of UV radiation, providing a more suitable environment for plant growth [23, 24].

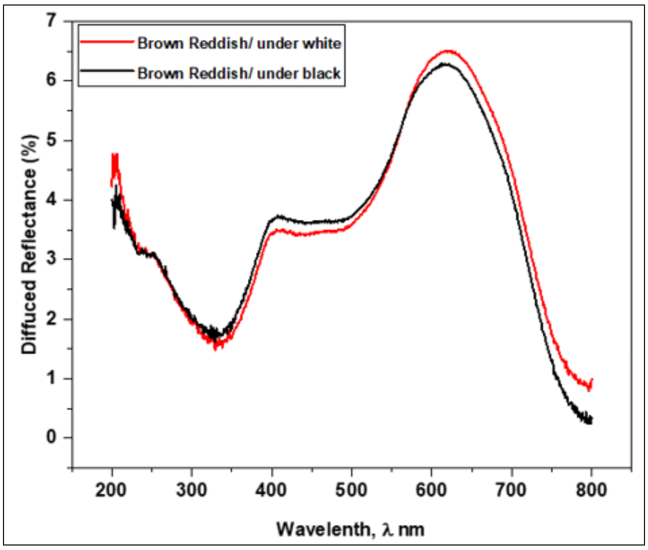

Fig 6: Diffused reflectance spectra over wavelength for Brown reddish sample

The Ultraviolet Protection Factor (UPF)

To determine the ultraviolet protection factor (UPF), the diffused transmittance for the samples was measured in the UV spectral range of 200-400 nm using the integrating sphere attachment on Cary 5000 spectrophotometer. Fig.7 shows the diffused spectral transmittance over wavelength for the four colored samples.

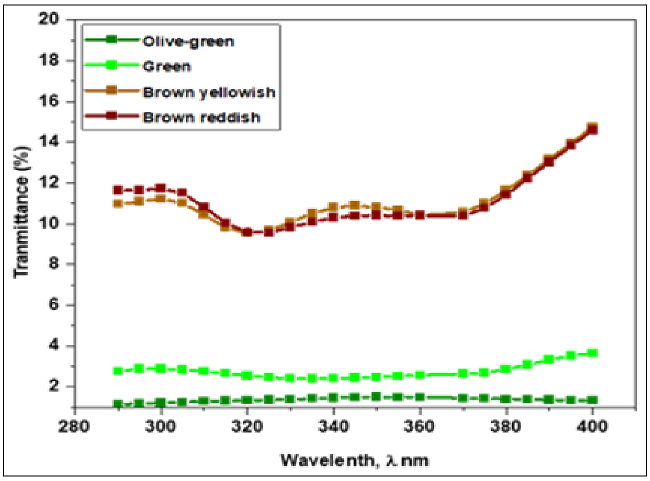

Fig 7: The spectral transmittance over wavelength for the four colored samples

The UPF is defined as the ratio between ED and ED_m where ED is the average effective UV radiation transmitted through the air while ED_m is the average effective UV radiation transmitted through the sample under investigation. Accordingly, the UPF is calculated using the following equation [25]:

$$UPF = \frac{ED}{ED_m} = \frac{\sum_{\lambda=290}^{400} S(\lambda)\, E(\lambda)\Delta\lambda}{\sum_{290}^{400} S(\lambda)\, E(\lambda)T(\lambda)\, \Delta\lambda} \quad (1)$$

Where E(λ) is the relative erythemal spectral effectiveness which is calculated according to the standard ISO/CIE 17166:2019 and S(λ) is the solar spectral irradiance in (W/m2/nm) according to the CIE [26] while T(λ) is the spectral transmittance at wavelength λ; and Δλ is the wavelength (in nm). The Ultraviolet Protection Factor (UPF) is categorized according to various international standards, such as the Australian/New Zealand and the American Society for Testing and Materials Standards (ASTM). These classifications denote the degree of UV protection offered by the fabric, with higher UPF values signifying superior protection, as outlined in Table 1 [27].

Table 1: The UPF classification categories according to AS/NZS 4399:2017

Classification	UPF rating
Minimum	15-20
Good	25-35
Excellent	50, 50+

Another classification is outlined in the ASTM standard for assessing the efficacy of sun-protective fabrics ASTM D6603 [28]. Although ASTM D6603 does not prescribe a specific UPF classification system, it sets forth the methodology for testing fabrics to determine their UPF values. These UPF values, derived from testing, can then be utilized to categorize the level of UV protection offered by the fabric as seen in Table 2.

Table 2: The UPF classification categories according to ASTM D6603

Classification	UPF rating	UV protection
Good	15-24	93.3-95.9%
Very Good	25-399	96.0-97.4%
Excellent	40, 50+	97.5%+

Both standards assess the UV-blocking effectiveness of fabrics and garments. The UPF rating indicates the amount of UV radiation that can penetrate the fabric and reach the skin. Higher UPF ratings indicate better protection against harmful UV rays [29, 30]. The standard recommends labeling products with the specific UPF value obtained during testing. This labeling allows consumers to easily identify the level of UV protection provided by the fabric. The UPF results of four colored samples are reported in Table.3.

Table 3: The UPF classification categories according to ASTM D6603

Samples	UPF Value	Statues
Brown yellowish	80.36	Excellent protection
Brown reddish	35.70	Very good protection
Green	9.19	No class
Olive green	8.87	No class

4. Conclusions

The paper provided the optical properties of colored polyethylene for greenhouse applications. Using different colors of low-density polyethylene (LDPE) films in greenhouses can serve multiple purposes and address specific needs in agricultural practices. additionally, the ultraviolet protection factor (UPF) was determined to assess which samples have good UV protection. Low-density polyethylene (LDPE) can be either opaque or transparent, depending on its formulation and intended application. The opaque nature of LDPE provides benefits such as light diffusion, UV protection, energy efficiency, privacy, and pest management in a greenhouse setting. On the other hand, transparent LDPE offers advantages such as high light transmission, solar heat gain, enhanced visibility, energy efficiency, compatibility with light-dependent processes, and improved aesthetics. Both opaque and transparent LDPE have their own set of advantages in greenhouse applications, and the choice between them depends on specific requirements, climate conditions, and the desired outcomes for plant growth and development. It is important to consider factors such as light levels, temperature regulation, UV protection, pest control, and the ability to monitor plant health when selecting the appropriate LDPE type for a greenhouse. Ultimately, LDPE's versatility as a greenhouse covering material allows growers to tailor the light transmission, heat retention, and other environmental factors according to the needs of the cultivated plants, leading to optimal growth, productivity, and overall success in greenhouse operations.

5. Conflicts of interest

There are no conflicts to declare.

6. References

1. Maraveas C. Environmental Sustainability of Greenhouse Covering Materials, Sustainability. 2019; 11:6129. Doi: https://doi.org/10.3390/su11216129.
2. Maraveas C, Kotzabasaki MI, Bayer IS, Bartzanas T. Sustainable Greenhouse Covering Materials with Nano- and Micro-Particle Additives for Enhanced Radiometric and Thermal Properties and Performance, AgriEngineering. 2023; 5:1347-1377. Doi: https://doi.org/10.3390/agriengineering5030085.
3. Briassoulis D, Schettini E. Analysis and design of low-density polyethylene greenhouse films, Biosyst. Eng.

2003; 84:303-314.

4. Dilara PA, Briassoulis D. Standard testing methods for mechanical properties and degradation of low density polyethylene (LDPE) films used as greenhouse covering materials: A critical evaluation, Polym. Test. 1998; 17:549-585.
5. Huang Z, Guo Y, Zhang T, Zhang X, Guo L. Fabrication and Characterizations of Zeolite β–filled Polyethylene Composite Films, Packag. Technol. Sci. 2013; 26:1-10. Doi: https://doi.org/https://doi.org/10.1002/pts.1986.
6. Jin H, Gonzalez-Gutierrez J, Oblak P, ZupančičB, Emri I. The effect of extensive mechanical recycling on the properties of low density polyethylene, Polym. Degrad. Stab. 2012; 97:2262-2272. Doi: https://doi.org/https://doi.org/10.1016/j.polymdegradstab.2012.07.039.
7. Salakhov II, Shaidullin NM, Chalykh AE, Matsko MA, Shapagin AV, Batyrshin AZ, *et al*. Low-Temperature Mechanical Properties of High-Density and Low-Density Polyethylene and Their Blends, Polymers (Basel). 2021; 13. Doi: https://doi.org/10.3390/polym13111821.
8. Alghdeir M, Mayya K, Dib M. Characterization of Nanosilica/Low-Density Polyethylene Nanocomposite Materials, J. Nanomater, 2019, 1-8. Doi: https://doi.org/10.1155/2019/4184351.
9. Kyu T, Hu S, Stein RS. Characterization and properties of polyethylene blends II. Linear low - density with conventional low - density polyethylene. J. Polym. Sci. Part B Polym. Phys. 1987; 25:89-103. Doi: https://doi.org/10.1002/polb.1987.090250107.
10. Nolley E, Barlow JW, Paul DR. Mechanical properties of polypropylene-low density polyethylene blends, Polym. Eng. Sci. 1980; 20:364-369. Doi: https://doi.org/https://doi.org/10.1002/pen.760200508.
11. Shida RN, Cancio LV. Correlation of low density polyethylene rheological measurements, with optical and processing properties, Polym. Eng. Sci. 1977; 17:769-774. Doi: https://doi.org/https://doi.org/10.1002/pen.760171102.
12. Ngu JLS, Noshida I, Akmil M, Chuah AL, Thevy RC. Thermal properties of low-density polyethylene/ALPHA- alumina nanocomposites, J. Thermoplast. Compos. Mater. 2011; 25:415-426. Doi: https://doi.org/10.1177/0892705711411340.
13. Luyt AS, Molefi JA, Krump H. Thermal, mechanical and electrical properties of copper powder filled low-density and linear low-density polyethylene composites, Polym. Degrad. Stab. 2006; 91:1629-1636. Doi: https://doi.org/https://doi.org/10.1016/j.polymdegradstab.2005.09.014.
14. Arrakhiz FZ, El Achaby M, Malha M, Bensalah MO, Fassi-Fehri O, Bouhfid R, Benmoussa K, *et al*. Mechanical and thermal properties of natural fibers reinforced polymer composites: Doum/low density polyethylene, Mater. Des. 2013; 43:200-205. Doi: https://doi.org/https://doi.org/10.1016/j.matdes.2012.06.056.
15. Johnson MB, Wilkes GL, Sukhadia AM, Rohlfing DC. Optical properties of blown and cast polyethylene films: Surface versus bulk structural considerations, J. Appl. Polym. Sci. 2000; 77:2845-2864. Doi: https://doi.org/https://doi.org/10.1002/1097-4628(20000923)77:13<2845::AID-APP6>3.0.CO;2-7.
16. Painter LR, Arakawa ET, Williams MW, Ashley JC. Optical Properties of Polyethylene: Measurement and Applications, Radiat. Res. 1980; 83:1-18. Doi: https://doi.org/10.2307/3575254.
17. Shen L, Nickmans K, Severn J, Bastiaansen CWM. Improving the Transparency of Ultra-Drawn Melt-Crystallized Polyethylenes: Toward High-Modulus/High-Strength Window Application, ACS Appl. Mater. Interfaces. 2016; 8:17549-17554. Doi: https://doi.org/10.1021/acsami.6b04704.
18. Laverde G. Agricultural Films: Types and Applications, J. Plast. Film Sheeting. 2002; 18:269-277. Doi: https://doi.org/10.1177/8756087902034748.
19. Russo P, Acierno D, Marinucci L, Greco A, Frigione M. Influence of natural and accelerated weathering on performances of photoselective greenhouse films, J. Appl. Polym. Sci. 2013; 127:2213-2219. Doi: https://doi.org/10.1002/app.37914.
20. Delgado AE, Aperador Chaparro W, García Cáceres RG. Effect of modified greenhouse covers on the development of plants of lycopersicon esculentum mill, DYNA. 2020; 87:91-97. Doi: https://doi.org/10.15446/dyna.v87n213.81082.
21. Zhu G, Xia N, Xue M, Li Z, Zhao H, Qu C. Effects of colored polyethylene film mulch on pest populations, plant growth and yield of peanut in Northern China, J. Asia. Pac. Entomol. 2022; 25:101944. Doi: https://doi.org/https://doi.org/10.1016/j.aspen.2022.101944.
22. Lin Y, Cao J, Zhu M, Bilotti E, Zhang H, Bastiaansen CWM, Peijs T. High-Performance Transparent Laminates Based on Highly Oriented Polyethylene Films, ACS Appl. Polym. Mater. 2020; 2:2458-2468. Doi: https://doi.org/10.1021/acsapm.0c00404.
23. Khraishi N, Al-Robaidi A. Effect of weathering on UV-stabilized low density polyethylene films (LDPE) for a multilayer greenhouse cover, Polym. Degrad. Stab. 1991; 32:105-114. Doi: https://doi.org/https://doi.org/10.1016/0141-3910(91)90066-Z.
24. Basfar AA, Ali KMI, Mofti SM. UV stability and radiation-crosslinking of linear low density polyethylene and low density polyethylene for greenhouse applications, Polym. Degrad. Stab. 2003; 82:229-234.
25. Laperre J, Gambichler T, Driscoll C, Böhringer B, Varieras S, Osterwalder U, *et al*. Determination of the ultraviolet protection factor of textile materials: Measurement precision, Photodermatol. Photoimmunol. Photomed. 2001; 17:223-229. Doi: https://doi.org/https://doi.org/10.1111/j.1600-0781.2001.170504.x.
26. Erythema reference action spectrum and standard erythema dose, CIE, n.d. https://www.iso.org/standard/74167.html.
27. AS/NZS 4399:2017: Standards New Zealand, n.d. https://www.standards.govt.nz/shop/asnzs-43992017/ (accessed March 23, 2024).
28. D6603 Standard Specification for Labeling of UV-Protective Textiles, n.d. https://www.astm.org/d6603-19.html (accessed March 23, 2024).

29. Quintero-Arias DG, Acuña-Caita JF, Asensio C, Valenzuela JL. Ultraviolet Transparency of Plastic Films Determines the Quality of Lettuce (Lactuca sativa L.) Grown in a Greenhouse, Agronomy. 2021; 11:358. Doi: https://doi.org/10.3390/agronomy11020358.
30. Belhachemi A, Maatoug M, Canela-Garayoa R. Comparative analysis by UV-vis and FT-IR spectroscopy of the chemical degradation of polyethylene used as greenhouse cover film, J. Elastomers Plast. 2022; 54:891-905. Doi: https://doi.org/10.1177/00952443221077439.