

Performance of bio-based films in agricultural and food packaging applications

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Abstract

The importance of bio-based products in the global economy is increasing rapidly. New markets develop for innovative products made from bio-based feedstocks. The agrofood sector has an important dual role: producer of renewable raw materials and gradually a major user of bio-based products. The functionality of bio-based and conventional films used in the agrofood sector was investigated in this work for a set of representative mulching and food packaging films. The evaluation was based on testing critical mechanical and other functional properties of the films. Mechanical properties tested included strength, elongation, impact resistance, penetration strength, as applicable. Specific film characteristics were addressed, including moisture sensitivity and the low packaging temperatures effect. Other functional properties tested include water vapour (WV) permeability, contact angle and radiometric properties. Differences were identified in the performance of the various bio-based materials when compared to conventional films. Among them, their higher water vapour permeability, and differences in the penetration and impact resistance, tensile strength and other physical properties. Additional properties such as durability are under investigation. The overall mechanical performance of the bio-based films was found to be satisfactory in general. The higher WV permeability of bio-based mulching films may result in a two-way transfer of moisture depending on the ambient conditions and soil humidity. Bio-based packaging films allow for achieving optimized EMA packaging conditions because of their high WVTR combined with their barrier function to CO₂ and O₂ gases. The characteristics of the bio-based films offer new design possibilities for targeted applications.

Keywords: Bio-based materials, packaging films, mulching films, mechanical and functional properties, testing methods

1. Introduction

Plastics production in Europe (EU28+NO/CH) appears to be stable (59 mt) over the period 2004-2014 while at worldwide level it grows (225-311 mt) (PlasticsEurope, 2015). The Packaging sector has the highest share of the European plastics at 39.5% while Agriculture has a relatively low share of 3.4% (2014 data; PlasticsEurope, 2015). A major negative consequence of the expanding use of plastics for protected horticulture is related to handling the plastic wastes and the associated environmental impact as only a small percentage, on the average, of the constantly rising amount of agricultural plastic waste is currently recycled (Briassoulis et al. 2010). The agricultural plastic waste cannot always be recovered and recycled while, in many cases, waste mismanagement practices are applied. A large portion of this waste is left on the fields or buried or burnt uncontrollably by the farmers releasing harmful substances with the associated obvious negative consequences to the environment and possibly for the safety of the food produced (Briassoulis et al. 2010). On-site burning or burring of agricultural plastics is illegal (Briassoulis et al. 2010). The main reasons for the mismanagement especially of the plastic mulching film waste are the high labour cost and the technical difficulties for the proper removal and disposal of the agricultural plastic wastes following the end of the cultivation (Briassoulis et al. 2010, Briassoulis, D. 2007). Costs for polyethylene mulch disposal (not including labour) can be up to \$100 per acre (250 \$/ha) (Shogren, 2004). Recycling is not considered as a cost efficient /or a technically feasible solution, for the thin and dirty mulching and low-tunnel films that have to be sent for a most costly disposal (e.g. energy recovery). An attractive solution, in parallel to the circular economy principles (Labelagriwaste project, 2006-09), is the use of bio-based materials in the place of conventional fossil-oil based polymers for development of biodegradable in soil mulching films. The use of bio-based biodegradable in the soil mulching films results in significant saving in material (thinner films) and in the elimination of the disposal cost.

Concerning packaging applications, the food sector including horticultural produce, has the highest share of conventional fossil-oil based packaging material demand (WPO, 2008). The majority of these plastics are non-biodegradable, while some of them, such as food packaging materials, are difficult to recycle or reuse due to being complex laminates having varying levels of contaminations like colourants, printing inks and adhesives. Since plastic packaging accounts for a significant majority of total plastic waste it has caused increasing environmental concerns favouring their replacement with biodegradable – compostable bio-based plastics.

The production of bio-based plastics reached 1.7 Mt (3.5% of the global plastics market) in 2014 and is estimated to grow to 7.9 Mt by 2019 (European Bioplastics, 2015). According to European Bioplastics (2015) the European market for bioplastics covers, at present, a volume of about 0.2-0.5 Mt. The annual growth of this sector is estimated at 20% and it is estimated that the European market for bioplastics in 2020 will reach 1-3 Mt (5-10% of the global plastics market) (Biochem project, 2010). The market potential of bio-based plastics is very high based on the estimations that after 2030,

bio-based plastics may reach a share of 70-100% of the plastics market, including both, those that will replace conventional plastics and completely new innovative ones (Biochem project, 2010). Technological development for new bio-based plastics is fast (Shen, 2009) with many applications (e.g. mulch films, compostable waste bags, packaging films and rigid packaging etc.).

Examples of frequently used biodegradable (under composting conditions) bio-based plastics in packaging applications are PLA, starch blends (like Mater-Bi) and PLA blends (like Ecovio). Products vary from films, trays and foamed products to non-woven materials for tea bags. In addition, the use of the non-biodegradable, bio-based plastics like bio-PE in shopping bags and bottles and bio-PET for bottles increases.

Most materials of biodegradable in soil plastic mulches that are currently available commercially are based on plant starch, blended with other polymers and/or plasticizers. Biodegradable mulching film may be made from biological sources (i.e., bio-based), while some are derived from fossil fuel sources or blends.

The importance of bio-based products in the global economy is increasing rapidly. The functionality of innovative bio-based films developed and used in the agrofood sector is therefore a major issue. The functionality of selected representative bio-based and biodegradable mulching and food packaging films was investigated through testing of a series of key mechanical and physical properties, compared to the corresponding behaviour of conventional films.

2. Materials

2.1. Materials – Bio-based packaging films

Packaging films selected for testing are shown in Table 1. Bio-based products include: Mater Bi EF51V, PLA Nativia NTSS (bi-axially oriented three layer sealable film) and Ecovio. These products are typical examples of bio-based biodegradable packaging films that have a commercial significance. Biaxially oriented polypropylene film (BOPP) was used as conventional fossil-oil based reference packaging film product.

Table 1. Commercial bio-based food packaging films evaluated through inter-laboratory tests

Material	Producer	Commercial product	Description (Product Information)
Mater-Bi [®]	Novamont	Mater-Bi EF51V- 25 μm	Thermoplastic biodegradable material for film blowing
PLA	Taghleef	Nativia NTSS Van der Windt 27 - 30 μm	Bi-axially oriented three layer sealable film (external heat sealable PLA-layers (MST= 85°C); internal PLA core).
Ecovio [®]	BASF	Ecovio F2331 - 30 μm	Compound of the biodegradable copolyester ecoflex [®] and polylactic acid (PLA).
Ecovio [®]	BASF	Ecovio F2223 - 50 μm	
BOPP	Hellenic Petroleum	CO-3-X HP - 30 μm	Biaxially oriented polypropylene film (BOPP). Conventional fossil oil-based reference product.

2.2. Materials – Bio-based mulching films

Mulching films selected for testing are shown in Table 2. Products selected are mulching film Hytibio Noir and Mater-Bi EF04P. These products are typical examples of bio-based biodegradable mulching films that have a commercial significance. Linear Low Density Polyethylene (LLDPE) 3-layer mulching film was used as conventional fossil-oil based reference mulching film product.

Table 2. Commercial bio-based mulching films evaluated through inter-laboratory tests

Material	Producer	Commercial product	Description (Product Information)
Mater-Bi [®]	Novamont	Mater-Bi EF04P - 15 μm	Thermoplastic biodegradable in soil mulching film; contains renewable resources
HYTIBio	Hyplast	HYTIBio - 15 μm	Biodegradable black mulch film
LLDPE	Plasika Kritis	KRITIFIL 6020- 20 μm	Linear Low Density Polyethylene 3-layer black mulching film

3. Methods

3.1. Evaluation of the mechanical functionalities of food packaging films

3.1.1. Key mechanical functionalities of food packaging films

Among the key requirements for the materials used for food packaging are: protection, tampering resistance and special physical, chemical or biological needs to ensure safe and high quality products for the consumer. Some properties of specific bio-based polymers may be enhanced, depending on the particular material and the targeted application requirements, by the use of laminates and additives including nanomaterials such as nanocellulose (Huq et al. 2014, Duncan, 2011). Bio-based plastic packaging films should also meet the requirements set by Framework Regulation EC 1935/2004 on materials and articles intended to come into contact with food.

The mechanical properties of bio-based plastic food packaging materials are important for both processing and during use of the products. The most important mechanical properties of the bio-based plastic food packaging films identified and evaluated for the selected materials include: A. Tensile properties (tensile strength and elongation at break) of bio-

based films are the main mechanical properties characterising the mechanical behaviour of the products and depend on the polymer and the specific blend with other materials (e.g. starch complexed with biodegradable polyesters), use of plasticisers, chemical modifications or combinations of the above (Weber, 2000) and also on processing). Temperature effects on mechanical properties should also be evaluated (e.g. packaging of frozen products: at low temperatures the mechanical properties of bio-based materials may be affected making the polymeric materials brittle and sensitive to mechanical forces (Weber, 2000)). C. Humidity may also affect the mechanical properties of bio-based materials (loss of mechanical properties under water or humid conditions originating either from the ambient or the contained food product (Weber, 2000)). D. The packaging bio-based material should be resistant to tearing. E. Penetration resistance is another important end-use property of thin flexible packaging films. A sharp-edged product can destroy the integrity of the film, possibly contaminating the food and/or changing the packaging conditions and reducing the shelf-life.

3.1.2. Testing of key mechanical functionalities of food packaging films

The key mechanical properties of the selected bio-based packaging films evaluated according to standard testing methods are shown in Table 3. Testing the tensile properties, and penetration resistance was performed with a dynamometer Instron 4204. The penetration resistance was measured using a probe complying with ASTM F1306. Testing tear propagation according to ISO 6383-2 is currently in progress.

Table 3. . List of the mechanical properties of packaging films evaluated and the testing methods

Property	Testing method	Remarks
Tensile properties	ISO 527-3:1995 or ASTM D882-12	
Temperature effect on tensile properties	ISO 527-3:1995 or ASTM D882-12	Testing at -18°C
Humidity effect on tensile properties	ISO 527-3:1995 or ASTM D882-12	Testing samples soaked in water
Penetration resistance	ASTM F1306-90(2008) or EN 14477:2004	

3.2. Evaluation of the physical functionalities of food packaging films

3.2.1. Key physical functionalities of food packaging films

Apart from the key mechanical properties required for the materials used for food packaging, additional functionalities are very important for food packaging films regarding the quality, the safety and the shelf life of the packaged food products. Various functional properties of food packaging films such as gas transport and transparency can differ significantly depending on the material, composition and processing. Gas transport (barrier) and radiometric properties are the most important physical characteristics of bio-based films when used as packaging materials. The gas barrier properties are important when the packaging is used for food products (e.g. horticultural produce) and for modifying the in-package atmosphere (Modified Atmosphere Packaging – MAP). Important properties evaluated for the selected materials include: A. In a typical MAP, a barrier film with low oxygen permeability protects food from oxidation. B. Water vapour (WV) permeability is also critical for several applications in this field. Many food products have to be protected from excessive humidity during their transportation and storage since water is related to infections. However, in certain applications such as Equilibrium Modified Atmosphere (EMAP), which is intended for fresh vegetables and fruits, controlled WV transport through the packaging film is preferred as a means to remove excess humidity due to transpiration. C. The radiometric properties of the packaging films are also important in relationship to marketing considerations. High light transmittance (clarity) is very important for applications where the packaged products have to be visible to the consumers (e.g. fresh fruits). D. Wetting tension of films with respect to water and inks is critical for most food packaging applications. The condensation of water in the form of small droplets at the inner surface of a package results in lower visibility thus decreases the appeal of the packaged product to the customers. Wettability with respect to solvents used for printing is an important functional property of packaging films.

3.2.2. Testing of key physical functionalities of food packaging films

The key physical properties of the selected bio-based packaging films evaluated according to international standard testing methods are shown in Table 4. Testing of the Radiometric properties was performed by a Spectrophotometer HITACHI U-4001 (visible & UV radiation). Water vapour transmittance was measured by exposing samples to control conditions of 38°C and 90%RH. Static contact angles with water for the packaging films were measured by image analysis for estimating the water condensation behaviour of the films. Migration of chemical compounds from packaging polymers into foods, and food safety issues in general, are not considered in this work. End-of-life options, biodegradation in soil for mulching films, compostability of packaging films are covered widely in the relevant literature.

Table 4. . List of the physical properties of packaging films evaluated and the testing methods

Property	Testing method	Remarks
Radiometric properties	ASTM D1003 – 13	
Gas transport properties - Water vapour transmittance	ASTM E96 / E96M – 14	
Wetting tension	ASTM D7490 - 13 , ASTM D7541 - 15 ISO 8296:2003 or ASTM D2578	Static contact angles with water for packaging films

3.3. Evaluation of the mechanical functionalities of mulching films

European Standard EN13655 is applicable to polyethylene and copolymers based mulching films. The Standard specifies the basic requirements for the optical and mechanical characteristics of various types of mulching plastics films used in agriculture and horticulture in the European market.

3.3.1. Key mechanical functionalities of mulching films

Bio-based mulching films should meet a set of minimum design requirements, including: adequate strength and elongation at break for mechanical installation, durability and 100% biodegradation in the soil preferably before the next cultivation season, without ecotoxicity effects (Briassoulis, 2007). The performance of bio-based biodegradable mulching and other agricultural films over their useful lifetime may be comparable to that of the conventional films in terms of tensile strength while the elongation at break of thin bio-based films may drop to very low values within the first weeks of their exposure. The elongation at break value is a sensitive property for thin bio-based biodegradable in soil mulching films as it deteriorates rather quickly when the films are exposed to open field conditions as compared to conventional films. However, despite the significant decrease of the elongation at break, the film remains intact without signs of failure or biodegradation as the tensile strength is not affected during its useful lifetime and, as a result, the whole mechanical behaviour of the bio-based films appears to be satisfactory. This, provided that installation ensures that the holes for the transplantation are opened using appropriate equipment avoiding possible slits that might lead to subsequent failure due to tear propagation.

The most important mechanical properties of the bio-based mulching films have been identified and evaluated for the selected materials include: A. The tensile properties of the bio-based mulching films, both strength and elongation at break, should allow them to be laid and perforated with the same machinery used for traditional plastic film and provide excellent yields as they are very thin, without experiencing mechanical failure problems. Possible water and humidity or low temperature effects on tensile properties need also to be investigated (e.g. under water or humid conditions originating rain, irrigation, high soil water content conditions or low winter temperatures). B. The bio-based mulching films should also be resistant to tear propagation. It is important that no tearing is initiated from the holes made for transplantation. C. Likewise, puncturing by weeds should be avoided. Slow penetration resistance is important for mulching films to be able to resist strong weed species (e.g. *Cyperus rotundus*) that can penetrate and grow through thin films. D. Impact resistance is among the mechanical properties reported for plastic mulching films and covers also rapid penetration resistance. The exposure of these films to open field conditions may result in damages caused by impact. The film needs however to remain intact during use, resisting damage during planting of the crops or by other farmer activities and environmental factors such as hail, high winds, birds or animals. E. Deterioration of the tensile properties of a given bio-based film in the machine direction and transverse direction due to photo-degradation is also an important indirect measure of the deterioration of the other mechanical properties (Briassoulis, 2006). The bio-based mulching films should function satisfactorily during the whole cultivation period for which they are designed to. This means that failures due to impact, tearing or premature biodegradation should be avoided. As mulching film is required to have a durability to match its service life, a weathering test is included in the EN13655 Standard. Enhanced durability is achieved by the use of carbon black acting as stabiliser. If higher durability is required, a small particle size weathering grade of carbon black is selected (for thin films) and, in some cases, a combination of antioxidants is used to avoid degradation during processing that may also affect adversely the film's weathering performance (Cabot, 2008).

3.3.2. Testing of key mechanical functionalities of mulching films

The key mechanical properties of the selected bio-based mulching films evaluated according to international standard testing methods are shown in Table 5. Testing of the tensile properties and penetration resistance was performed by the equipment used to test the packaging films. The effect of weathering is measured by exposing the samples to a QUV accelerated weathering tester at the lab of QWS (Blegium). These tests are in progress. Impact resistance was tested by the Free-Falling Dart Method-A according to ISO 7765-1 or ASTM 1709 provisions using an ATS FAAR (societa per a zioni) machine.

Table 5. List of the mechanical properties of mulching films evaluated and the testing methods

Property	Testing method	Remarks
Tensile properties	ISO 527-3:1995 or ASTM D882-12	Standard conditions; also testing at
Testing low temperature and water effects		-18°C & samples soaked in water
Impact resistance	ISO 7765-1:1988 or ASTM D1709	
Penetration resistance	ASTM F1306-90 (2008)	

3.4. Evaluation of the physical functionalities of mulching films

3.4.1. Key physical functionalities of mulching films

Gas barrier properties of mulching films are also important as they affect the microenvironment of the air and soil under the mulch cover. In cases when transparent or coloured bio-based mulching films, the radiometric properties are also important as they affect the control of weeds and temperature of the soil and the plant above the film. The most important physical functionalities identified and evaluated for the selected materials include: A. One of the most

important physical properties which distinguishes the bio-based mulching films from the conventional LDPE or LLDPE is their water vapour permeability (WVP) as it affects the irrigation needs. Even though bio-based biodegradable mulching films are hydrophilic and exhibit higher WVP in comparison to LDPE films, the provided resistance to water evaporation from soil is sufficient while it allows for rain or increased moisture to enter the space underneath the film. B. Black films block the Photosynthetic Active Radiation (PAR) range of the sun radiation suppressing the weeds growth, the main reason of their dominant use in Agriculture. As black films absorb the solar radiation and warm up, they heat significantly the soil with beneficial effects for many cultivations during spring/fall seasons. Transparent films, on the opposite, transmit the radiation and heat the soil intensely (more than other colours), with the heat trapped between the film and the soil as a result of the greenhouse effect. Such films are not used to control the growth of weeds but mainly for solarization (combined with good barrier properties) during the summer and warming the soil for the early cultivation of vegetables at the end of the winter.

3.4.2. Testing of key physical functionalities of mulching films

The key physical properties of the selected bio-based mulching films evaluated according to international standard testing methods are shown in Table 6. Testing of the barrier properties was performed by the equipment used to test the packaging films.

Table 6. List of the physical properties of mulching films evaluated and the testing methods

Property	Testing method	Remarks
Radiometric properties	ASTM D1003 – 13	Non applicable to black films
Gas transport properties - Water vapour transmittance	ASTM E96 / E96M – 14	

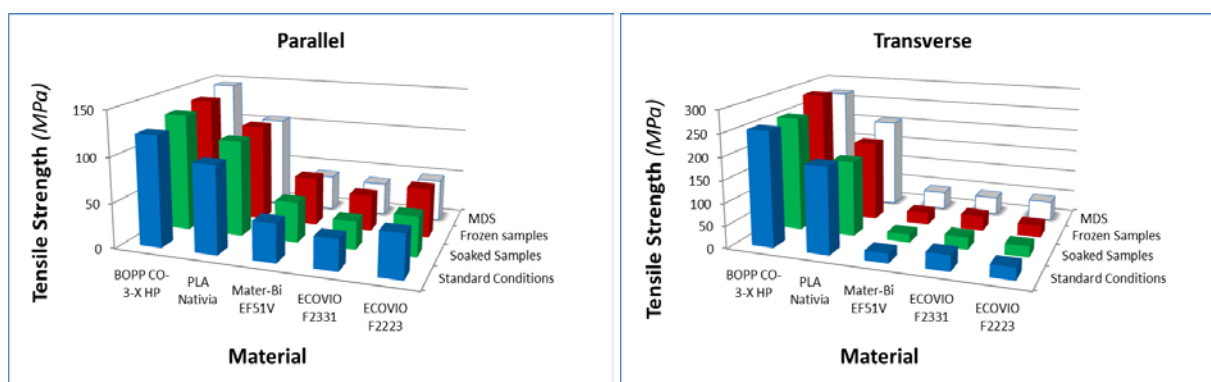
4. Results and Discussion

4.1. Packaging films

4.1.1. Mechanical functionalities of food packaging films

The tensile properties of the packaging films under standard testing conditions and under conditions of low temperature (at -18°C) and water are presented in Figure 1. Tensile strength values are in agreement with the corresponding values given by the manufacturers (MDS). Tensile strength of the films is not affected by the low temperature and water. Mater-Bi and Ecovio films have low tensile strength values in MD/TD directions (Mater-Bi: 43.0/21.5 MPa, Ecovio F2331: 34.0/35.0, Ecovio F2223: 48.0/27.0) as compared to PLA and the reference BOPP films. Elongation at break values, measured under standard testing conditions, are also in agreement with the values given by the manufacturers (MDS) except for one case. Mater-Bi and Ecovio films have higher elongation at break values in MD/TD directions, as compared to PLA and the reference BOPP films, especially in TD (BOPP: 47%; PLA: 96%). The results indicate reduction of the elongation at break under frozen conditions (in MD/TD directions; higher in TD) for all PLA based and Mater-Bi films (reduction % MD/TD: PLA: 35.4/30.6; Ecovio F2331: 31.7/42.3; Ecovio F2223: 21/48; Mater-Bi: 10.7/33.0). The elongation at break of Mater-Bi is also reduced under water conditions (reduction % TD: 42.0).

The penetration resistance measured according to ASTM F1306-90 revealed a typical linear elastic behaviour for BOPP and PLA films with high stress at yield and tensile strength while the Ecovio and Mater-Bi films experience two-peak curves: the first peak represents yielding and the second one represents rupture. This behaviour does not allow direct application of the method ASTM F1306-90 for the cases of the Ecovio and Mater-Bi films (and films with similar behaviour). Penetration resistance for these films was calculated based on the first yielding-depending peak. The results presented in Figure 2 indicate high penetration resistance values for BOPP and PLA films and significantly lower resistance values for the Mater-Bi and Ecovio films.



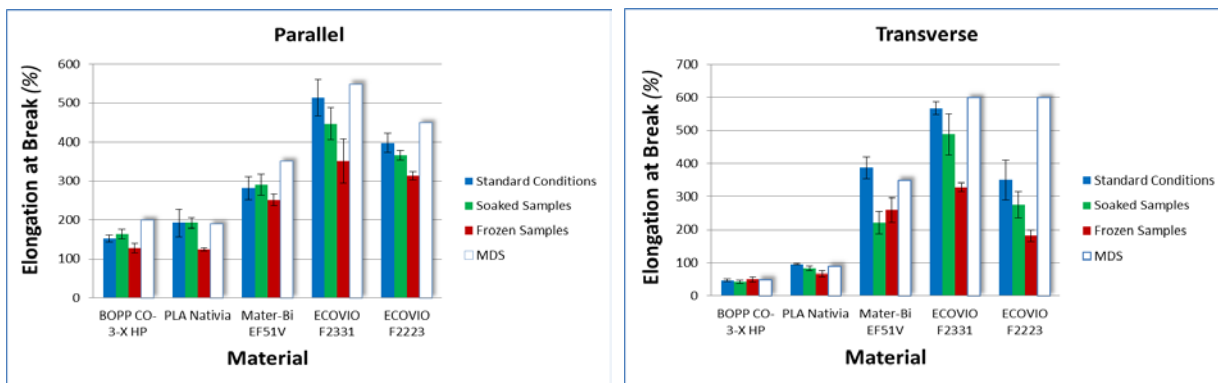


Figure 1. Tensile properties of bio-based food packaging films

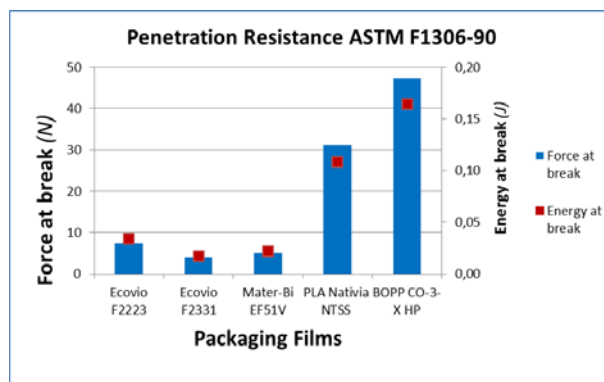


Figure 2. Penetration resistance of bio-based food packaging films (ASTM F1306-90)

4.1.2. Physical functionalities of food packaging films

The water vapour transmittance values measured according to the standard ASTM E96 / E96M – 14 under conditions: 38°C 90%RH, are presented in Figure 3. WVTR of all bio-based films exceeds significantly the corresponding values of the conventional reference films. The radiometric properties of the packaging films are presented in Figure 3. The two Ecovio films, followed by Mater-Bi films, exhibit high haze values (Ecovio F2331: 71%; Ecovio F2223: 94%; Mater-Bi: 38%) while BOPP and PLA present high clarity (Haze %: PLA: 1, BOPP: 5). It is interesting to notice that the total transmittance values measured for bio-based packaging films with high haze values depend on the spectra wavelength.

The static contact angles with water were measured to evaluate the films behaviour with respect to water condensation in the form of small droplets at the inner package surface. The results confirm that BOPP and PE reference film are clearly hydrophobic materials (contact angles 100° and 94°) while the Mater-Bi (85°), PLA (70°) and Ecovio F223, F2331 films (78°, 68°) show slightly more hydrophilic characteristics. In any case, Mater-Bi, PLA and Ecovio packaging films are not hydrophilic and special coatings (or layers) are needed to eliminate the probability for water condensation inside the packaging and allow for better printing using water-based inks.

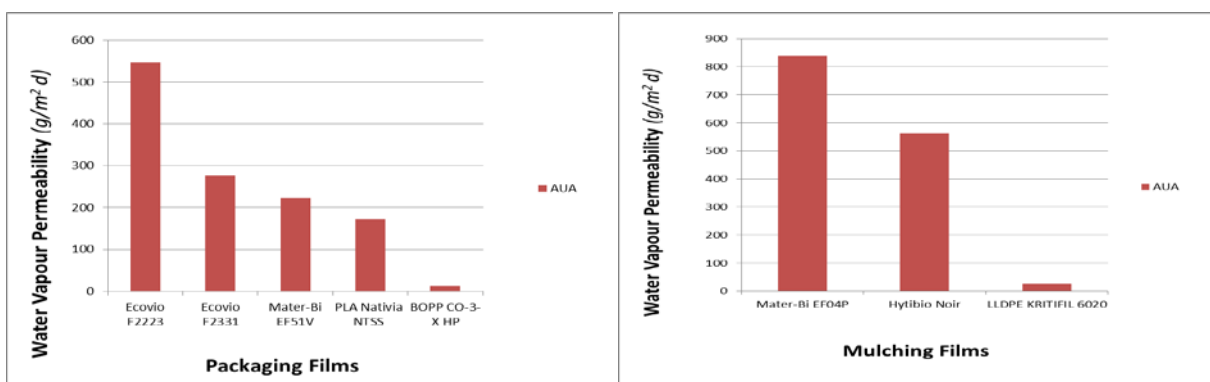


Figure 3. Water Vapour Transmittance of bio-based food packaging and mulching films

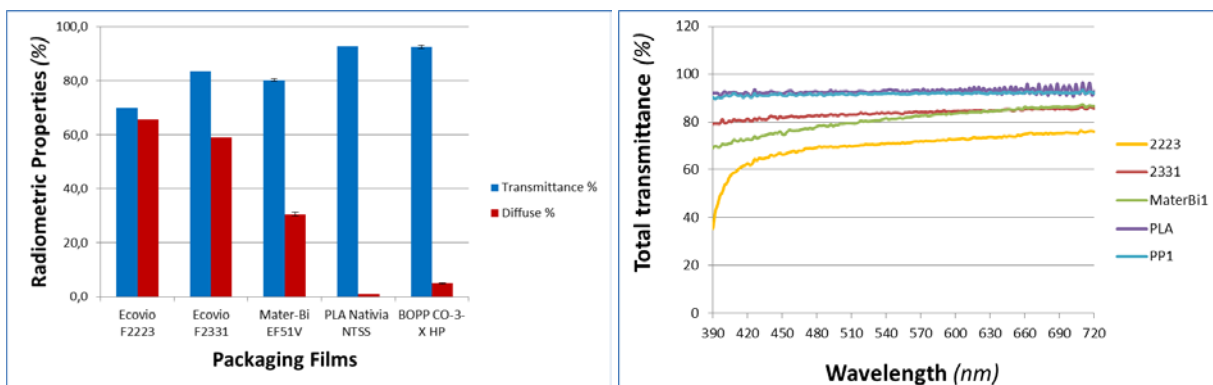


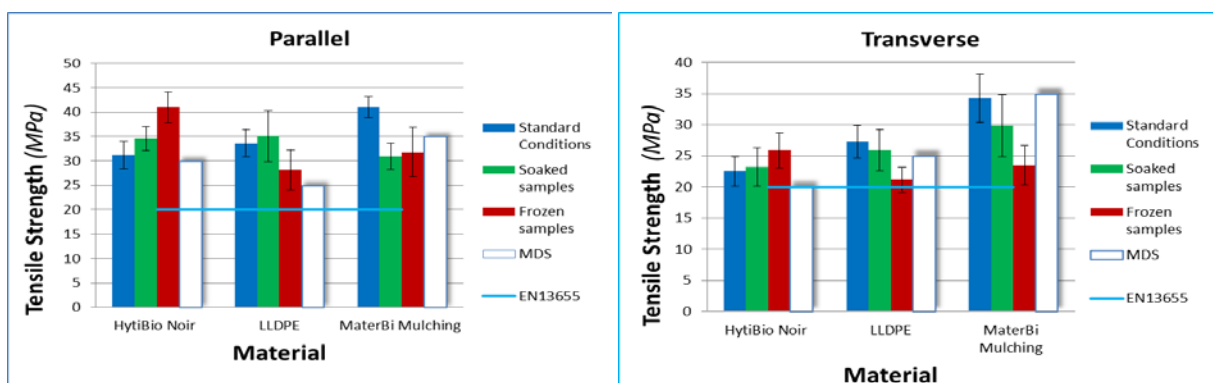
Figure 4. Radiometric properties of bio-based food packaging films

4.2. Mulching films

4.2.1. Mechanical functionalities of mulching films

The tensile properties of the mulching films under standard testing conditions and under conditions of low temperature (-18°C) and water are presented in Figure 5. Tensile strength values are in agreement with the values given by the manufacturers (MDS). Tensile strength of the Mater-Bi film is decreased under low temperature in MD/TD (with water in MD). The elongation at break of Mater-Bi & LDPE is reduced under frozen conditions (MD, TD) and HytiBio under frozen conditions (TD). The elongation at break of Mater-Bi film is also reduced under water conditions in (MD). The bio-based films satisfy the EN13655 requirements for conventional films except for the elongation at break in MD for HytiBio, while Mater-Bi does not meet this requirement under low temperature and water.

The measured penetration and impact resistance of the mulching films are shown in Figure 6. The penetration resistance of the thin ($15\ \mu\text{m}$) bio-based films Mater-Bi and HytiBio is comparable and lower than that of the thicker LLDPE film ($20\ \mu\text{m}$). On the contrary, the impact resistance of the mulching films appears to be much higher for the thin bio-based films as compared to the conventional LLDPE film resistance and the EN13655 requirement (50g).



4.2.2. Physical functionalities of mulching films

The water vapour transmittance values of the mulching films, measured as in the case of the packaging films under conditions: 38°C 90%RH, are presented in Figure 3. Again, WVTR of all bio-based films exceeds significantly the corresponding values of the conventional reference LLDPE mulching film.

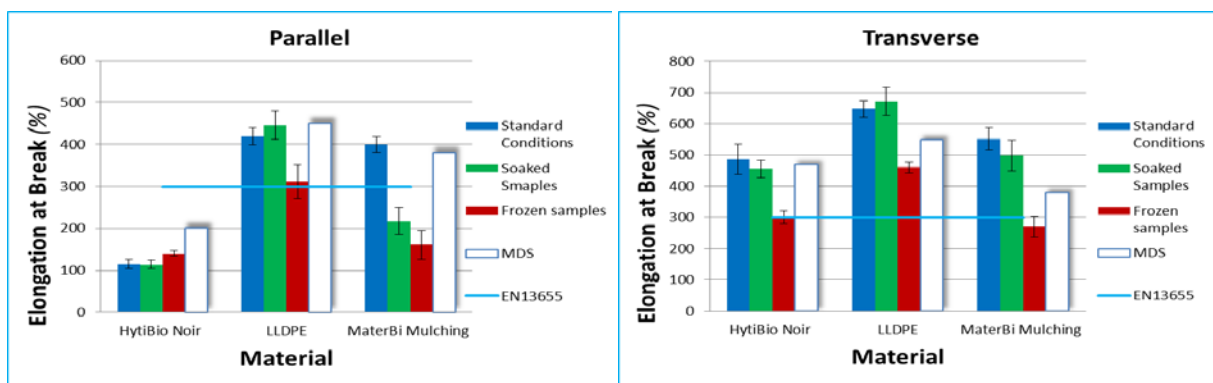


Figure 5. Tensile properties of bio-based mulching films

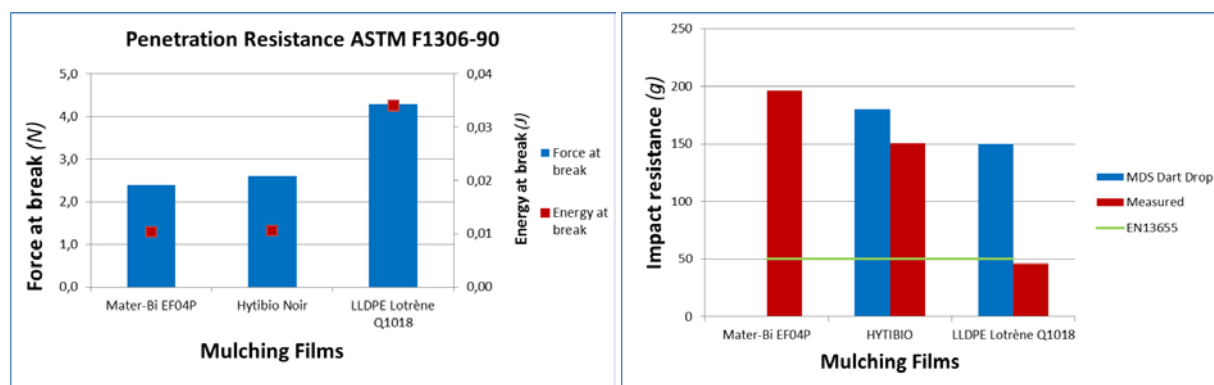


Figure 6. Penetration and impact resistance of bio-based mulching films

5. Conclusions

Differences were identified in the performance of the various bio-based materials when compared to conventional films. Among them, their higher water vapour permeability, and differences in the penetration and impact resistance, tensile strength and other physical properties. Additional properties such as durability and tear resistance are under investigation. The overall mechanical performance of the bio-based films was found to be satisfactory in general. The bio-based mulching films exceed the requirements set by the European Standard EN13655 for conventional normal films of thickness 10-25 μm for impact resistance and tensile properties, except for the elongation at break in MD, a behaviour that does not affect the performance of these films. The higher WV permeability of bio-based mulching films may result in a two-way transfer of moisture depending on the ambient conditions and soil humidity. Bio-based packaging films allow for achieving optimized EMAP conditions because of their high WVTR combined with their barrier function to CO_2 and O_2 gases. The characteristics of the bio-based films offer new design possibilities for targeted applications.

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References

- BIOCHEM project. 2010. Assessment of the Bio-based Products Market Potential for Innovation. Final Report. September 30, 2010. Eco-innovation, Europe Innovation
- Briassoulis D., Hiskakis M., Scarascia G., Picuno P., Delgado C., Dejean C. 2010. Labeling Scheme for Agricultural Plastic Wastes in Europe. Quality Assurance and Safety of Crops & Foods. 2(2), 93 – 104
- Briassoulis, D. 2006. Mechanical Behaviour of Biodegradable Agricultural Films under Real Field Conditions. Polymer Degradation and Stability, 91, 1256:1272
- Briassoulis, D. 2007. Analysis of the Mechanical and Degradation Performance of Optimised Agricultural Biodegradable Films. Polymer Degradation and Stability. 92 (6), 1115-1132
- Cabot. 2008. Masterbatch Selection Guide for Agricultural Film Applications. Technical Report. Cabot corporation, MA, USA, www.cabot-corp.com/plastics Accessed May10, 2016
- Duncan T.V. 2011. Applications of nanotechnology in food packaging and food safety: Barrier materials, antimicrobials and sensors. 1, 1–24, <http://dx.doi.org/10.1016/j.jcis.2011.07.017> Accessed May10, 2016
- European Bioplastics. 2015. Bioplastics - facts and figures. Available at: <http://www.european-bioplastics.org>
- Huq T., Khan R.A., Riedl B., Lacroix M., 2014. Nanocellulose-based composites and bioactive agents for food packaging. Crit Rev Food Sci Nutr. 54(2), 163-74. doi: 10.1080/10408398.2011.578765
- LabelAgriWaste project. 2006-2009. Labelling agricultural plastic waste for valorising the waste stream, Collective research, Contract No. 516256-2, <http://LabelAgriWaste.aua.gr> Accessed May10, 2016
- PlasticsEurope, Plastics – the Facts 2015. An analysis of European plastics production, demand and waste data; <http://www.plasticseurope.org> Accessed May10, 2016
- Regulation (EC) No 1935/2004 of the European Parliament and of the Council of 27 October 2004 on materials and articles intended to come into contact with food and repealing Directives 80/590/EEC and 89/109/EEC
- Shen L., Haufe J., Patel M.K. 2009. Product overview and market projection of emerging bio-based plastics, PRO-BIP 2009., Utrecht University. Final Report, June 2009, Revised in November 2009, The Netherlands
- Shogren, R.L. and Hochmuth, R.C., 2004. Field evaluation of watermelon grown on paper-polymerized vegetable oil mulches. HortScience 39, 1588-1591
- Weber C.J. 2000. Bio-based Packaging. Materials for the Food Industry. Status and Perspectives. A European Concerted Action report, Publisher, KVL, November 2000, ISBN 87-90504-07-0
- WPO 2008. Market Statistics and future trends in global Packaging. World Packaging Organization. www.worldpackaging.org Accessed May10, 2016