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Proceeding Paper

Application of Cellulose-Based Film for Broccoli Packaging †

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Abstract: Broccoli is a highly perishable vegetable with unique nutritional characteristics. Modified atmosphere packaging (MAP) has proven to be a successful technology to extend broccoli shelf-life. The main disadvantage of MAP is the extensive use of petrochemical-based films resulting in huge quantities of domestic plastic waste. In this study, suitability of a biodegradable cellulose-based film for broccoli florets packaging was evaluated, as an alternative to polypropylene film. Florets packaged in cellulose-based film showed a high mass loss and extremely low in-package O_2 concentrations, which made this material unsuitable for broccoli packaging application. Improved gas and water vapor barrier properties should be considered for biodegradable packages, in order to make their application for vegetable packaging feasible.

Keywords: cellulose-based film; packaging; storage; postharvest shelf-life; quality; *Brassica oleracea* var. *italica*

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1. Introduction

Broccoli is a vegetable highly valued by modern consumers due to its health-promoting properties. However, since broccoli has a high respiration rate, it presents accelerated senescence during storage and a short shelf-life [1]. Modified atmosphere packaging (MAP) has proven to be a successful technology to preserve broccoli quality and extend its shelf-life [2]. MAP technology consists in packaging horticultural products in permeable films. Inside the package, a modified atmosphere, with decreased O_2 concentration and increased CO_2 concentration with respect to normal air, is generated with the interplay of product respiration and package permeability. This modified atmosphere slows down the product respiration rate, extending product shelf-life [3]. The main disadvantage of MAP is the extensive use of petrochemical-based films, resulting in huge quantities of domestic plastic waste. Replacing these films with bio-based and biodegradable materials could contribute to reducing the environmental impact of plastics [4]. In this line, in recent years, cellulose-based materials have been developed for their application in food packaging [5]. The aim of this study was to evaluate the suitability of a cellulose-based film for broccoli florets packaging, as an alternative to conventional polypropylene film.

2. Materials and Methods

2.1. Plant Material and Experimental Design

Broccoli heads (*Brassica oleracea* var. *italica* cv. Legacy) were cut into florets, washed, disinfected (NaClO, 100 ppm), dried, and packaged under a passive modified atmosphere. Approximately 100 g of broccoli florets was packaged in micro-perforated biaxially orientated polypropylene (PP) and cellulose-based (NatureFlex^{TM} NVS23, Futamura Group, Cumbria, UK) (CB) bags. Broccoli packaged in macro-perforated polypropylene was used as a control. Bags were sealed using a Supervac GK105/1 packaging machine (Wien, Austria) with air injection. Samples were stored at 4 °C during 14 d. At preselected storage times (0, 7, and 14 d), three packages (each package constituted an experimental unit) were sampled for each packaging film. Different packages were used at each sampling point. Samples were immediately evaluated and the following quality attributes were measured throughout shelf-life: headspace gas composition, mass loss (ML), texture, and sensory attributes.

2.2. Headspace Gas Composition

O_2 and CO_2 concentration inside packages was measured using a gas analyzer (OXYBABY® 6.0, WITT-Gasetechnik, Witten, Germany), extracting a 6 mL sample directly from the package. Results were expressed as partial pressure (kPa) of O_2 and CO_2 inside the bags.

2.3. Mass Loss

Mass loss (ML) was calculated by weighing broccoli florets prior to packaging (day 0) and at each sampling point. It was expressed as a percentage of initial weight (%).

2.4. Texture

A texture analysis was performed using a TA.XT2i Texture Analyzer (Stable Micro Systems Ltd., Godalming, UK). The Texture Analyzer was equipped with a 3 mm diameter cylinder probe in order to evaluate hardness of broccoli florets' stalks through a penetration test. Test conditions used for measurements were a 2.0 mm s^{-1} pre-test speed, 1.0 mm s^{-1} test speed, 5.0 mm s^{-1} post-test speed, and 5 mm penetration distance. Data of force (N) versus time (s) were registered using Texture Exponent Software (Version 3.2, Stable Micro Systems Ltd., Godalming, UK). The hardness value was determined as maximum force (N) registered in the force vs. time curves. Measurements were made on 4 broccoli stalks per experimental unit.

2.5. Sensory Evaluation

Overall appearance, color, and odor of broccoli florets were individually scored using a subjective scale from 1 to 5. A panel composed of seven members with sensory evaluation experience in vegetable quality was trained and carried out the evaluation. The rating scale for overall appearance was 5 = excellent, as freshly harvested; 4 = very good, minor defects; 3 = fair, moderate defects; 2 = poor, major defects; and 1 = very poor, inedible. In the case of odor, 5 = typical odor; 4 = slight off-odor; 3 = moderate off-odor; 2 = strong off-odor; and 1 = rot odor. In the case of color, 5 = dark green; 4 = green, yellow traces; 3 = light green, slightly yellow; 2 = light green, very yellow; and 1 = yellow. A score of 3 was considered as the limit of marketability and a score of 2 as the limit of edibility [6].

2.6. Statistical Analysis

Two-way ANOVA considering packaging condition, storage time, and their interaction was performed and when significant differences were observed, Tukey's test was applied ($p < 0.05$). Data are expressed as the mean ± standard error. XLSTAT (Statistical and data analysis solution, Lumivero, Denver, CO, USA) software was used for statistical analyses.

3. Results and Discussion

3.1. Headspace Gas Composition

PP samples showed a slight modification of internal package atmosphere ($p < 0.05$), reaching equilibrium O_2 and CO_2 concentration of 17.5 ± 0.7 and 3.6 ± 0.8 kPa, respectively.

CB samples showed a rapid change in headspace composition, reaching O_2 and CO_2 concentration of 2.4 ± 1.2 and 22.5 ± 1.6 kPa at day 3, respectively (Figure 1). According to the literature, CO_2 concentrations higher than 20 kPa could induce fermentative mechanisms, which would be detrimental to product quality. Over time, there was an excessive accumulation of CO_2 (40.4 ± 1.6 kPa at day 9) and depletion of O_2 (0.5 kPa at day 9), which makes cellulose-based film unsuitable for application in the packaging of high-respiration-rate products such as broccoli.

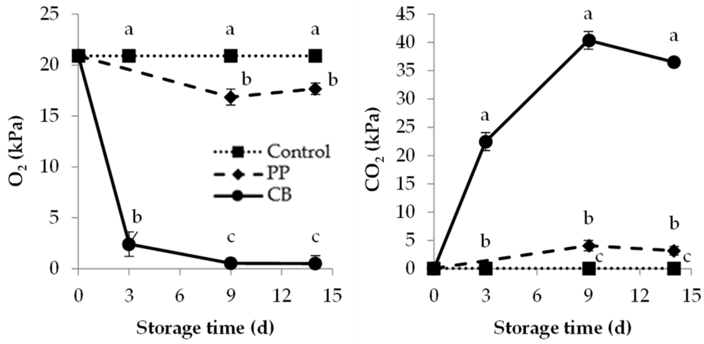

Figure 1. Effect of packaging condition on headspace O_2 and CO_2 concentration throughout storage at 4 °C. Mean values (n = 3) and standard error (vertical bars) are represented. Different letters indicate significant differences between packaging conditions at each sampling time ($p < 0.05$).

3.2. Mass Loss (ML)

Florets in cellulose-based film showed a marked ML, significantly higher than PP and control samples ($p < 0.0001$) (Figure 2). This result is striking because cellulose-based film provided a lower barrier to water vapor than the macro-perforated film. This could be explained with the high-water vapor transmission rate (WVTR) of the NatureFlex^{TM} film, which causes a low relative humidity inside the package, thus increasing the broccoli transpiration rate. At day 9 of storage, CB samples showed ML values higher than 7%, which exceeds the marketability limit for fresh broccoli [7]. Therefore, the high WVTR of the cellulose-based film could be a limitation for its application on high-respiration- and -transpiration-rate products such as broccoli.

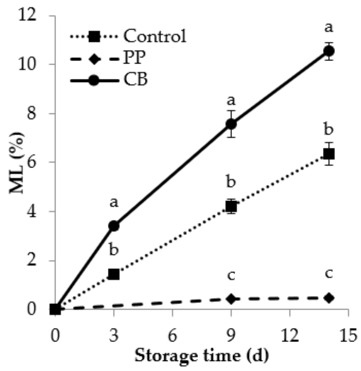

Figure 2. Effect of packaging condition on mass loss (ML) of broccoli florets throughout storage at 4 °C. Mean values (n = 3) and standard error (vertical bars) are represented. Different letters indicate significant differences between packaging conditions at the same sampling time ($p < 0.05$).

3.3. Texture

A significant effect of packaging film on broccoli florets' hardness was found (Figure 3). No change in hardness was observed for PP samples. CB samples showed a significant loss of hardness throughout storage ($p < 0.05$). This behavior could be due to the development of fermentative processes (low O_2 in-package concentration), which could damage the tissue structure [8], and to the extensive ML verified in these packages. Therefore, the cellulose-based film proved not to be a good packaging alternative for maintaining broccoli florets' texture.

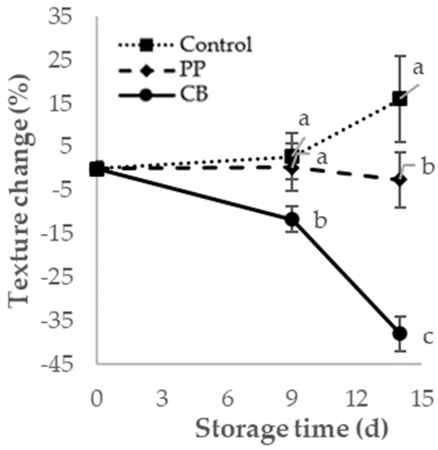

Figure 3. Effect of packaging condition on broccoli florets' hardness throughout storage at 4 °C. The data are expressed as the change in hardness relative to the initial value (%). Mean values ($n = 3$) and standard error (vertical bars) are represented. Different letters indicate significant differences between packaging conditions at the same sampling time ($p < 0.05$).

3.4. Sensory Evaluation

Sensory attributes' evolution of broccoli florets packaged in different films is shown in Figure 4. PP samples presented scores above the marketability limit throughout all of the storage period. Control florets showed a rapid and significant decrease in the color and overall appearance score. Florets in cellulose-based film showed no significant difference in the color score compared to PP florets. However, they showed a marked decrease in characteristic odor scores. Additionally, overall appearance decreased to the minimum score. Therefore, it can be assumed that gaseous conditions established inside the cellulose-based film favored the development of fermentative metabolism, producing volatile substances that generated off-odors, compromising broccoli florets' shelf-life.

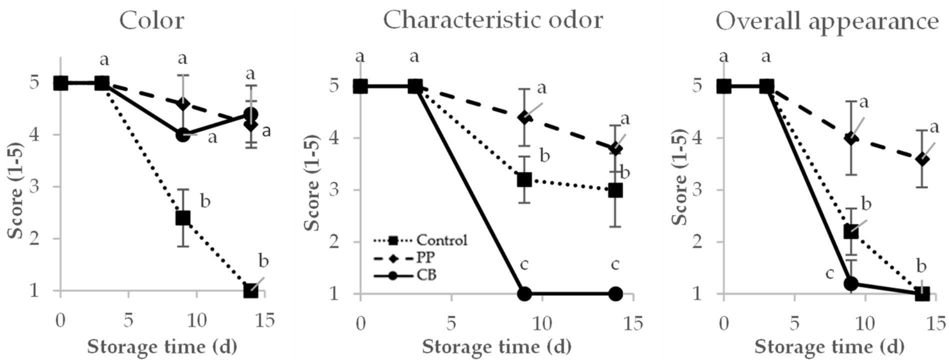

Figure 4. Effect of packaging condition on sensory attributes of broccoli florets throughout storage at 4 °C. Mean values ($n = 3$) and standard error (vertical bars) are represented. Different letters indicate significant differences between packaging conditions at the same sampling time ($p < 0.05$).

4. Conclusions

Too low O_2 concentrations and the excessive product mass loss presented with cellulose-based film make it unsuitable for packaging broccoli florets in the conditions assayed.

Interventions in the film that improve its gas and water vapor barrier properties should be considered to make its application in vegetable packaging feasible.

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Conflicts of Interest: The authors declare no conflict of interest.

References

1. Paulsen, E.; Barrios, S.; Baenas, N.; Moreno, D.A.; Heinzen, H.; Lema, P. Effect of temperature on glucosinolate content and shelf life of ready-to-eat broccoli florets packaged in passive modified atmosphere. *Postharvest Biol. Technol.* **2018**, *138*, 125–133. [CrossRef]
2. Jia, C.G.; Xu, C.J.; Wei, J.; Yuan, J.; Yuan, G.F.; Wang, B.L. Effect of modified atmosphere packaging on visual quality and glucosinolates of broccoli florets. *Food Chem.* **2009**, *114*, 28–37. [CrossRef]
3. Fonseca, S.C.; Oliveira, F.A.R.; Brecht, J.K. Modelling respiration rate of fresh fruits and vegetables for modified atmosphere packages: A review. *J. Food Eng.* **2002**, *52*, 99–119. [CrossRef]
4. Paulsen, E.; Lema, P.; Martínez-Romero, D.; García-Viguera, C. Use of PLA/PBAT stretch-cling film as an ecofriendly alternative for individual wrapping of broccoli heads. *Sci. Hortic.* **2022**, *304*, 111260. [CrossRef]
5. Shaikh, S.; Yaqoob, M.; Aggarwal, P. An overview of biodegradable packaging in food industry. *Curr. Res. Food Sci.* **2021**, *4*, 503–520. [CrossRef] [PubMed]
6. Winkler, S.; Faragher, J.; Franz, P.; Imsic, M.; Jones, R. Glucoraphanin and flavonoid levels remain stable during simulated transport and marketing of broccoli (*Brassica oleracea* var. *Italica*) heads. *Postharvest Biol. Technol.* **2007**, *43*, 89–94. [CrossRef]
7. Wiley, R.C. Preservation Methods for Minimally Processed Refrigerated Fruits and Vegetables. In *Minimally Processed Refrigerated Fruits & Vegetables*; Springer: Boston, MA, USA, 1994; pp. 66–134. Available online: https://link.springer.com/chapter/10.1007/978-1-4615-2393-2_3 (accessed on 1 October 2022).
8. Techavuthiporn, C.; Thammawong, M.; Nakano, K. Effect of short-term anoxia treatment on endogenous ethanol and postharvest responses of broccoli florets during storage at ambient temperature. *Sci. Hortic.* **2021**, *277*, 109813. [CrossRef]