

Performance of Pre-Cut Lettuce Packaged in Biodegradable Film Formed on Commercial Vertical-Form-Fill-and-Seal Machines

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ABSTRACT: The purpose of this study was to determine the feasibility of using biodegradable films suitable for fresh-cut lettuce with commercial vertical-form-fill-and-seal packaging machines (VFFS) equipped with heat-sealing bars. Biodegradable high-density polyethylene (BHDPE) and polypropylene (BPP) films were tested. Commercial bags of pre-cut Romaine sealed in a polyethylene/oriented polypropylene (PE/OPP) bag formed on a VFFS machine were used as the control. All bags were held at 4.4°C, 80% RH and assessed for reduction in quality during storage per a commercial (in-house) standard utilized by a large pre-cut salad packer in Salinas, California.

When the biodegradable films were sealed with a VFFS machine equipped with a thermal-bar heat sealer, a 52.5% fail rate was observed due to the non-continuity of the seals. Leaks were found when bags were vacuum tested to 14 in Hg absolute for 15 seconds. However, a 45.5% fail rate was also observed for commercial bags made using the same VFFS machine, suggesting similar seal concerns for current industry film structures. Though an attempt was made to only store bags that were sealed properly, bags made from the biodegradable films sealed with the thermal-bar did not perform as well as the commercial packages and the shelf-life of the pre-cut Romaine was shortened. When biodegradable bags were sealed using a bar impulse sealer, hermetic seals were obtained. The Romaine stored in these bags had a similar rate of decay and level of pinking after 14 days storage as Romaine packaged in the commercial PE/OPP bags. These results indicate that the use of commercial impulse sealers, rather than thermal-bar heat sealers, would allow industry to utilize these biodegradable films for pre-cut lettuce mixes.

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INTRODUCTION

FRESH-CUT produce is defined as any fruit or vegetable that has been cut and packaged for consumer use without being cooked or prepared by means of heating (Mayen, 2005). Fresh-cut produce sales have increased in the last 20 years and were \$1.9 billion in 2000 (Sexton, 2003). This increase in sales over the last 2 decades has led to an increase in landfill waste, resource scarcity and consumer [environmental] concerns over the films being used to package these products (Sexton, 2003).

A traditional film currently used in the U.S. for fresh-cut produce is oriented polypropylene (PP), referred to as OPP (Del Nobile, 2007). In recent years, many bio-based and biodegradable films have been developed to serve the U.S. market but little if any data is available regarding their processing requirements or suitability for use with the commercial Vertical-Form-Fill-and-Seal (VFFS) packaging machines currently used to package fresh-cut produce. This has limited the adoption of bio-based and biodegradable films by the produce industry.

In the U.S., fresh-cut produce is typically processed on packaging lines where gravity is used to fill bags with product, and in-line, thermal-bar heat sealers are used to seal the bags. This set-up is commonly referred to as VFFS packaging line. To run on these lines, films must possess sufficient mechanical strength, low static charge and a controllable amount of slip (NIIR Board, 2002). Sufficient mechanical strength prevents elongation and tearing of the film. A low static charge reduces the dust the film attracts, layer separation and jamming. Slip refers to the coefficient of friction of the film and film with insufficient slip may jam in the VFFS machine or elongate. If the film is too slippery, it may not feed properly (NIIR Board, 2002).

When a bag to hold pre-cut produce is formed and sealed, the seal must be continuous and strong. When sufficient heat is applied, molecular entanglement within the polymer chains produces a hermetic seal that resists rupture from both normal handling and the pressure changes that may occur during transportation. Heat seal integrity primarily depends on the pressure and temperature of the sealing jaws, and dwell time. Dwell time is the length of time, typically in milliseconds, that the sealing jaws are clamped on the plastic film. The temperature of the sealing jaws is determined by heat controllers and their accuracy is impor-

tant. If a VFFS machine does not have sufficiently accurate temperature controllers, films with narrow sealing ranges may not seal correctly (NIIR Board, 2002).

The shelf life of pre-cut produce is dependent upon the degree of processing of the product, permeation characteristics of the packaging or lidding film, storage temperature, initial quality of the product (Ballantyne et al., 1988) and sharpness of cutting knives (Solica-Fortney and Martin-Belloso, 2003). Permeation refers to the rate at which gases, such as carbon dioxide and oxygen, move through a film and the films used in the pre-cut industry typically have widely varying permeation rates (Kader et al., 1989). When a film is correctly chosen, its use with a properly processed and stored pre-cut product can increase shelf life by 5 to 14 days (Ballantyne et al., 1988).

The equilibrium levels of oxygen and carbon dioxide that occur with a package are affected by a number of factors: the size of the package, the amount of product, the product itself, the temperature of storage, the length of storage and the type of film used. Film water vapor transmission may also be important when wilting of product or condensation within a package are considerations (Ballantyne et al., 1988).

Polyethylene/oriented-polypropylene films are typically used to package pre-cut produce. The films possess low moisture transmission rates, good mechanical stability, and have controllable slip, permeation and optical properties that are easily modified for specific applications (NIIR Board, 2002).

Curtzwiler et al. (2008) conducted research to characterize currently-available biodegradable films that could, potentially, be used to package pre-cut produce. It was concluded that a biodegradable high-density polyethylene (BHDPE) and a biodegradable polypropylene (BPP) were acceptable substitutes for the PE/OPP films currently used by the pre-cut industry as these biodegradable films had similar transmission rates for oxygen, carbon dioxide and water vapor as the PE/OPP films. Though previous studies characterized biodegradable films for their barrier and mechanical properties, at the time of this study, there was no published research evaluating the machinability of these films or their potential use with fresh-cut produce. The purpose of this study was therefore to determine the feasibility of using the BHDPE and BPP films with commercial vertical-form-fill-and-seal packaging machines (VFFS) equipped with thermal-bar heat sealers and used in the pre-cut lettuce industry.

MATERIALS AND METHODS

The industry standard film was a two-layer laminate consisting of polyethylene (PE) and oriented-polypropylene (OPP). It was supplied by a major pre-cut packager in Salinas, California and had an average thickness of 0.058 mm (Curtzwiler et al., 2008). The alternative films tested were a 0.051 mm biodegradable high-density polyethylene (BHDPE) and a 0.061 mm biodegradable polypropylene (BPP) both supplied by Bloomer Plastics (Bloomer, WI). The BHDPE and the BPP films were provided with or without anti-fog treatment, and one roll of BHDPE was provided with slip, but without anti-fog treatment.

Coefficient of Friction Testing

Before cutting samples, the machine direction was identified for each material using a Nikon 73231 optical microscope. The sample cutting surface and ruler were cleaned with alcohol before use, and latex gloves were worn during sample prep and testing to limit sample contamination. Three test runs were performed for each sample; on the third run the COF value was recorded. Five samples of each film type were tested for inside-to-inside, and five for outside-to-outside, COF. All samples were conditioned for a minimum of 40 hours prior to testing at 23°C, 50% relative humidity. Tests were conducted according to ASTM Standard D1894-06 (Anonymous, 2006) using a Model 32-50-00 Coefficient of Friction Tester (Testing Machines Inc., Ronkonkoma, New York). The manufacturer provided the angle interpretation table.

Machinability Testing Part I: Vertical-Form-Fill and Seal Packaging Lines

Films selected for this test included BPP without or without anti-fog treatment, BHDPE with or without anti-fog treatment, and BHDPE without anti-fog but with slip treatment. The line used for testing employed a Hayssen Ultima Twin-8-16HR (HayssenSandiacre, Duncan, SC) VFFS machine to package pre-cut Romaine lettuce. Each film was loaded onto the machine and run through a series of temperature and dwell time settings to determine suitability for use. Films were tested according to a modified ASTM 03078-02 (Anonymous, 2008) until packages made from the films had a seal that would maintain integrity for 15

seconds when tested under water at 14" Hg absolute (Pak-Vac Leak Tester, Haug, Morgan Hill, CA), or until it was determined that the film would not produce a suitable seal using a VFFS machine equipped with a thermal-bar heat sealer, regardless of temperature and dwell time.

Shelf-life Study Part I: Bags Sealed Using VFFS Machinery

Shelf-life studies were conducted simultaneously at the packager in Salinas, California and California Polytechnic University (Cal Poly), San Luis Obispo, California. A total of 18 each of the PE/OPP, BPP with antifog, and BHDPE (no antifog but with slip) bags of pre-cut Romaine lettuce were used for the study. The PE/OPP and the BPP bags were leak tested before use with only bags passing the leak test being used in this study. The BHDPE bags were initially leak-tested but were found to have poor seal quality. Therefore, subsequent bags produced using BHDPE were simply removed from the packing line and used without being leak-tested.

All bags were stored at 4.4°C, 80% RH for 14 days. Bags were weighed initially and after 7 and 14 days to determine moisture loss from the lettuce. Oxygen and CO₂ in the headspace of each bag was measured daily using a Model 6600 O₂/CO₂ Headspace Analyzer (Illinois Instruments, Johnsborg, IL.). Lettuce was assessed for pinking and decay daily based on color charts and a proprietary methodology developed by the packer in Salinas, California.

Shelf-life Study Part II: Impulse vs Thermal-bar Sealed Bags

In the first shelf-life study, the primary problem with the bags made from the biodegradable films was seal integrity. The VFFS machinery employed thermal bars to seal a laminated film (PE/OPP), whereas the biodegradable films were non-laminated polypropylene or high density polyethylene. Therefore, a second test was conducted in which biodegradable salad bags were hand-sealed at Cal Poly using an 18", 600 watt impulse sealer (AIE-500, Fisher Scientific). The bags were made to the same dimensions, 25.4 × 22.2 cm, as the commercially-available PE/OPP bags.

Bags of freshly-packaged pre-cut Romaine were obtained from the packer in Salinas, California and immediately transported on ice to Cal Poly. Eighteen bags were repacked into BPP bags (with no slip, no

anti-fog) and 18 were repacked into BHDPE bags (with no slip, no anti-fog). The bags were opened and the lettuce was transferred in a laminar flow hood to prevent microbial contamination. Repacked bags were quickly transferred to a Smith Supervac GK180 vacuum/flush bag sealer. Bags were flushed with industrial-grade nitrogen to obtain a headspace volume and initial O₂/CO₂ levels comparable to those found in the bags of pre-cut Romaine obtained from the packer in Salinas. Control bags were not leak tested but all biodegradable bags were leak tested at 14" Hg absolute for 15 seconds using a Test-A-Pack System (Carleton Technologies, Orchard Park, NY).

All bags were stored at 4.4°C, 80% RH for 14 days. As before, the bags were weighed at 0, 7 and 14 days to assess weight loss from the product as affected by film type. Headspace O₂/CO₂ levels were measured daily. All lettuce was assessed daily for pinking and decay by observing the lettuce directly through the bags and after opening at 14 days. Only the "surface" lettuce was observed, i.e., the bags were not shaken during the observation process and only the lettuce closest to the film was evaluated, per the protocol developed by the Salinas packer. The biodegradable and control bags were leak tested again after 14 days storage. After 14 days, all lettuce bags were opened and assessed for off-odors and degree of sliminess. Sliminess was determined tactically.

Head Space Volume

Headspace was determined through water displacement. Each bag was submerged completely in water and the evacuated air was collected and measured. Five bags of each film type were tested.

Statistical Analysis

For the shelf-life studies, the researchers were normalized on-site to the proprietary procedures used by the Salinas, CA packer to assess and quantify pinking and decay. Pinking and decay were quantified for each study by 3 researchers who also, collectively, assessed sliminess and the presence or absence of off-odors. The experimental design was completely randomized with 18 replicates per treatment. All data was analyzed using the PROC GLM procedure of the Statistical Analysis Systems Ver. 9.1 software package (SAS Institute, Raleigh, NC). Where applicable means were separated using Duncan's Multiple Range Test ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Coefficient of Friction Testing

The BPP films with and without anti-fog had coefficient of friction values that were the closest to the values obtained from representative industry films (Table 1). The BHDPE films with and without anti-fog had much higher coefficient of friction values than those obtained from the industry films. However, both types of biodegradable film had much higher COF values than the industry films tested.

Machinability: VFFS Packaging Lines

The BHDPE film without anti-fog was run on the VFFS machinery (Table 2), but the seals were of poor quality. Bags produced were used in shelf-life testing, but were not leak tested due to poor seal strength. The BHDPE film with anti-fog was not run due to the high COF of the film. The BPP film with slip was run on the packaging line with moderate success. During this trial run, ninety-percent of the BPP bags were thrown off the line before leak-testing due to obvious poor seals. A total of 80 bags of the BPP with slip were leak tested: 38 passed and 42 failed (52.5% fail rate). At this time, the control (commercial) bags were also leak tested. Out of 66 bags tested, 36 passed and 30 failed (45.5% fail rate). Regardless, all BPP and PE/OPP bags were leak tested and only those bags which passed were used in the study.

Due to the poor performance of the BPP with anti-fog, and the BHDPE with slip, films with similar or higher COF values were not

Table 1. Characteristics of Films Tested on February 7, 2008.

Film Type	Anti-fog Capability	Slip	COF ^z	
			Inside to Inside	Outside to Outside
Garden Salad ^y	Yes	Yes	0.17	0.19
Caesar Salad ^y	Yes	Yes	0.24	0.33
Premium Romaine ^y	Yes	Yes	0.13	0.16
BPP	No	No	0.23	0.49
BPP	Yes	No	0.22	0.45
BHDPE	No	No	0.33	0.52
BHDPE	Yes	No	0.40	1.81

^yCommercial packages from Salinas, CA packer containing respective pre-cut mixes.

BPP = biodegradable polypropylene

BHDPE = biodegradable high-density polyethylene

Table 2. Vertical-form-fill and Seal Machine Parameters Used at a Packer in Salinas, CA.

Setting Description	BPP ^z	BHDPE
Front Jaw	345°F	295°F
Rear Jaw	340°F	295°F
Platen	310°F	280°F
System Speed		35 bags/min
Bag Length	125–130 mm	125–130 mm
Vibration-line feeders	1016	1016
Vibration-main	1790	1790
Target weight of product	255 g	255 g
Average weight	255.4 g	255.4 g
Regular Roller ^y	30–130	30–120
Pull belts ^y	20–120	20–120
Platen ^y	120–347	114–345
Stager ^y	120–359	120–359
Stripper ^y	120–355	135–355
Jaw Close ^y	170–340	170–340
Knife ^y	240–320	200–300
Dwell time ^y	7 ms ^x	10 ms
Typical Seal Orientation	Outside-to-outside	Outside-to-outside

^zFilm does not have anti-fog, but does have slip.

^yBased on a 360° cycle.

^xMillisecond.

BPP = biodegradable polypropylene

BHDPE = biodegradable high-density polyethylene

tested. The films not run were the BPP without anti-fog or slip, BHDPE with anti-fog but without slip and the BHDPE without anti-fog or slip.

Shelf-life Study Part I: Bags Sealed Using VFFS Machinery

In this study, bags were formed from biodegradable films which were sealed with a thermal-heat bar. The resulting seals were of poor quality, in spite of the fact that the BPP bags had been leak tested at the packer. During subsequent storage, the bags made from both biodegradable films did not perform as well those made from the commercial PE/OPP in maintaining the quality of pre-cut Romaine lettuce. Most of the lettuce in the biodegradable bags became unmarketable within 5 days after packing [data not shown].

Shelf-life Study Part II: Impulse vs Thermal-bar Sealed Bag

In this study, bags developed leaks during storage and handling at the

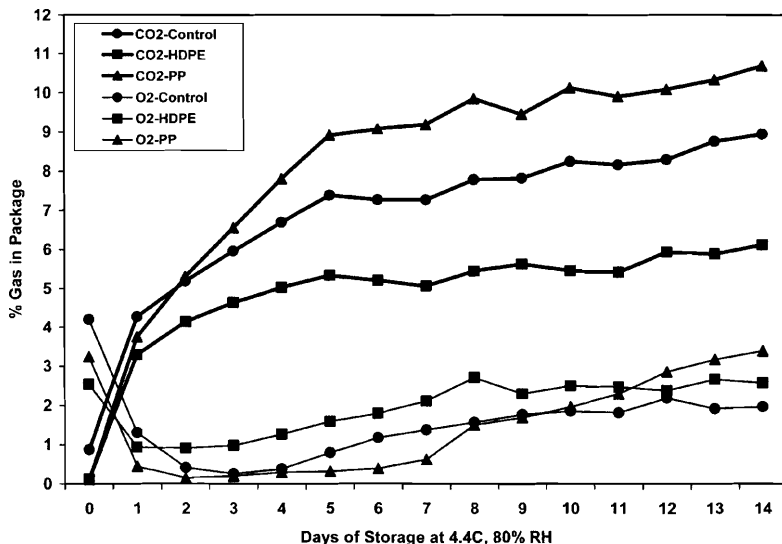


Figure 1. Levels of oxygen and carbon dioxide in the headspace of bags containing pre-cut Romaine. Control = commercial polyethylene/oriented polypropylene laminate, HDPE = biodegradable high-density polyethylene, PP = biodegradable polypropylene.

same rate (16.7%), regardless of the film or sealing machinery that was used. The levels of O₂ and CO₂ in PE/OPP bags were intermediate to those that developed in bags made with the biodegradable films (Figure 1). Overall, the levels of O₂ were lower and CO₂ higher in bags constructed from BPP. Lettuce in the PE/OPP commercial bags had the strongest smell after 14 days of storage but tended to have the least amount of sliming (Table 3).

There was an interaction between package film and storage duration on the amount of water lost from stored pre-cut Romaine (Figure 2).

Table 3. Effect of packaging on the overall amount of sliming and development of off-odors from pre-cut Romaine lettuce during 14 days storage at 4.4°C, 80% RH.

	Off-odor Level ^z	Slimy Product (% bags)
PE/OPP (Control)	3.7 a ^y Faint to moderate off-odor	13 b ^x
Biodegradable Polypropylene	3.1 b Faint odor	21 b
Biodegradable high-density PE	2.9 b Faint odor	53 a

^z1 = fresh; 2 = no odor; 3 = faint off-odor; 4 = moderate off-odor; 5 = spoiled smell.

^yPr > F = 0.0551.

^xPr > F < 0.05.

However, the amount of water lost was minimal (≤ 0.25 g after 14 days) regardless of packaging.

The rates of decay for lettuce packaged in the PE/OPP bags or biodegradable PP bags were comparable (Figure 3), as were the number of bags which became unmarketable due to excessive decay of the lettuce during 14 days storage (Figure 4). In contrast, the lettuce stored in bags made from the biodegradable high-density PE decayed at a faster rate and to a greater extent than lettuce bagged in either the PE/OPP or biodegradable polypropylene bags. The number of HDPE bags that were unmarketable started to increase at day 3, the PP bags at day 12 and the control at day 13.

Lettuce stored in biodegradable high-density PE “pinked” at a faster rate (Figure 5) and to a greater extent (Figure 6) than lettuce bagged in either PE/OPP or biodegradable polypropylene. Romaine stored in the biodegradable PP bags tended to pink at a slower rate and at a later time than lettuce stored in the bags made from PE/OPP.

Overall, decay levels were lowest for pre-cut Romaine stored in the PE/OPP bags, but the overall level of pinking was the same for lettuce stored in either the PE/OPP or BPP bags (Table 4).

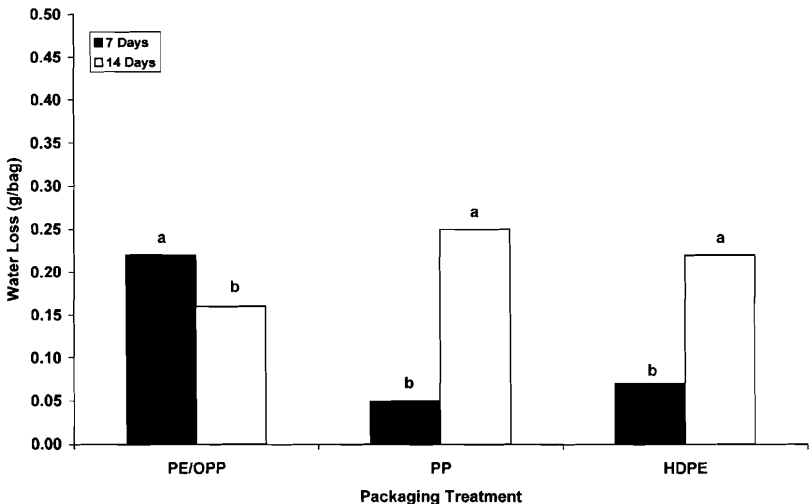


Figure 2. Weight loss from pre-cut Romaine lettuce during 14 days storage at 4.4°C, 80% RH. Comparisons should be made for values at a specific day of storage. Means separation determined using Duncan's Multiple Range Test, $\alpha = 0.05$. Control = commercial polyethylene/oriented polypropylene laminate, HDPE = biodegradable high-density polyethylene, PP = biodegradable polypropylene.

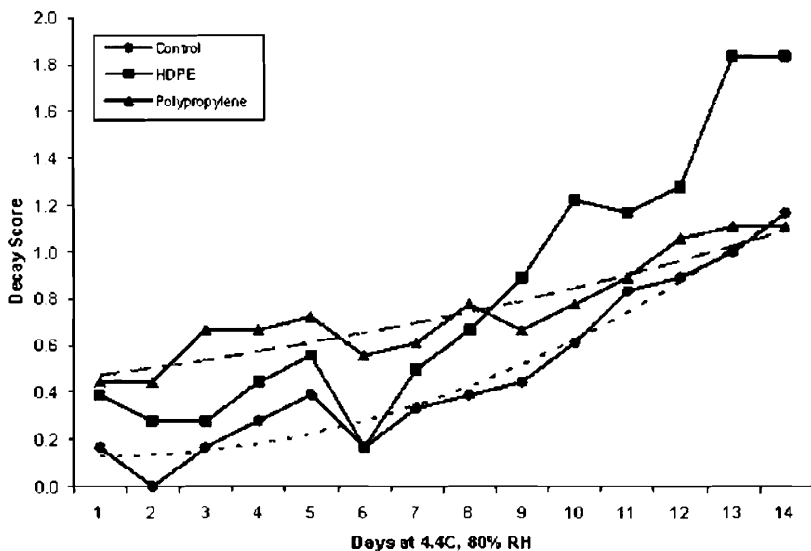


Figure 3. Effect of packaging on the rate of decay of pre-cut Romaine lettuce during 14 days storage at 4.4°C, 80% R.H. "Best fit" hatched lines indicate the relative rates of decay of the Romaine packaged in biodegradable polypropylene vs. the commercial PE/OPP (control). HDPE = biodegradable high density polyethylene.

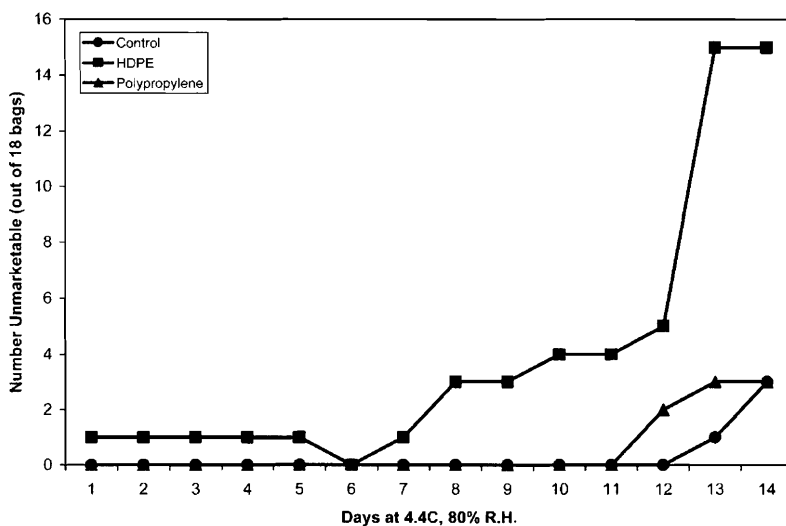


Figure 4. Effect of packaging on cumulative decay as it relates to the number of bags of pre-cut Romaine lettuce which became unmarketable during 14 days storage at 4.4°C, 80% RH. 0 = None; 1 = total decay less than size of a quarter (4.62 cm²); 2 = total area ≥ 4.62 cm² (failure). Control = commercial polyethylene/oriented polypropylene laminate, HDPE = biodegradable high-density polyethylene, PP = biodegradable polypropylene.

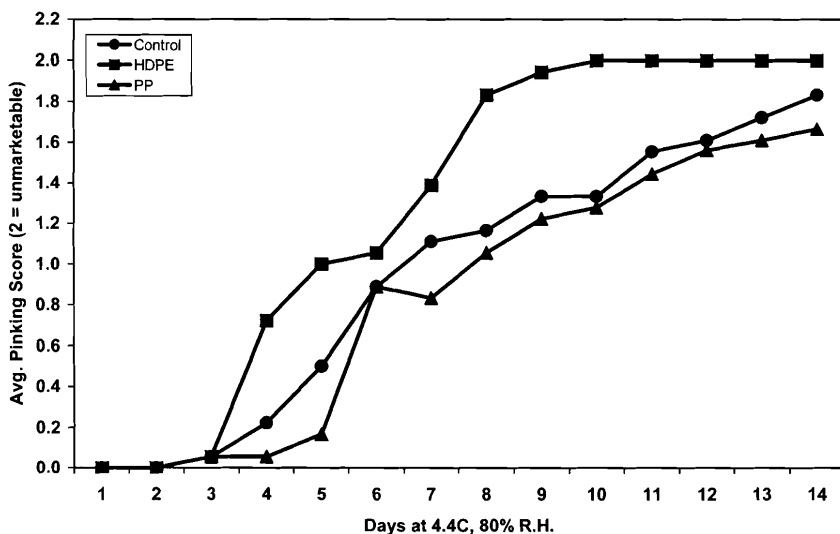


Figure 5. Effect of packaging on the rate of pinking of pre-cut Romaine lettuce during 14 days storage at 4.4°C, 80% RH. 0 = None; 1 = some pinking but marketable; 2 = unmarketable. Control = commercial polyethylene/oriented polypropylene laminate, HDPE = biodegradable high-density polyethylene, PP = biodegradable polypropylene.

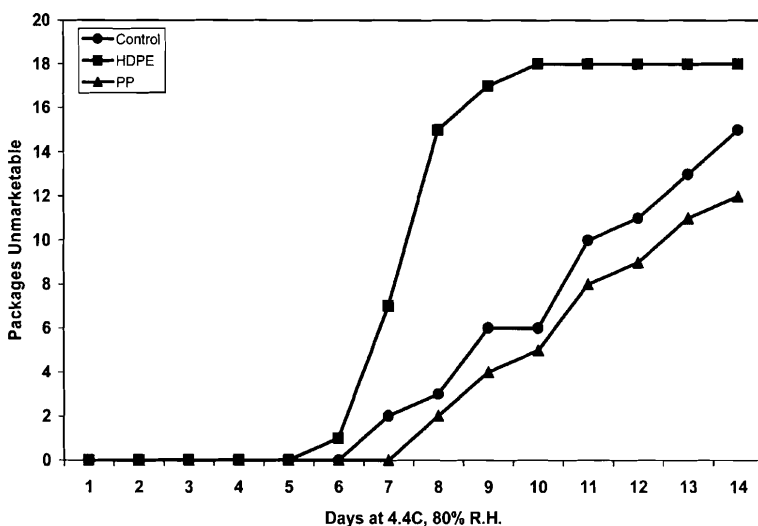


Figure 6. Effect of packaging on cumulative pinking as it relates to the number of bags of pre-cut Romaine lettuce which became unmarketable during 14 days storage at 4.4°C, 80% RH. 0 = None; 1 = some pinking but marketable; 2 = unmarketable. Control = commercial polyethylene/oriented polypropylene laminate, HDPE = biodegradable high-density polyethylene, PP = biodegradable polypropylene.

Table 4. Effect of packaging on the overall amount of decay and pinking of pre-cut Romaine lettuce during 14 days storage at 4.4°C, 80% RH.

Film Type	Decay Level ^z	Pinking Level ^y
PE/OPP (Control)	0.50 b	0.95 b
Biodegradable Polypropylene	0.75 a	0.84 b
Biodegradable high-density PE	0.82 a	1.29 a

^z0 = None; 1 = total decay less than size of a quarter (4.62 cm²); 2 = total area ≥ quarter (failure).

^y0 = None; 1 = some pinking but marketable; 2 = unmarketable.

DISCUSSION

Biodegradable polypropylene and high-density polyethylene required the use of an impulse sealer and increased dwell time to obtain satisfactory closure of bags formed from the films. The biodegradable polypropylene performed well in maintaining the quality of pre-cut Romaine lettuce stored for 14 days at 4.4°C, 80% R.H., resulting in a shelf-life comparable to that of commercially-packaged, pre-cut Romaine. The results indicate that the use of biodegradable bags for the pre-cut salad industry is feasible if care is taken that seal integrity is insured. Subsequent investigation should assess the impact of using impulse sealers in VFFS machinery on product thru-put. The results likewise indicate that improvements are needed to broaden the heat-seal temperature range of biodegradable films for ease of running on commercial VFFS machinery. This study also indicates a need for biodegradable laminated films compatible with commercial VFFS packaging lines.

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