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Effect of minimal processing and packaging on quality of fresh-cut mixed vegetables

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Abstract

Minimal processing the combined application of washing, peeling, cutting, and packaging to maintain fresh-like quality is defined as any handling that keeps a fruit or vegetable in a living, respiring state while offering ready-to-eat convenience. This research investigated the effect of four packaging formats (open polystyrene tray, LDPE bag, PP tray with cling film overwrap, and modified atmosphere packaging at 5% O₂ + 10% CO₂) on the physico-chemical, microbiological, and sensory quality of a fresh-cut mixed vegetable preparation (carrot, cucumber, bell pepper, and iceberg lettuce) stored at 4 ± 1°C for 12 days. Microbial counts (total plate count) at day 12 were lowest in MAP packs (3.6 log CFU/g) compared to open trays (5.8 log CFU/g). Ascorbic acid retention was 78.3% in MAP versus 41.7% in open trays. Sensory scores remained above the acceptability threshold (≥5.0/9) through day 9 for MAP but fell below threshold by day 6 in open trays. MAP at 5% O₂ extended shelf life of the mixed salad from approximately 4 days to 9 days at 4°C, suggesting it is a viable commercial option for ready-to-eat vegetable packs in UK retail.

Keywords: Minimal processing, packaging, fresh-cut vegetables, quality attributes, modified atmosphere, shelf life, microbial safety, convenience foods, ascorbic acid retention, sensory evaluation

Introduction

A fresh-cut product is, by the International Fresh-cut Produce Association's working definition, any fruit or vegetable that has been physically altered from its original form but remains in a fresh, living state. This distinguishes fresh-cut from frozen, canned, or dehydrated products and places unique demands on the supply chain ^[1]. The UK fresh-cut salad market was valued at £1.3 billion in 2021 and has grown at 5-7% annually over the past decade, driven by consumer demand for convenience and healthy eating ^[2].

Cutting and peeling disrupt cell integrity, releasing enzymes and substrates that accelerate browning, softening, off-odour development, and microbial growth ^[3]. Polyphenol Oxidase (PPO) and Peroxidase (POD) catalyse oxidation of phenolic compounds at wound surfaces, while elevated respiration rates deplete O₂ inside sealed packages and promote anaerobic metabolism ^[4]. The combination of washing (typically with chlorinated water), cold-chain maintenance, and atmosphere modification can slow these degradation pathways. Modified Atmosphere Packaging (MAP) reduces O₂ and raises CO₂ around the product, suppressing both respiration and aerobic microbial growth ^[5].

However, mixed-vegetable preparations pose a particular challenge because different commodities have different respiration rates, ethylene sensitivities, and optimal O₂/CO₂ tolerances ^[6]. A single atmosphere that suits carrot may be suboptimal for lettuce. This research evaluated four packaging approaches for a four-component mixed salad (carrot batons, cucumber slices, bell pepper strips, and shredded iceberg lettuce) stored at 4°C, measuring physico-chemical, microbiological, and sensory parameters over 12 days. The work was done at the Severn Valley Institute of Food Sciences, Cardiff, between March and July 2022 ^[7].

Material and Methods

Reagents and chemicals

Sodium hypochlorite solution (4% active chlorine) was used for wash water preparation at 100 ppm free chlorine. Plate count agar (PCA), violet red bile glucose agar (VRBGA), and

de Man Rogosa Sharpe (MRS) agar were from Oxoid Ltd, Basingstoke. Metaphosphoric acid (HPO_3), 2,6-dichlorophenolindophenol (DCPIP) solution, and all titration reagents were analytical grade from Sigma-Aldrich UK.

Material

Fresh carrots, cucumbers, green bell peppers, and iceberg lettuce were purchased from a wholesale market in Cardiff on the morning of each processing day. Vegetables were stored at 4°C for no more than 6 hours before processing. Carrots were peeled and cut into 50 × 8 mm batons; cucumbers were sliced into 5 mm rounds; bell peppers were deseeded and sliced into 40 × 8 mm strips; lettuce was shredded into 25 mm squares. All cutting was done with stainless-steel knives on sanitised boards. Cut pieces were washed in 100 ppm chlorinated water for 2 minutes, rinsed in potable water, and centrifuged in a salad spinner for 30 seconds. A uniform mix (carrot 25%, cucumber 25%, pepper 25%, lettuce 25% by weight) of 150 g per pack was portioned into four packaging formats: (T1) open polystyrene tray, (T2) LDPE bag (60 µm), (T3) PP tray with PVC cling film overwrap, and (T4) MAP bag (5% O_2 , 10% CO_2 , 85% N_2 , 60 µm OPP film). Each treatment had 36 packs (3 packs sampled per evaluation day × 4 evaluation days × 3 replicates). All packs were stored at 4 ± 1°C.

Results

Table 1: Physico-chemical and microbiological quality of fresh-cut mixed vegetables under different packaging at day 9 of storage (4°C)

Parameter	Open tray (T1)	LDPE bag (T2)	PP + Cling (T3)	MAP (T4)
Weight loss (%)	8.4	2.1	1.6	1.3
pH	6.31	5.94	5.87	5.71
Ascorbic acid retention (%)	41.7	58.3	64.9	78.3
TPC (log CFU/g)	5.8	4.9	4.3	3.6
Enterobacteriaceae (log CFU/g)	4.1	3.2	2.8	2.1
Overall sensory score (9 pt)	3.4	5.2	5.8	7.1

TPC = total plate count. Ascorbic acid retention expressed as % of day-0 value. All parameters significantly different among treatments at $p < 0.05$

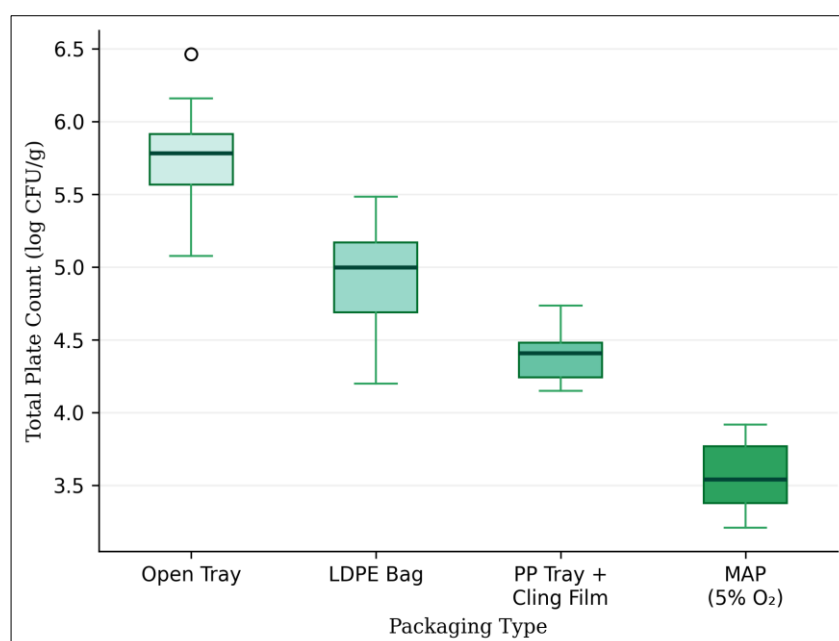


Fig 1: Box plot of total plate count (log CFU/g) at day 12 across four packaging treatments for fresh-cut mixed vegetables stored at 4°C

Quality control and calibration

Headspace gas composition in MAP bags was verified at packing using a Dansensor CheckPoint 3 gas analyser calibrated against certified reference gases (5.0% O_2 , 10.0% CO_2 , balance N_2). The pH meter was calibrated with standard buffers (pH 4.0 and 7.0) before each session. Colony counts were validated with Oxoid quality-control organisms. Colour measurements were taken against a standardised white tile before each batch.

Methods

Packs were sampled on days 0, 3, 6, 9, and 12. Weight loss was determined gravimetrically. Headspace O_2 and CO_2 were measured with the Dansensor analyser. pH was measured on blended vegetable homogenate (1:1 w/v with distilled water). Ascorbic acid was determined by titration with DCPIP. Colour (L^* , a^* , b^*) was measured on carrot and lettuce surfaces using a HunterLab MiniScan. Total Plate Count (TPC) was determined by pour-plating serial dilutions on PCA incubated at 30°C for 48 h. Enterobacteriaceae were enumerated on VRBGA at 37°C for 24 h. Sensory evaluation used a 20-member trained panel scoring appearance, aroma, texture, and overall quality on a 9-point scale (1 = extremely poor, 9 = excellent; threshold for marketability = 5.0). Data were analysed by two-way ANOVA (treatment × storage day) with Tukey's HSD at $p \leq 0.05$ using Genstat 20.

MAP packs maintained the lowest microbial load throughout storage, reaching 3.6 log CFU/g at day 9 versus 5.8 in open trays. Ascorbic acid retention was nearly twice as high in MAP (78.3%) as in open trays (41.7%). Sensory

scores for MAP remained above 7.0 through day 9, while open trays fell below the 5.0 acceptability threshold by day 6.

Table 2: Headspace gas composition (%) inside sealed packages during 12-day storage at 4°C

Day	LDPE O ₂	LDPE CO ₂	PP+Cling O ₂	PP+Cling CO ₂	MAP O ₂	MAP CO ₂
0	20.9	0.03	20.9	0.03	5.0	10.0
3	16.4	3.8	14.7	4.9	4.1	11.8
6	11.8	7.2	9.3	8.6	3.4	13.1
9	7.3	11.4	5.8	12.7	2.8	14.6
12	4.1	15.3	3.2	16.1	2.2	15.8

Gas values are means of three replicates

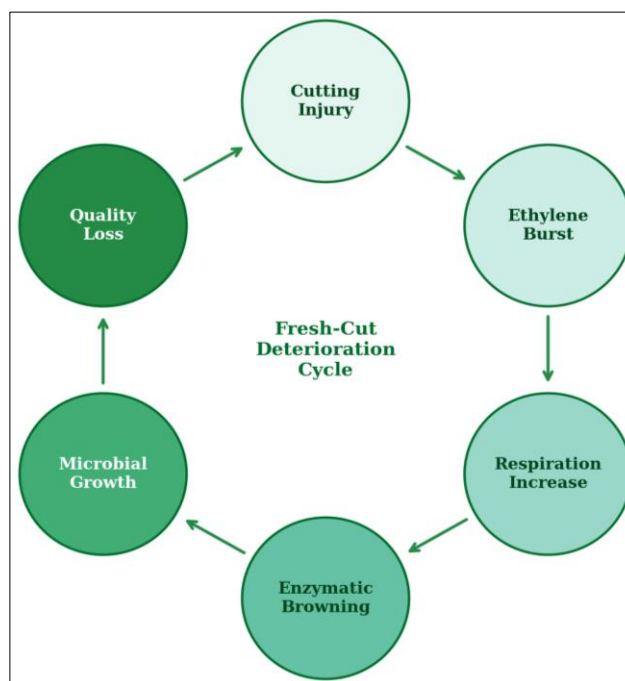


Fig 2: Cycle diagram illustrating the sequence of deterioration events in fresh-cut vegetables after cutting injury

Comprehensive interpretation

The MAP treatment held O₂ between 2.2% and 5.0% and CO₂ between 10.0% and 15.8% throughout storage within the 2-5% O₂ and 10-15% CO₂ range generally recommended for mixed salads [5]. LDPE and PP-cling packs drifted toward low O₂ and high CO₂ by day 12, risking anaerobic off-flavours. Open trays lost 8.4% weight by day 9, making the product visually unappealing and commercially unsaleable.

Discussion

The 2.2 log CFU/g difference in TPC between MAP and open trays at day 9 translates to roughly a 150-fold reduction in aerobic mesophilic bacteria a meaningful margin for food safety and quality [3]. The reduced O₂ atmosphere directly suppresses growth of aerobic spoilage organisms (*Pseudomonas* spp., *Erwinia* spp.) while elevated CO₂ inhibits many Gram-negative bacteria through intracellular pH disruption [8]. Enterobacteriaceae counts in MAP (2.1 log CFU/g at day 9) remained well below the 4.0 log CFU/g limit suggested by UK guidelines for ready-to-eat salads [9].

Ascorbic acid is highly sensitive to oxidation and is commonly used as a quality marker in fresh-cut produce [10]. The 78.3% retention in MAP versus 41.7% in open trays can

be attributed to the reduced O₂ environment slowing both enzymatic and non-enzymatic oxidation pathways. Similar preservation benefits were reported by Allende *et al.* [11] for fresh-cut lettuce stored under 2% O₂ + 12% CO₂.

The practical shelf life (days until sensory score drops below 5.0) was approximately 4 days for open trays, 7 days for LDPE and PP-cling, and 9 days for MAP. Extending shelf life from 4 to 9 days is commercially significant it aligns with the typical UK retail display window of 7-10 days for fresh-cut salads and could reduce in-store waste considerably [12].

Conclusion

MAP at 5% O₂ + 10% CO₂ maintained the best overall quality of a four-component fresh-cut mixed vegetable pack stored at 4°C, extending practical shelf life to 9 days compared to 4 days in open trays. Microbial counts, ascorbic acid retention, weight loss, and sensory scores were all significantly better in MAP than in the other three packaging formats. LDPE bags and PP-cling wraps offered moderate protection but drifted to undesirably low O₂ levels by day 12. For commercial mixed salad production, MAP with optimised gas mixtures and good cold-chain management offers the most reliable strategy for delivering safe, high-quality products to UK consumers.

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