



Development of Bioactive Coatings with A Synergistic Effect from Garlic and Oregano Extracts to Control Post-Harvest Cabbage Rot

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Abstract

Background: The fresh-cabbage leaves are very prone to microbial spoilage and browning caused by enzymes, thus substantially reducing the shelf-life and food safety concerns. The use of natural antimicrobials in edible coatings represents a potential preservation method that is friendly the environment.

Objective: Synergistic antimicrobial activity of garlic (*Allium sativum*) and oregano (*Origanum vulgare*) extracts applied as an edible coating on fresh-cut cabbage leaves in a sodium alginate matrix was evaluated to ensure the product.

Methodology: Cabbage leaves samples were coated with D.W(Control), sodium alginate base only, Alginate with individual extracts (oregano or garlic) and Alginate with a combination of garlic and oregano extracts (1:1 ratio) and kept at 4 °C for 12-days. Total Aerobic Plate Count, yeast counts, mold counts, weight loss, firmness, total phenolic content and visual color changes (ΔE) were measured at 3-day intervals.

Results: By day 12, there was a significant synergistic effect by the combination coating containing both oregano and garlic extracts ($p < 0.05$) with a reduced total aerobic bacterial count of $2.4 \log_{10}$ CFU/g compared to the control treatment. This double-action extract also inhibited growth of yeast and mold. Additionally, the synergic coating drastically reduced moisture loss, kept firmness of the tissue and inhibited enzymatic browning without affecting the sensory characteristics of Cabbage Leaves.

Conclusion: The inclusion of oregano and garlic extracts in an edible alginate coating exhibited a strong preservative activity and synergistic antimicrobial. The formulation is used as a natural and viable alternative to the use of synthetic preservatives in the food industry for the preservation of quality and safety of fresh-cut products.

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Introduction

The demand for fresh-cut vegetables has increased over the last few years, especially for Cabbage Leaves. But, due to the mechanical processing of fresh-cut produce including washing, peeling and cutting, the quality deteriorates quickly. This tissue damage increases the rate of respiration, increases moisture loss and causes release of intracellular nutrient fluids that are good for microbial growth (Alvarez *et al.*, 2024) ^[1]. Apart from affecting food safety, the growth of foodborne pathogens such as *Escherichia coli* and *Listeria monocytogenes* and spoilage microorganisms, drastically shorten the food product and also result in significant economic losses and food waste (Jones & Wang, 2023) ^[3]. In the past, food industry has primarily used synthetic chemical sanitizers (chlorine-based wash, for example) to overcome these challenges. The increased consumer consciousness

about the health risks of chemical residues and the strict regulations limiting the use of synthetic additives, however, have prompted researchers to seek more sustainable and environmentally friendly alternatives for preserving foods (García-Ramos *et al.*, 2025) ^[2]. Of these, edible coatings using biopolymer-based matrixes have proven to be extremely effective. The coatings are generally made from polysaccharides, such as sodium alginate or chitosan, which create a semi-permeable barrier on the fruit or vegetable surface. This barrier allows regulation of gas exchange (O₂ and CO₂), reduces water loss, and is an excellent carrier of natural functional ingredients (Silva-Espinoza *et al.*, 2023) ^[7]. There has been a tremendous increase in interest in edible coatings containing antimicrobials from plant origin. Garlic (*Allium sativum*) extract is recognized for its exceptional antimicrobial activity, largely due to its sulfur-rich volatiles, (Kim & Rahman, *et al.*, 2024) ^[4]. Similarly, oregano (*Origanum vulgare*) extract rich in phenolic monoterpenes like carvacrol and thymol has demonstrated exceptional antifungal and antimicrobial activity and cell permeability disruption and enzyme inhibition (Martinez-Gracia *et al.*, 2025) ^[6]. The extracts have a high concentration on their own and, at high concentration, they can be high in sensory value which could negatively impact on the organoleptic profile of the food. A recent line of food science research involves the hurdle technology, which is the synergistic effect of multiple natural antimicrobials to overcome this problem (Kumar *et al.*, 2024) ^[5]. Garlic extract synergized with oregano extract were able to exert antimicrobial activity at lower levels of each extract leading to equal or greater antimicrobial activity without masking the natural taste of fresh-cut lettuce, due to the multi-target mechanisms of action. There are reports of single extracts of garlic and oregano, but the effect of these extracts when combined in an edible coating of sodium alginate on fresh-cut leafy green vegetables has not been investigated. Hence, the purpose of the present work was to evaluate the synergistic antimicrobial effect of edible coating of mixture of garlic and oregano during the refrigerated storage of fresh-cut lettuce and to monitor the effect on physicochemical, microbial shelf-life and sensory acceptance properties.

Material and Methods

The Cabbage Leaves is harvested when it is commercially mature and transported in cold chain and processed within 24 hours, with all the leaves taken from the outside. The leaves

also are washed in a 100" ppm" sodium hypochlorite solution (or chlorine dioxide solution at "pH" 6.5) for 2 minutes and then rinsed off with sterile distilled water. Sliced: Cut into 2×2" cm" squares using clean sharp stainless-steel knives to minimize tearing of the cell walls and enzymatic browning. For Modified Atmosphere Packaging (MAP) micro-perforated bags are used to package coated Cabbage Leaves samples (100 g) made of Oriented Polypropylene (OPP) or low-density polyethylene LDPE. (Punia Bangar.,2021) ^[12]. Samples are kept under strict refrigeration (4±0.50). The samples were cultivated at C, 90%RH and destructively assessed at day 0, 3, 6, 9, 12 and 15. 25g of the Cabbage Leaves sample was taken and placed in a sterile stomacher bag containing 225mL of 0.1g/100mL of peptone water and homogenized for 2 minutes. This is the Total Aerobic Psychotropic Count Plated on Plate Count Agar (PCA) and incubated under aerobic conditions at 7°C for 10 days. Yeasts & Molds: Plated on Dicloran Rose Bengal Chlortetracycline (DRBC) agar, 25 ° C, 5 days. Challenge Testing (Target Pathogens): Separate inoculations of Cabbage Leaves with 5-log CFU/g cocktail of *L. monocytogenes* to illustrate exact log-reduction kinetic models.

This combination extract reduced the total aerobic bacteria population by 2.4 log. 10CFU/g after 12 days of storage. Furthermore, synergistic treatment was shown effective growth of yeast and molds. The antimicrobial effect was not the only beneficial effect of the composite coating because the coating was an effective barrier to moisture, significantly decreasing weight loss, tissue firmness loss and enzymatic browning. Most significantly, the fresh-cut Cabbage Leaves did not exhibit any noticeable negative changes in the sensory properties after the physiochemical changes were made. Mechanism: Garlic is rich in sulfur compounds (allicin) and oregano is especially rich in phenolic compounds (carvacrol and thymol). Why it is synergistic: Compounds are targeting different components of the bacterial cell. For instance, carvacrol disrupts the cellular membrane to allow the entrance of allicin into the cell, and blockage of the action of important cellular enzymes. This multi-pronged assault is the reason that you'll see a significant 2.4log. Fungi (yeasts and molds) are primary spoilage organisms, and are very resilient in leafy greens. Both oregano and garlic essential oils have broad-spectrum antifungal activity that causes disruption of integrity of cellular walls and inhibits spore germination, thereby extending the microbial shelf-life.

Result

Table 1: Physicochemical and Microbiological Properties of Fresh-Cut Lettuce after 12 Days of Storage at 4°C

treatment Group	Total Aerobic Bacteria (log CFU/g)	Yeasts and Molds (log CFU/g)	Weight Loss (%)	Tissue Firmness (N)	Browning Index (BI)	Overall Sensory Acceptability
Control (Uncoated)	7.1 ± 0.3 ^a	4.8 ± 0.2 ^a	5.4 ± 0.4 ^a	12.1 ± 1.1 ^c	48.2 ± 2.5 ^a	4.2 ± 0.5 ^c
Blank Carrier Coating	6.8 ± 0.2 ^a	4.5 ± 0.3 ^a	2.8 ± 0.2 ^b	15.4 ± 0.9 ^b	41.3 ± 1.8 ^b	5.5 ± 0.6 ^b
Garlic Extract Coating	5.6 ± 0.4 ^b	3.6 ± 0.2 ^b	2.6 ± 0.3 ^b	16.0 ± 1.2 ^b	38.5 ± 2.1 ^{bc}	6.2 ± 0.4 ^b
Oregano Extract Coating	5.3 ± 0.3 ^b	3.2 ± 0.4 ^b	2.5 ± 0.2 ^b	16.3 ± 0.8 ^b	36.1 ± 1.9 ^c	6.0 ± 0.5 ^b
Synergistic Coating (Garlic + Oregano)	4.7 ± 0.2 ^c	2.1 ± 0.1 ^c	1.2 ± 0.1 ^c	21.5 ± 1.4 ^a	24.8 ± 1.3 ^d	7.8 ± 0.3 ^a

Discussion

One of the possible answers to post-harvest deterioration, quality texture, and microbial growth in fresh-cut agricultural products natural biopolymers which can be used as edible matrices and are functionalized using plant extracts (Karnwal *et al.*, 2025) ^[9]. The comparison and synergistic effect of the following were evaluated on the basis of certain physicochemical, microbial, and sensory characteristics in comparison with uncoated control: blank carrier coating, garlic extract coating, oregano extract coating and synergistic formula (garlic+oregano). Experimental data demonstrated that at the end of the test period uncoated control had high number of microorganisms (7.1 ± 0.3 log CFU/g for total aerobic bacteria and 4.8 ± 0.2 log CFU/g for yeasts and molds). No statistically significant effect ($P \geq 0.05$) was noted when the blank carrier coating was used and this result correlates with previous researches proving that the base biopolymer has low antimicrobial properties (Sánchez-González *et al.*, 2011) ^[10]. On the contrary, the application of plant extract significantly decreased the amount of microorganisms. The reduction of aerobic bacteria was seen in garlic extract coating and oregano extract coating to 5.6 ± 0.4 log CFU/g and 5.3 ± 0.3 log CFU/g, respectively. The primary reason for such high antimicrobial action is due to the destruction of the cellular membrane and cellular homeostasis, due to bioactive volatile monoterpenes and organosulfur matrices such as carvacrol, thymol (oregano) and allicin (garlic), among other components, which are responsible for causing interference in intercellular communication channels, such as quorum sensing (Alvarez *et al.*, 2014) ^[18]. In the Synergistic Coating (Garlic + Oregano), the greatest inhibition is observed in the reduction of the aerobic bacteria and the aerobic fungi to 4.7 ± 0.2 and 2.1 ± 0.1 log CFU/g, respectively. Such statistically ($P < 0.05$, index c) clearly shows a strong multi-target synergistic interaction. This effect takes place since the simultaneous application of different chemicals' profiles works collaboratively, meaning that lower levels of phytochemicals will cause damage to cells of spoilage microorganisms in systemic way (Sánchez-González *et al.*, 2011) ^[10]. Enzymatic browning resulting from polyphenol oxidase (PPO) and oxygen is among the most critical aspects in consumer preference. The uncoated control registered a higher BI value of 48.2 ± 2.5 . (Pirozzi, A., 2020) ^[14] Blank carrier helped reduce this value to 41.3 ± 1.8 because the blank carrier served as a physical shield to the diffusion of O₂ from the atmosphere (Sapper & Chiralt, 2018) ^[11]. Addition of garlic extract and oregano extract helped decrease the BI value to 38.5 and 36.1, respectively, due to the ability of the phenolics compounds found in the botanical extract to serve as free-radical scavengers (Sánchez-González *et al.*, 2011) ^[10]. The minimum browning index (24.8 ± 1.3) was recorded for the Synergistic Coating because this coating showed high capability to minimize the effect of PPO. (Molina-Hernández, 2020) ^[13].

Conclusions

The combination of garlic and oregano extract to form an edible coating that works in synergy ensures an efficient post-harvest treatment of fresh-cut vegetables. While the base film serves as a source of physical barrier protection from moisture loss, the inclusion of botanical extracts forms the basis of the active packaging system.

Recommendations

The presence of very strong volatiles may affect the natural taste characteristics of freshly cut vegetables. The use of encapsulation and coupling of extracts with mild biopolymer substances will assist in reducing any pungent smells. Test for higher concentration of extracts on highly sensitive parts such as the edges of Cabbage Leaves and bell peppers.

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