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The Influence of Essential Oils Derived from Free-range Herbs *Echinophora platyloba* DC and *Ocimum Basilicum* L., in Conjunction with Chitosan-based Nanocapsules, on the Physicochemical, Textural, and Sensory Characteristics of Hamburgers

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ABSTRACT: This study aimed to examine the impact of essential oils derived from herbs *Echinophora platyloba* DC. and basil (*Ocimum Basilicum* L.), both in their free form and nanoencapsulated with chitosan, on the physicochemical, textural, sensory, and shelf-life characteristics of hamburgers during storage at refrigeration temperatures. Initially, the essential oils were extracted, followed by the preparation of nanocapsules utilizing these essential oils in conjunction with chitosan. In the present study, hamburger samples (comprising 95% beef) were prepared under various conditions to evaluate the effects of different essential oil formulations on their characteristics. Specifically, a control sample (T_0) was prepared without the inclusion of any essential oils. In addition, samples were prepared with the incorporation of free essential oils derived from herbs E. platyloba (T_1) and basil (T_3) individually at a concentration of 0.2%. A combination of both free essential oils was also evaluated (T_5) at the same concentration. Furthermore, samples were prepared using nanoencapsulated essential oils of herbs E. platyloba (T_2) and basil (T_4), which were incorporated using chitosan as a carrier, again at a concentration of 0.2%. A combined formulation of the nanoencapsulated essential oils was tested (T_6) at 0.2% All formulations were mixed with 100 g of hamburger dough and subsequently stored in a refrigerator at a temperature of 4 °C for a duration of 12 days. The findings indicated that the incorporation of E. platyloba and basil essential oils, both in free and encapsulated forms, exerted no significant impact on the fat, protein, and ash content of the hamburger samples ($p < 0.05$). Furthermore, the incorporation of E. platyloba and basil essential oils, both in free and encapsulated forms, has been observed to enhance antioxidant properties, as indicated by the Ferric Reducing Antioxidant Power (FRAP) assay. Additionally, these enhancements contributed to increased texture hardness and improved sensory attributes, while also positively affecting peroxide value and Total Volatile Nitrogen (TVN) levels. The duration of storage has been observed to adversely affect antioxidant properties, as measured by the Ferric Reducing Ability of Plasma (FRAP) assay, as well as texture hardness and sensory characteristics. Furthermore, an increase in peroxide value and Total Volatile Nitrogen (TVN) was noted in relation to extended storage time. Furthermore, the findings indicated that the treatment (T_6), which consisted of 0.1% essential oils of E. platyloba in conjunction with 0.1% basil nanoencapsulated with chitosan, was identified as the most effective treatment option. In conclusion, the incorporation of plant essential oils within nanocapsules presents a promising approach for the development of innovative, functional, and nutritionally advantageous products. This strategy leverages the antimicrobial and antioxidant properties of essential oils, thereby contributing to an extension of product shelf life.

Keywords: Basil, Chitosan, *Echinophora platyloba*, Hamburger, Nanocapsules.

Introduction

Beef burgers represent a significant category of meat products in numerous countries and enjoy widespread consumption on a global scale. These food items represent a valuable source of protein, fats, and essential minerals, including iron, selenium, zinc, phosphorus,

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potassium, and manganese. Additionally, they are rich in B vitamins, bioactive compounds, and essential amino acids. Furthermore, these products are characterized by their accessibility, affordability, and convenience as ready-to-eat options (Grassi *et al*., 2024; Morsy & Elsabagh, 2021). Meat and meat products are prone to lipid and protein oxidation during processing and storage, resulting in diminished nutritional value, sensory qualities, including taste and texture, and overall shelf life. Furthermore, meat and meat products, which are recognized as primary sources of protein for human nutrition, are susceptible to spoilage resulting from the contamination by pathogenic microorganisms. This contamination not only causes noticeable discoloration of the meat but also leads to the production of volatile amines, including ammonia, dimethylamine, and trimethylamine. These compounds are implicated in the spoilage process and are associated with pathogenic bacteria capable of inducing diseases in humans upon consumption of contaminated products (Zhang & Piao, 2023).

Essential oil is a complex mixture of volatile aromatic compounds characterized by a distinctive fragrance, which is extracted from various parts of aromatic plants, including flowers, fruits, seeds, stems, and leaves (Lages *et al*., 2021). These compounds exhibit bioactive properties and are environmentally sustainable, attributable to their content of polyphenols, flavonoids, and terpenoids. Owing to their robust antibacterial and antioxidant properties, these compounds are capable of inhibiting oxidative reactions, preventing the generation of free radicals, and suppressing the proliferation of pathogenic bacteria in food products. They are recognized as agents for food preservation (Zhang & Piao, 2023; Sojic *et al*., 2020; Lages *et al*., 2021). The incorporation of antioxidant-rich ingredients into meat product formulations has garnered significant attention in recent research. This practice aims to mitigate the detrimental effects of lipid oxidation, preserve textural and microbial properties, and maintain sensory characteristics, thereby extending the shelf life of these products (Ebrahimi *et al*., 2022). *Echinophora platyloba*, a species belonging to the Asteraceae family, is indigenous to Iran. This plant exhibits a range of biological effects attributed to the presence of saponins, flavonoids, alkaloids, and other phenolic compounds. Notably, it possesses antioxidant, antimicrobial, anti-inflammatory, and vasodilatory properties. Phenolic compounds found in plant extracts exhibit notable antioxidant properties, which can significantly contribute to the preservation of food products and the enhancement of human health (Ghaderi *et al*., 2021).

Basil, scientifically designated as *Ocimum basilicum L.*, is an annual herb belonging to the family Lamiaceae. Basil is an aromatic herb that is extensively employed as a culinary spice, primarily attributed to its unique and pronounced olfactory characteristics. Basil essential oil exhibits significant antioxidant and antimicrobial properties, attributable to its rich composition of phenolic compounds, including phenylpropanoids (notably eugenol, chavicol, and their derivatives) as well as terpenoids, which encompass monoterpene alcohols such as linalool, methylcinnamate, and limonene (Gurkan & Hayaloglu, 2023; Teneva *et al*., 2021).

Chitosan, a derivative of chitin obtained through the process of deacetylation, is a natural polysaccharide composed of α-amino-d-glucosamine monomers interconnected by 4,1β-glycosidic linkages. Chitosan exhibits significant

antioxidant and antibacterial properties, which has generated substantial interest in its application as a biodegradable biopolymer. This interest is largely attributable to its superior encapsulation capabilities, controlled release mechanisms, and low toxicity profile in drug delivery systems (Sun *et al*., 2021).

Microencapsulation is recognized as a highly effective strategy for safeguarding phenolic compounds derived from natural essential oils against various adverse factors, including light exposure, atmospheric oxygen, enzymatic activities, interactions with food constituents, fluctuations in pH, and temperature variations. These factors can significantly restrict the applicability of these compounds in food systems. Encapsulation facilitates the preservation of elevated concentrations of plant extracts in food products, thereby enhancing their sensory quality. Additionally, it increases the solubility of bioactive compounds and their antioxidant properties, while also promoting the controlled release of these compounds (Zhang & Piao, 2023; Tome *et al*., 2023; Radunz *et al*., 2020). Nanoencapsulation has the potential to enhance the bioavailability and stability of essential oils, regulate their specific release and delivery mechanisms, and mitigate undesirable sensory attributes associated with their use (Zhang & Piao, 2023).

Meat and meat products exhibit a significant degree of perishability, which can be attributed to their elevated levels of water, fat, and protein content. The primary mechanisms underlying spoilage are the oxidation of proteins and lipids, as well as the degradation caused by microbial proliferation. Foodborne diseases are widely recognized as a significant threat to public health on a global scale. Consequently, there is a critical need for effective preservation strategies aimed at inhibiting the proliferation of pathogenic microorganisms in food products. Nevertheless, there has been a notable increase in the demand for food safety and healthier meat products. Therefore, it is imperative to explore natural antioxidants as a means of preserving the quality of meat and its derived products, thereby addressing consumer demand. To achieve this objective, essential oils derived from plants are employed as natural food preservatives due to their potent antibacterial and antioxidant characteristics. Furthermore, the incorporation of chitosan-based nanocapsules has been shown to enhance the stability of essential oils, thereby improving their quality and potentially extending the shelf life of meat and meat products. Consequently, this study examined the influence of essential oils derived from Euphorbia and basil, both in their free forms and encapsulated in chitosan nanoparticles, on the physicochemical, textural, and sensory characteristics of hamburgers during refrigerated storage at 4°C. Furthermore, an investigation was conducted into the physicochemical properties of the microcapsules containing essential oil. This analysis encompassed various characteristics, including particle size, zeta potential, encapsulation efficiency, and morphological attributes. Furthermore, properties including antioxidant activity, chemical structure, and morphology were systematically investigated.

Materials and Methods

- ***Materials***

The E. platyloba plant was sourced from the Jahanbin Heights, located in the Chaharmahal and Bakhtiari province, characterized by an elevation ranging from

2000 to 2500 meters above sea level, at a latitude of 32 degrees and a longitude of 55 degrees. Additionally, the purple basil plant was procured from the Seed and Seedling Improvement Center in Tehran province. Subsequent to the preparation of the plant specimens, their scientific nomenclature was validated through the utilization of identification keys and consultations with botanical experts. Subsequent to the washing process, the samples were dried at room temperature (25 °C) in a shaded environment to maintain their aromatic properties and olfactory characteristics. The essential oils were extracted via water distillation employing a glass Clevenger apparatus over a period of four hours. Following the separation of the essential oil from the aqueous phase, dehydration was carried out utilizing sodium sulfate. The dehydrated essential oil was subsequently transferred into 2 ml plastic microtubes that were aluminum-coated, and the samples were stored at 4 °C until further utilization. Food-grade chitosan was acquired from Sigma-Aldrich, a supplier based in the United States. N-hexane, thiobarbituric acid, and various other materials and reagents were procured from Merck, a company based in Germany.

- ***Methods***
- ***Preparation of Nanocapsules Containing Essential Oils Derived from Aromatic Plants E. platyloba and Basil Utilizing Chitosan as a Matrix Material***

Nanocapsules were synthesized utilizing the ionic gelation method. A quantity of 0. 1 g of chitosan, characterized by a deacetylation degree ranging from 85% to 90% and a molecular weight of 200 kilodaltons, was dissolved in 50 mL of a 1% (v/v) acetic acid solution using a magnetic stirrer. Consequently, a chitosan solution with a concentration of 2 mg/mL was obtained. The pH of the chitosan solution described above was regulated to a range between 4. 78 Subsequently, 120 mg of polysorbate (Tween 80) was incorporated into the chitosan solution while maintaining continuous stirring for a duration of 30 minutes to achieve homogeneity in the resulting solution. The essential oils derived from each plant were combined with 4 mL of 80% acetone at predetermined concentrations. Subsequently, this mixture was incrementally added dropwise to the chitosan solution while maintaining continuous stirring at a rotational speed of 1200 rpm for a duration of 30 minutes. Subsequently, a volume of 10 mL of sodium tripolyphosphate solution (concentration of 4 mg/mL, pH 4) was incrementally added to the homogeneous emulsion while maintaining moderate agitation for a duration of 60 minutes. The synthesized plant essential oil nanocapsules were concentrated via centrifugation at 10,000 × g for 35 minutes at a temperature of 4 °C. Subsequently, the nanocapsules were washed with a 1% (v/v) polysorbate (Tween 80) solution, followed by dispersion in distilled water. The resulting preparation was stored at 4 °C until required for further application (Zhang *et al*., 2020).

- ***Freeze-drying of Nanocapsules Containing Essential Oils Derived from Aromatic Plants E. platyloba and Basil***

Before the freeze-drying process, the samples were frozen in a freezer at -80°C for 1 hour. The main drying was carried out at -60°C and 0.011 mbar for 24 hours and the final drying was performed at -75°C and 0.012 mbar for 1 hour. The samples were stored in a low vacuum desiccator until required (Obradovic *et al*., 2022).

- ***Making Hamburgers 95 Percent***

In order to prepare a 95% beef burger batter, the raw materials were prepared in accordance with the formulation outlined in the article, with certain modifications implemented. To achieve this objective, equal quantities of beef tenderloin and shoulder meat, procured from a local supermarket, were utilized in the study. Subsequent to the elimination of surplus adipose tissue, tendons, and osseous fragments, the onions (3.5%) alongside the prepared meat portions were measured utilizing a digital scale with a precision of 1 gram (model PX3000, Pand Industries, Iran). These materials were subsequently processed using a meat grinder (Moulinex, HV8, France). A mixture of salt (1%) and spices (0.5%), which included black pepper, coriander seeds, and lemon powder, was incorporated into the onion and meat mixture following precise measurements taken with a digital scale possessing a sensitivity of 0. 001 g (model AND GF-600, manufactured in Japan). The control sample, designated as C, comprised 100 grams of prepared hamburger batter formulated with 95% beef, without the incorporation of any essential oils. Additionally, treatments incorporating both free and encapsulated essential oils were integrated into the formulation in accordance with the specifications outlined in Table 1. The resultant mixtures were homogenized through a molding process and fabricated into specimens with dimensions of 10 cm in diameter and 1 cm in thickness. Subsequently, wax papers were interposed between each specimen, which were then packaged and labeled in polyethylene plastic bags containing six pieces each. The packaged specimens were stored in a refrigerator at a temperature of 4 °C for a duration of 12 days, with evaluations conducted on days 1, 4, 8, and 12 (Mozafari *et al*., 2023; Rashidimehr *et al*., 2019).

- ***The Encapsulation Efficiency of Essential Oils Derived from Aromatic Plants E. Platyloba and Basil***

In order to assess encapsulation efficiency, an initial volume of 1 mL from each sample was subjected to centrifugation at 13,000 revolutions per minute (rpm) for a duration of 30 minutes to facilitate the separation of the capsules. Subsequently, to ensure the complete removal of particles that were not separated through centrifugation, the samples were subjected to filtration employing a 0. 22 µm syringe filter. A volume of 40 µL from each sample was aliquoted and subsequently diluted to a final volume of 2 mL with methanol. Subsequently, the absorbance was measured using a UV-visible spectrophotometer at a wavelength of 275 nm (Erfani *et al*., 2019).

The encapsulation efficiency was determined utilizing the methodology delineated in Formula (1):

Table 1. Introduction of the treatments used in the research

Treatment	Free essencial oil E. platyloba (%)	Free essencial oil Basil (%)	Nanocapsol essencial oil E.platyloba (%)	Nanocapsol essencial oil Basil (%)
C	0	0	0	0
T1	0.2	0	0	0
T2	0	0	0.2	0
T3	0	0.2	0	0
T4	0	0	0	0.2
T5	0.1	0.1	0	0
T6	0	0	0.1	0.1

$$EE\% = \frac{EO\ Total\ EO - Free\ EO}{Total\ EO} \times 100$$ Encapsulation efficiency 1

where,
Total EO = Total essential oil used
Free EO= Free Essential Oil

- ***Morphological Characteristics of E. Platyloba and Basil Essential Oils Nanoencapsulated using Chitosan***

Scanning electron microscopy was employed to analyze the morphology and verify the dimensions at the nanoscale, specifically for features measuring less than 100 nanometers. A small aliquot of the sample was deposited onto an aluminum substrate utilizing silver adhesive. Subsequently, the substrate was subjected to a thin layer of gold deposition within a coating apparatus for a duration of six minutes to render the sample conductive. The specimens were subsequently transferred to a vacuum chamber for analysis. A beam of accelerated electrons, operating at a voltage of 20 kV, was directed towards the samples, and an image was generated based on the electrons that were reflected from the samples (Rezaei Savadkouhi *et al*., 2020).

- ***FTIR Measurement of Structural Properties of Essential Oils of E. Platyloba and Basil Nanoencapsulated using Chitosan***

An FTIR (Fourier Transform Infrared) spectrometer was utilized to conduct infrared spectroscopy analyses. Thin film tablets, exhibiting a thickness of less than one millimeter, were synthesized through a process involving the integration of water with microcapsule samples, followed by a coating procedure utilizing potassium bromide. The preparation protocol involved the use of a freeze-drying apparatus, where the mixture was subjected to a pressure of approximately 60 kPa for a duration of 10 minutes, adhering to a mass ratio of 20:1. The tablets were procured, and the transmission spectrum of the samples was subsequently analyzed within the wavenumber range of 400 cm^{-1} to 4000 cm^{-1}, utilizing a resolution of 0. 5 cm^{-1} (Erfani *et al*., 2019).

- ***The Assessment of Particle Size Distribution and Zeta Potential of Essential Oils Derived from E. platyloba and Basil Nanoencapsulated using Chitosan***

The mean carrier size and zeta potential were assessed utilizing a Nano series Zetasizer, employing a helium-neon laser at a controlled temperature of 25 ± 0. 1°C For the purpose of conducting measurements, samples were prepared utilizing deionized water and subsequently positioned within a folded capillary cell. The data obtained from the device were analyzed utilizing the Malvern Zetasizer software. The samples were subjected to three measurements, and the results are reported as the mean accompanied by the standard deviation (Obradovic *et al*., 2022).

- ***Burger Tests***
- ***Total Fat***

The total fat content of meat and its derivatives was quantified utilizing the Soxhlet extraction method applied to raw samples (National Standards Organization of Iran N. 742, 2003). The fat percentage was determined as a weight percentage utilizing the formula delineated in Equation (2).

$$F = \frac{m2 - m1}{m0} \times 100$$ Fat percentage formula 2

where,
m_0 = weight of the test sample in grams

m_1 = weight of the extraction flask and the boiling stone in grams

m_2 = weight of the extraction flask, the boiling stone and the fat after drying in grams

- ***Total Protein***

The total protein content in meat and its derivatives is quantified by determining the total nitrogen present in the raw sample, utilizing the macro Kjeldahl method for measurement (National Standards Organization of Iran N.924, 1973). The protein percentage was determined in terms of weight percentage, utilizing formula 3.

$$P = \frac{1.4 \times 6.25 \times V}{a \times 1000} \times 100$$ Protein percentage formula 3

where,

1.4= Each cubic centimeter of 0.1 normal sulfuric acid is equivalent to 1.4/1000 grams of nitrogen

6.25= Meat protein coefficient

v = Volume of burette used after titration

a = Sample weight

- ***Total Ash***

The residue produced from the combustion of the test sample, conducted at a temperature of 550 ± 25 °C, is quantified utilizing the dry ash methodology applied to the raw sample (National Standards Organization of Iran N. 744, 2002). The percentage of total ash present in the analyzed sample was determined utilizing Equation (4).

$$a = \frac{m2 - m0}{m1 - m0} \times 100$$ Total ash formula 4

where,

a = Total ash content in the sample, in grams Percentage

m_0 = Weight of the empty crucible in grams

m_1 = Weight of the crucible containing the test sample in grams

m_2 = Weight of the crucible containing the ash in grams

- ***Measurement of Iron Reducing Power (FRAP)***

In this method, antioxidants function as reducing agents, facilitating the conversion of iron(III) to iron(II). The alteration of the test solution's color from yellow to green or blue is contingent upon the reducing potential of the essential oil. To assess this property, 0. 1 grams of the essential oil were homogenized with 5 milliliters of distilled water using a cold porcelain mortar maintained in an ice bath. The resultant homogenate was subjected to filtration employing Whatman filter paper No. Certainly Please provide the text you would like me to rewrite in a more academic style. Subsequently, 15 mL of the Ferric Reducing Antioxidant Power (FRAP) reagent, comprising a 300 mM sodium acetate buffer with a pH of 3. 6, ferric tripyridyl triazine, and ferric chloride, was infused into 50 µL of the extracted essential oil. The resulting mixture was subjected to vortexing and subsequently incubated for a duration of four minutes at a temperature of 30 °C. The absorbance of the solutions was measured at a wavelength of 593 nm, using a control comprised of 50 µL of distilled water and 1. 5 mL of FRAP reagent as a reference. Ferrous ammonium sulfate served as a control for comparative analysis (RezaeiSavadkouhi *et al*., 2022).

- ***Peroxide Index***

Approximately 0.01 to 0.3 grams of the sample were combined with 9.8 milliliters of a chloroform-methanol mixture (30-70%) using a stirrer. Subsequently, a

solution of ammonium thiocyanate was introduced to the mixture. In the subsequent phase of the experiment, 50 microliters of iron solution were combined and allowed to equilibrate at room temperature for a duration of five minutes. Ultimately, the absorbance of the solution was measured at a wavelength of 500 nm (Mojaddar Langroodi *et al*., 2018).

- ***Total Volatile Nitrogen Bases (TVB-N)***

The TVB-N index was assessed employing the micro-Kjeldahl distillation method, a technique utilized for the evaluation of proteolytic degradation. The concentration of TVB-N in each sample was quantified in milligrams per 100 grams of sample, employing equation (5) for this calculation (Shafiei & Mostaghim, 2022).

$$TVB-N = \frac{A - B \times 14}{W} \times 100$$

Formula for measuring the total volatile nitrogenous base index 5

where,

A= Titration volume for the test sample (ml)

B= Titration volume of the blank sample (ml)

W= Sample weight (g)

- ***Texture Assessment***

The textural properties of the cooked hamburgers were assessed utilizing a texture profile analyzer (TPA). In order to assess the textural properties of the beef burgers, the samples were subjected to frying at a temperature of 180°C for a duration of three minutes. Subsequently, the samples were stored at a temperature of 4°C for a period of 12 hours, until the internal temperature of the samples was reduced to 4°C. A comprehensive texture analysis was conducted, evaluating the parameters of hardness, resilience, gumminess, cohesion, and chewiness. To achieve this objective, the samples were sectioned into pieces measuring 3 cm by 3 cm. A stainless steel cylindrical probe, 25 mm in diameter, was utilized to assess penetration, operating at a velocity of 1 mm/s to a depth of 50%. The results obtained from the Texture Profile Analysis (TPA) test enable the assessment of various textural properties, including hardness, resilience, gumminess, cohesion, and chewiness. The hardness index was quantified in Newtons or grams, representing the maximum force necessary to compress the samples using the device probe. The elasticity parameter serves as a quantitative measure of tissue elasticity, assessing the extent to which a specimen reverts to its initial form following deformation induced by an initial compression. The property of gumminess is derived from the interaction of hardness and cohesion. The cohesion index serves as an evaluative metric for assessing the stability of a product in response to deformation following a second compressive force, in comparison to its behavior during the initial deformation associated with the first compressive application. Gumminess is defined as the quantity of energy necessary to masticate a solid substance and render it suitable for ingestion. Additionally, it is derived from the product of the gumminess property and the elasticity index (Ghoturi *et al*., 2023).

- ***Sensory Evaluation***

In order to conduct sensory evaluations pertaining to color, aroma, flavor, texture, and overall acceptability, various treatments were subjected to frying in a deep fryer utilizing frying oil maintained at a temperature of 170°C for a duration of 5 minutes. The sensory characteristics examined in this study were evaluated

using a 5-point hedonic scale, which quantifies the level of liking or enjoyment. The cooked samples were systematically organized and assigned a three-digit identification code using a random number table, in accordance with a complete block design methodology. The evaluations were conducted using a standardized questionnaire administered to a panel of 30 trained assessors, who were selected from departmental staff. The sample comprised an equal distribution of genders, with participants spanning an age range of 20 to 40 years. All participants possessed prior knowledge and experience in the field of sensory analysis. Moreover, all judges involved in the study were identified as consumers of beef burgers. The analyses were carried out in a controlled training laboratory environment that maintained natural temperature and lighting conditions, with a minimum spatial separation of one and a half meters between each judge. Subsequent to the consumption of each sample, participants were instructed to ingest water in order to neutralize their palate. The sensory characteristics assessed were defined through the following criteria:

Color: (5) No discoloration, (1) Severe discoloration

Odor: (5) Very good, (1) Very unacceptable or bad smell

Taste: (5) Very tasty, (1) No good taste

Texture: (5) Hard, (1) Very soft

Overall Acceptance as Overall Acceptance: (5) Very good, (1) Very unacceptable (Mozafari *et al*., 2023; D'Ambra *et al*., 2023).

- ***Data Analysis Methods and Tools***

To conduct a comparative analysis of the mean values of assessed traits in relation to the independent variables of time and concentration of both free and nanoencapsulated essential oils of Eucalyptus and Basil, utilizing chitosan as a medium, statistical analysis was performed using SPSS version 24. Additionally, graphical representations of the data were generated using Microsoft Excel version 2019. To assess the differences among the resultant data, a one-way analysis of variance (One-way ANOVA) was employed. Furthermore, to ascertain the presence of significant differences among the mean values of the various treatments, Duncan's test was applied at a 95% probability level ($P \leq 0.05$).

Results and Discussion

The findings regarding the encapsulation efficiency of essential oils derived from E. platyloba and Basil plants are delineated in Table 2.

Table 2. The average encapsulation efficiency of essential oil samples derived from E. platyloba and Basil plants, expressed as mean values ± standard deviation

	encapsulation efficiency
E. platyloba	88.948±0.770
Basil	88.722±0.207

Examining the microstructural characteristics of the nanocapsule matrix enhances our comprehension of its properties. Figures 1, 2, 3, and 4 present electron microscope images depicting the surface characteristics of chitosan nanocapsules encapsulating essential oils derived from E. platyloba and basil. Figures 1 and 2 illustrate capsules containing essential oils derived from E. platyloba, while Figures 3 and 4 depict capsules specifically containing essential oils of basil, representing sizes of 500 nm and 1 μm, respectively. The evaluation of encapsulated essential oils derived from E. platyloba and basil was conducted utilizing electron microscopy. This assessment involved the application of

chitosan for the encapsulation, with specific particle sizes of 500 nanometers and 1 micrometer being utilized in the analysis. The results indicate that the capsules exhibit a smooth and compact microstructure, suggesting the establishment of a well-organized matrix. The incorporation of essential oils was found to significantly enhance the roughness of the capsules while concurrently diminishing their cohesion. This phenomenon can be ascribed to the more pronounced structural characteristics of the capsules, as evidenced by the observed increase in film thickness. Additionally, the arrangement and spatial orientation of various molecules during the capsule formation process may result in diverse configurations, further contributing to these alterations in physical properties (Ahmad *et al*., 2012). The capsules exhibit a soft texture and possess a sponge-like morphology, characterized by the presence of visible holes and pores throughout the entire cross-section of the film. The manifestation of holes and porosity within the cross-sectional structure of the capsules is associated with the volatility characteristics of the essential oil. Indeed, these cavities represent regions that are occupied by essential oil that has volatilized from the surface of the capsules during the drying process. The incorporation of essential oil into the capsule matrix has resulted in the development of a heterogeneous structure characterized by the presence of essential oil droplets dispersed within a continuous polysaccharide network (Jouki *et al*., 2014).

Figure 5 presents the Fourier-transform infrared (FTIR) spectra of chitosan nanocapsules, the essential oil derived from E. platyloba, and chitosan nanocapsules encapsulating the aforementioned essential oil. In the study of chitosan nanocapsules, as illustrated in Diagram 5, a notable shift in the amide I peak was observed, transitioning from 1647 cm^{-1} to 1651 cm^{-1}. Additionally, new spectral peaks emerged at 1238 cm^{-1}, attributed to C-O-C stretching, and at 1555 cm^{-1}, corresponding to the amide II group. These spectral changes suggest the formation of a complex, potentially facilitated by electrostatic interactions between the NH^{3+} groups of chitosan and the phosphoric groups of tripolyphosphate (TPP) within the nanoparticles (Yoksan *et al*., 2010; Jingou *et al*., 2011).

The spectral analysis of the essential oil E. platyloba, as illustrated in Figure 5, reveals distinctive and well-defined peaks at the following wave numbers: 2959 cm^{-1}, which corresponds to CH stretching; 1589 cm^{-1}, associated with N-H bending; 1458 cm^{-1}, indicative of CH_2 bending; 1253 cm^{-1} and 1117 cm^{-1}, both related to C-O-C stretching; and 937 cm^{-1}, pertaining to C-H bending. The spectral analysis of chitosan nanocapsules incorporated with the essential oil E. platyloba, as illustrated in Figure 5, reveals that all characteristic peaks are observed at identical wavenumbers. This observation suggests that there is no significant alteration or interaction between the essential oil and the chitosan nanocapsules. Moreover, a comparative analysis of the Fourier-transform infrared (FTIR) spectrum of chitosan nanocapsules reveals that the incorporation of essential oil leads to a notable enhancement in the intensity of the CH stretching peak observed within the range of 2867-2955 cm^{-1}. This observation suggests an elevation in the concentration of ester groups, which may be attributed to the presence of essential oil molecules. The findings suggest that essential oil E. platyloba is likely to be incorporated within chitosan nanocapsules.

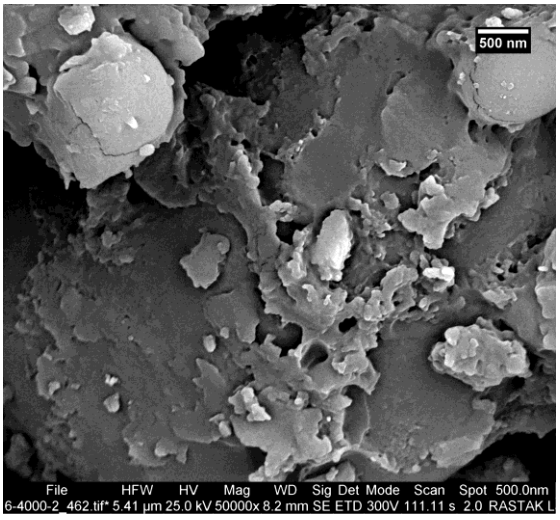

Fig. 1. Electron microscope image illustrating the cross-section of chitosan capsules encapsulating E. platyloba essential oil, at a magnification of 500 nm**.**

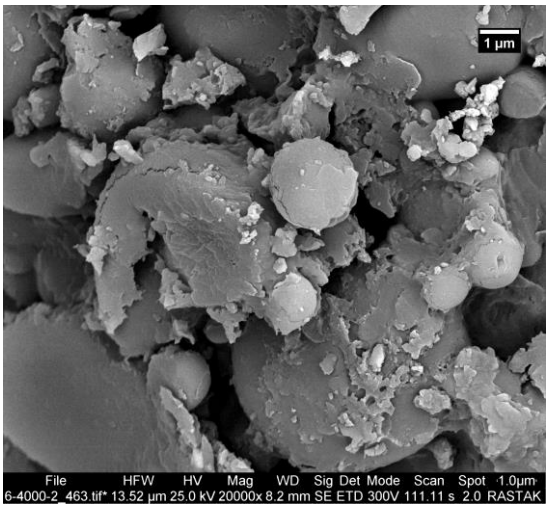

Fig. 2. Electron microscope image depicting the cross-sectional morphology of chitosan capsules that encapsulate E. platyloba essential oil, with a scale bar of 1 µm**.**

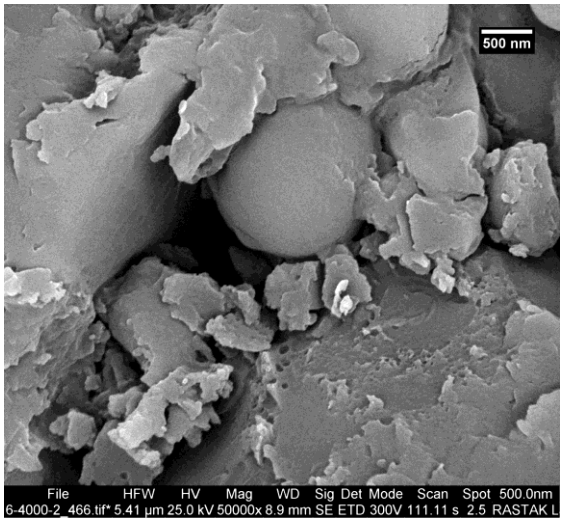

Fig. 3. Electron microscope image illustrating the cross-sectional view of chitosan capsules that encapsulate Basil essential oil, with a scale bar of 500 nanometers**.**

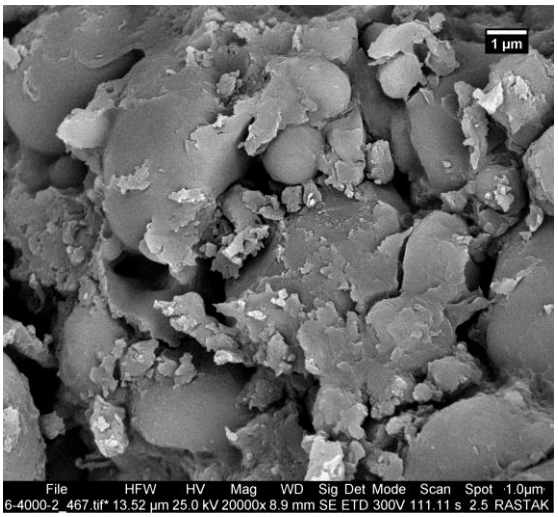

Fig. 4. Electron microscope image depicting the cross-sectional morphology of chitosan capsules that encapsulate Basil essential oil, with a magnification of 1 µm.

Figure 6 illustrates the Fourier Transform Infrared (FTIR) spectra of chitosan nanocapsules, chitosan nanocapsules encapsulating basil essential oil, and pure basil essential oil. The Fourier Transform Infrared (FTIR) analysis of basil essential oil, as illustrated in Figure 6, reveals a broad peak in the region exceeding 3000 cm^{-1}, which is associated with the presence of hydroxyl (–OH) groups. The substantial breadth of this peak suggests a high abundance of these functional groups within the compounds analyzed, indicating the potential for hydrogen bond formation among them. The spectral peaks observed in the 2700-3000 cm^{-1} region are associated with the presence of –C–H bonds.

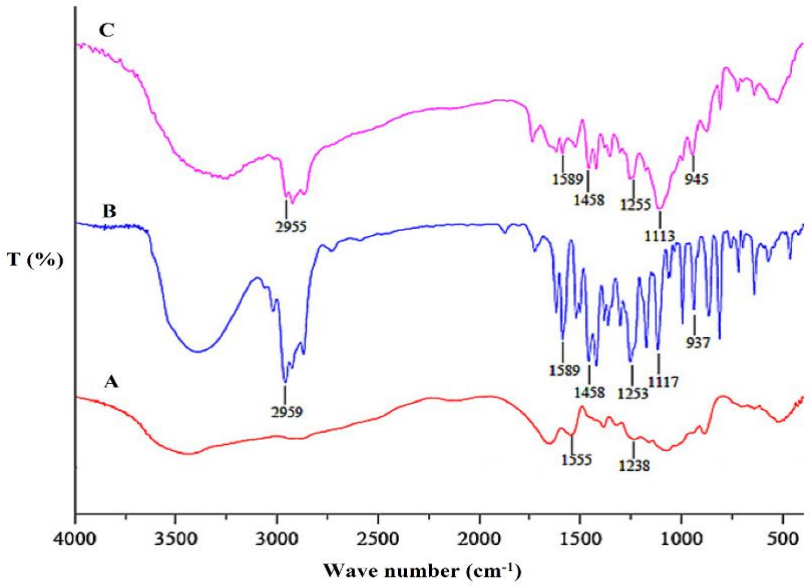

Fig. 5. Chemical structure of chitosan nanocapsules containing essential oil of E. platyloba
A: Chitosan nanocapsule, B: E. platyloba essential oil, C: Chitosan nanocapsule containing E. platyloba essential oil at a ratio of 0.5 to 1.

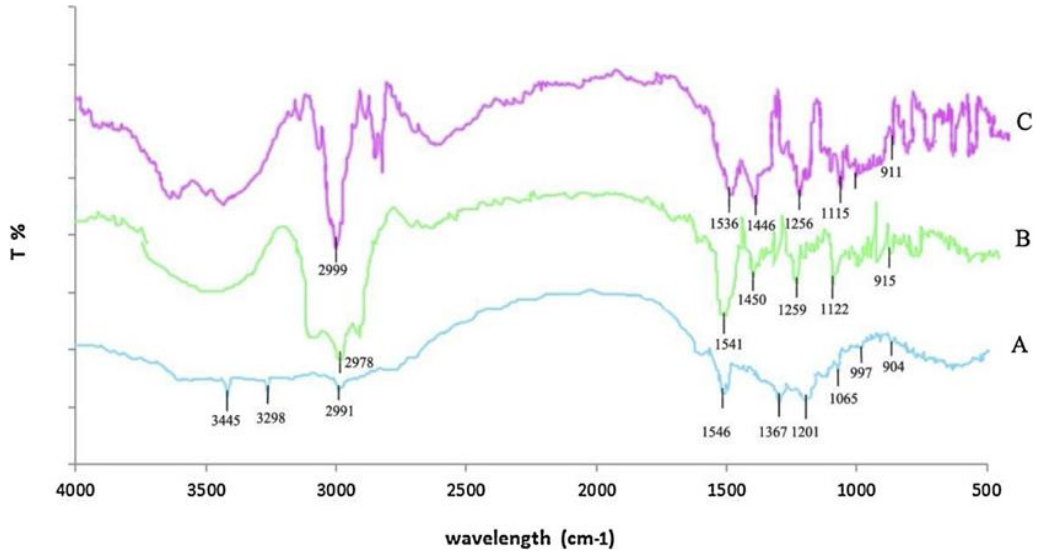

Fig. 6. Chemical structure of chitosan nanocapsules containing Basil essential oil
A: Chitosan nanocapsule without Basil essential oil, B: Chitosan nanocapsule containing Basil essential oil at a ratio of 0.5 to 1, C: Basil essential oil.

The pronounced peaks observed in the 1700-1850 cm^{-1} range correspond to the carbonyl functional groups (–C=O) present in the constituents of basil essential oil. The pronounced and well-defined peaks observed in the 1500 cm^{-1} region are associated with the aromatic components of the aromatic compounds present in this plant. The observed peaks in the spectral regions above 3500 cm^{-1}, as well as those occurring between 2000 cm^{-1} and 2500 cm^{-1}, can be attributed to the presence of various mineral compounds and salts, specifically zinc, manganese, iron, and calcium, within the basil plant. The significant broadening of the spectrum

observed can be attributed to the presence of a wide array of diverse organic and inorganic compounds within the plant. The infrared spectrum of chitosan nanocapsules, devoid of basil essential oil (6-A), exhibits several prominent absorption peaks. Specifically, a peak at 3445 cm^{-1} is attributed to the stretching vibration of hydroxyl (-OH) groups. The peak observed at 3298 cm^{-1} is associated with the stretching vibration of amino groups ($N-H_2$). Additionally, a peak at 2991 cm^{-1} corresponds to the stretching of carbon-hydrogen (C-H) bonds. The presence of $N-H_2$ in amide structure (II) is indicated by a peak at 1546 cm^{-1}, while the peak at 1367 cm^{-1} is related to the stretching of carbon-nitrogen (C-N) bonds. The peak at 1201 cm^{-1} is indicative of the β-(1-4) glycosidic bond, and the peak at 1065 cm^{-1} corresponds to the C-O-C stretching associated with the glucose ring. Furthermore, a peak at 997 cm^{-1} suggests C-O stretching, and the vibrational characteristics of the pyranose ring are reflected in the peak at 904 cm^{-1}. The absence of a peak corresponding to C-O stretching associated with the amide I region is noted, while two distinct peaks are observed at 1065 cm^{-1}, attributed to C-O-C stretching within the glucose ring, and at 1546 cm^{-1}, linked to the amide II functionality. These findings suggest the presence of electrostatic interactions between the PO_4^{-3} group of tripolyphosphate (TPP) and the NH^{3+} group of chitosan (Hosseini *et al*., 2013). The presence of peaks in chitosan nanocapsules encapsulating basil essential oil (6-B) suggests the successful incorporation of the essential oil within the chitosan nanocarriers. Notably, a pronounced peak was detected at 2991 cm^{-1}, a feature that was also identified in the basil essential oil itself. In comparison to chitosan nanocapsules devoid of basil essential oil (6-A), chitosan nanocapsules that incorporate basil essential oil (B) and those characterized solely by basil essential oil (6- C) exhibited significantly elevated concentrations of alcohols, ethers, carboxylic acid esters, anhydrides, alkanes, and methyl (CH_3) groups. The Fourier-transform infrared (FTIR) spectrum demonstrates that the incorporation of basil essential oil into chitosan nanocapsules leads to a notable enhancement in the intensity of the CH stretching peak observed at 2991 cm^{-1}. This increase suggests a higher concentration of ester groups originating from the compounds present in basil essential oil. The spectral analysis of chitosan nanocapsules encapsulating basil essential oil revealed that all peaks corresponding to the basil essential oil were observed at identical wavenumbers. This finding suggests an absence of significant alteration or interaction between chitosan and the basil essential oil. The findings obtained from Fourier Transform Infrared Spectroscopy (FTIR) suggest that basil essential oil has been effectively encapsulated within chitosan nanocapsules.

To examine the particle distribution and zeta potential of chitosan nanocapsules encapsulating E. platyloba and Basil essential oils, approximately 60 mg of the chitosan nanocapsules were dispersed in 2 ml of distilled water and subsequently introduced into the analytical device. According to Figures 7 and 8, the particle radius of chitosan nanocapsules incorporating basil essential oils was determined to range from 30.2-110.1 nanometers The mean equivalent particle radius was calculated to be 62.2 nm, while the zeta potential, reflecting the surface potential of the particles in their colloidal state, was measured at 0.22±63.61 mv According to Figures 9, 10, and Figure 11,

the particle radius of chitosan nanocapsules containing essential oils extracted from E. platyloba ranged from 20.7-100.1 nanometers The equivalent particle radius was determined to be 57. 7 nm, while the zeta potential was measured at 0.18±65.12 mv.

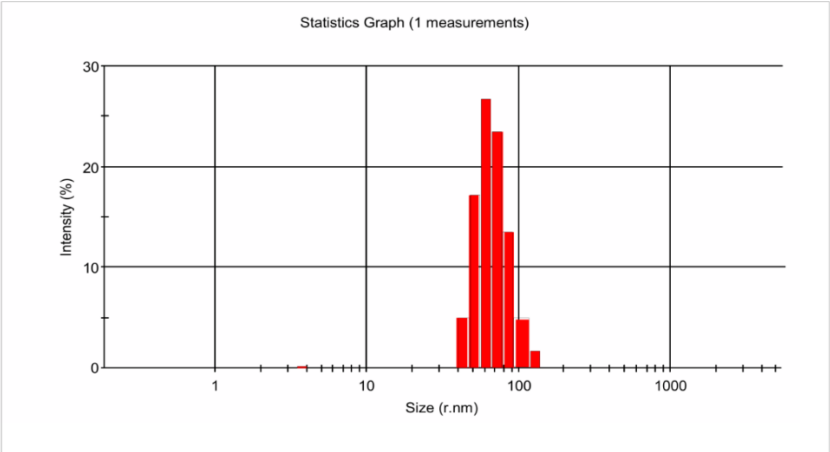

Fig. 7. Column chart of chitosan nanocapsule particle distribution containing Basil essential oil**.**

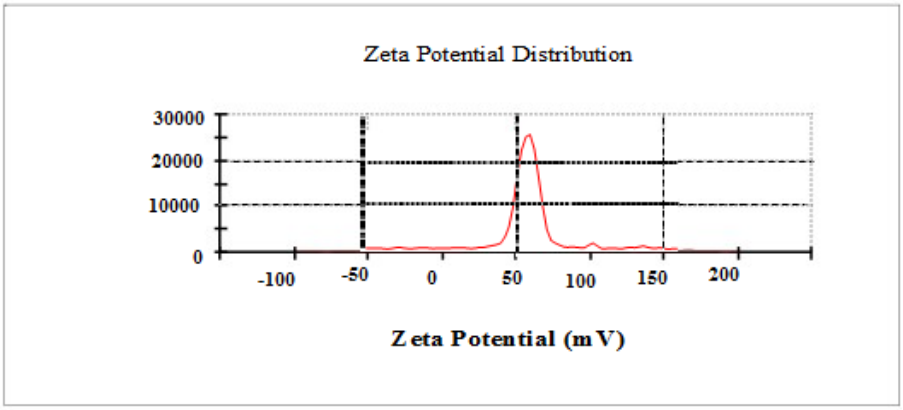

Fig. 8. Surface charge distribution in chitosan nanocapsules containing Basil essential oil.

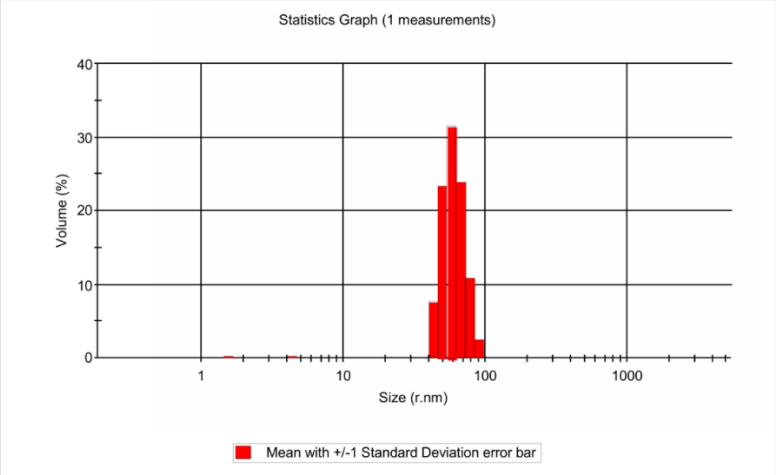

Fig. 9. Column chart of the distribution of chitosan nanocapsule particles containing E. platyloba essential oil.

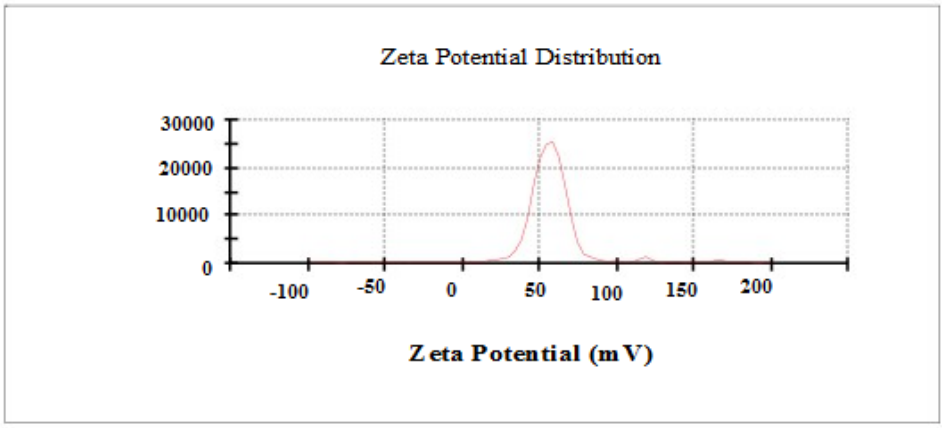

Fig. 10. Surface charge distribution in chitosan nanocapsules containing E. platyloba essential oil.

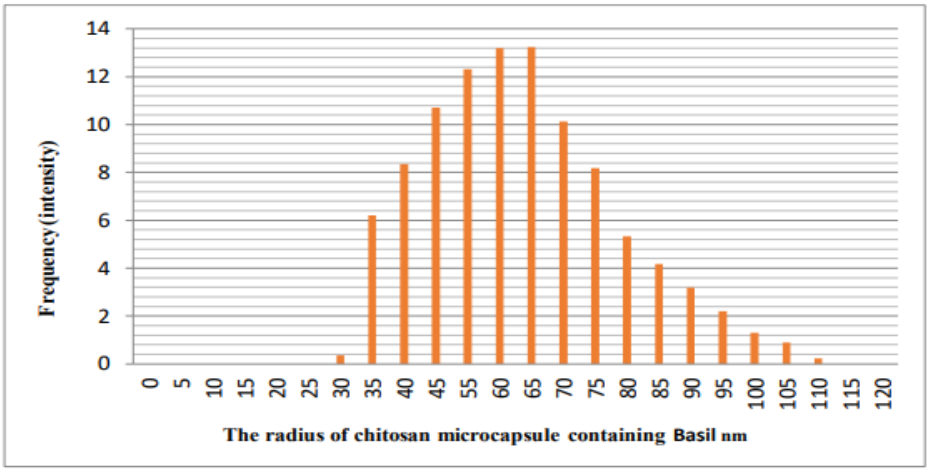

Fig. 11. Bar graph of the frequency distribution of particle size of chitosan nanocapsules containing Basil essential oil.

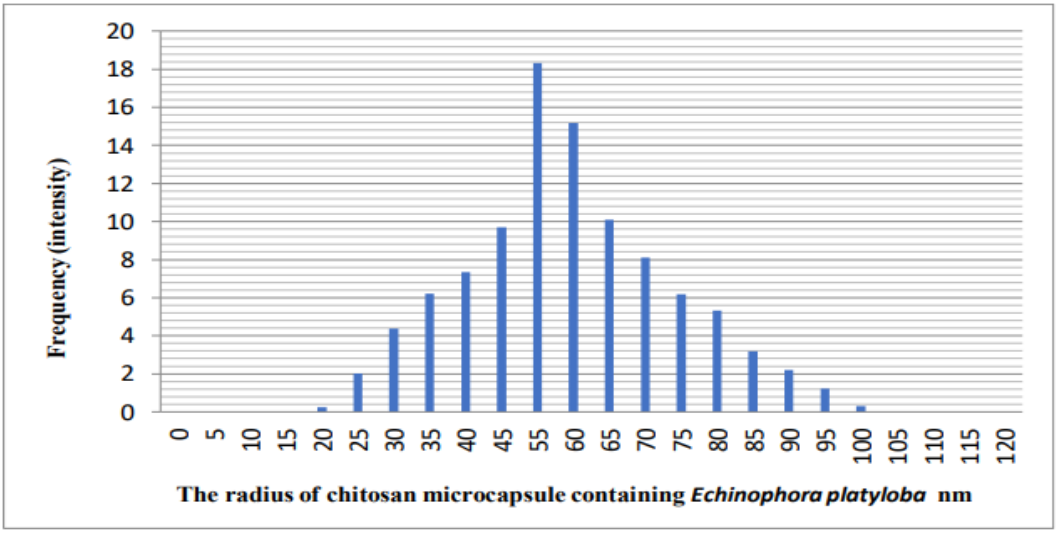

Fig. 12. Bar graph of the frequency distribution of particle size of chitosan nanocapsules containing essential oil of *Echinophora platyloba*.

Figures 11 and 12 illustrate the particle size distribution frequency of chitosan nanocapsules encapsulating basil essential oil and chitosan nanocapsules encapsulating E. platyloba essential oil, respectively. The data presented in the figure indicates that the particle radius of chitosan nanocapsules encapsulating E. platyloba exhibited a maximum frequency value of approximately 55 nm and a minimum frequency value of approximately 20 nm. In contrast, the nanocapsules containing basil demonstrated maximum and minimum frequency values of approximately 65 nm and 110 nm, respectively.

Furthermore, the data indicates that the relative dimensions of chitosan nanocapsules encapsulating E. platyloba essential oil are smaller in comparison to those of analogous samples containing basil essential oil. This discrepancy appears to be attributable to the lower average molecular weight of the constituents present in E. platyloba essential oil relative to those found in basil essential oil. The size index of nanocapsules is regarded as a significant determinant influencing the stability of microcarrier systems. An increase in particle size permits the incorporation of a greater quantity of bioactive compounds, thereby enhancing the overall proportion of nanocapsule materials present. This augmentation positively contributes to the stability of the nanocapsule system. Furthermore, the relative reduction in the size of nanocapsules enhances their effective surface area for the release of encapsulated compounds. This increase in surface area is regarded as a favorable indicator within the context of controlled delivery systems. Conversely, it has been reported that the particle size of food products must exceed 50 microns in order to produce an undesirable sandy texture (Aslani & Rostami, 2015). Consequently, the dimensions of the nanocapsules generated in the current investigation appear to establish suitable textural properties in food products, exemplified by hamburgers.

The results of the statistical analysis presented in Figures 13, 14 and 15 indicate that the treatments applied did not exert a statistically significant effect on the levels of fat, protein, and ash in the hamburger samples ($p > 0.05$) The findings indicate that the incorporation of both free and encapsulated essential oils derived from E. platyloba and basil did not exert a significant impact on the levels of fat, protein, and ash in the hamburger samples ($p > 0.05$). Due to the absence of proteins and fats in plant essential oils, their incorporation into the product did not result in an increase in the levels of these macromolecules. An increase in the quantity of dry matter results in a corresponding elevation in the relative concentrations of primary constituents, including protein, fat, and ash, within the final product. In contrast, plant essential oils are characterized by their volatile nature and predominantly non-solid composition, leading to a minimal presence of significant dry matter. Consequently, the incorporation of these elements does not yield a statistically significant impact on the concentrations of components such as fat, protein, and ash (Nateghi, 2021; Emam, 2017). The incorporation of plant essential oils into all examined hamburger samples did not result in any significant changes to the protein content. This observation suggests that essential oils may lack efficacy in the degradation of protein (Hoseinzadeh & Shirazinejad, 2019). Conversely, the uniform concentration of basil and E. platyloba essential oils across all treatments did not substantially influence

the fat, protein, and ash content in the hamburger samples. Research has demonstrated that elevating the concentration of plant essential oils induces alterations in the levels of fat, protein, and ash. In a recent study, the impact of *Allium Jesdianum* plant extract on the physicochemical, antioxidant, antimicrobial, and sensory properties of sausage was examined. The findings indicated that increasing the concentration of the aforementioned plant extract led to a notable increase in fat content when compared to the control treatments. In the aforementioned study, it was reported that the addition of *Allium Jesdianum* plant extract did not exhibit a statistically significant impact on the ash content of the sausage samples. This outcome aligns with the findings of the current investigation (Ghorbani *et al*., 2024). In this context, a study was conducted to investigate the antioxidant and antimicrobial properties of grape seed extract, while also assessing its sensory characteristics in sponge cake. The findings indicated that the increase in grape seed extract did not produce a statistically significant alteration in the protein content of the sponge cake. This outcome aligns with the conclusions drawn from the present study (Hoseinzadeh & Shirazinejad, 2019). In a separate investigation, researchers assessed the influence of betel nut sap essential oil on the physical, chemical, microbial, and sensory characteristics of jarred cheese. The findings indicated that the incorporation of betel nut sap essential oil did not significantly impact the fat and protein content of the product (Nateghi, 2021).

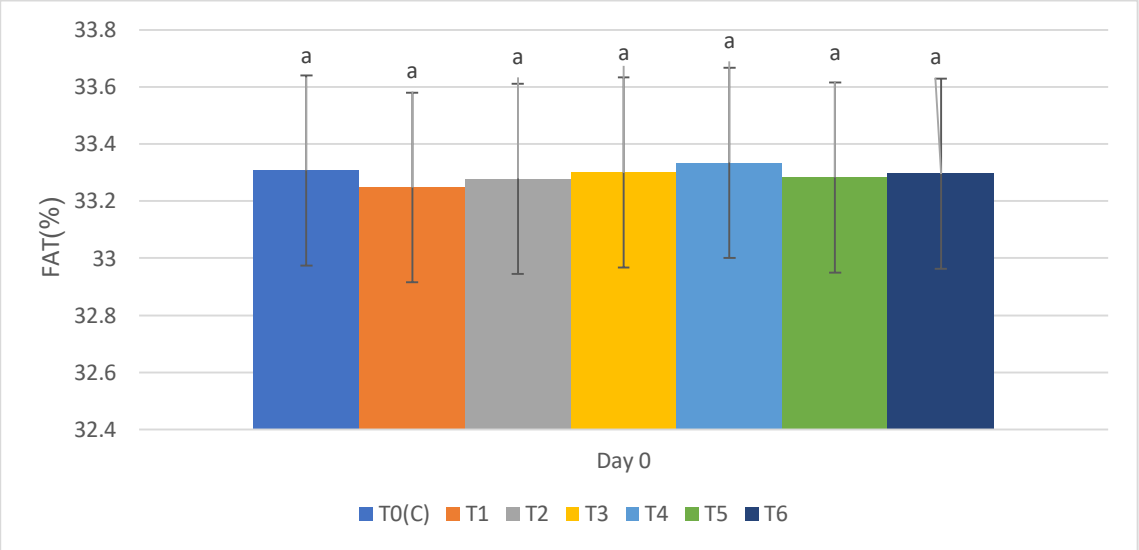

Fig. 13. Fat (%) of hamburger samples containing free and encapsulated essential oils of E. platyloba and Basil**.** Different letters indicate significant differences between treatments ($p<0.05$).
Results for fat are expressed on a dry weight basis.
T0 (C): Control, T1: Treatment containing 0.2% free essential oil of E. platyloba, T2: Treatment containing 0.2% free essential oil of Basil, T3: Treatment containing 0.2% nanoencapsulated essential oil of E. platyloba with chitosan, T4: Treatment containing 0.2% nanoencapsulated essential oil of Basil with chitosan, T5: Treatment containing 0.1% essential oil of E. platyloba and 0.1% free essential oil of Basil, T6: Treatment containing 0.1% essential oil of E. platyloba and 0.1% nanoencapsulated essential oil of Basil with chitosan.

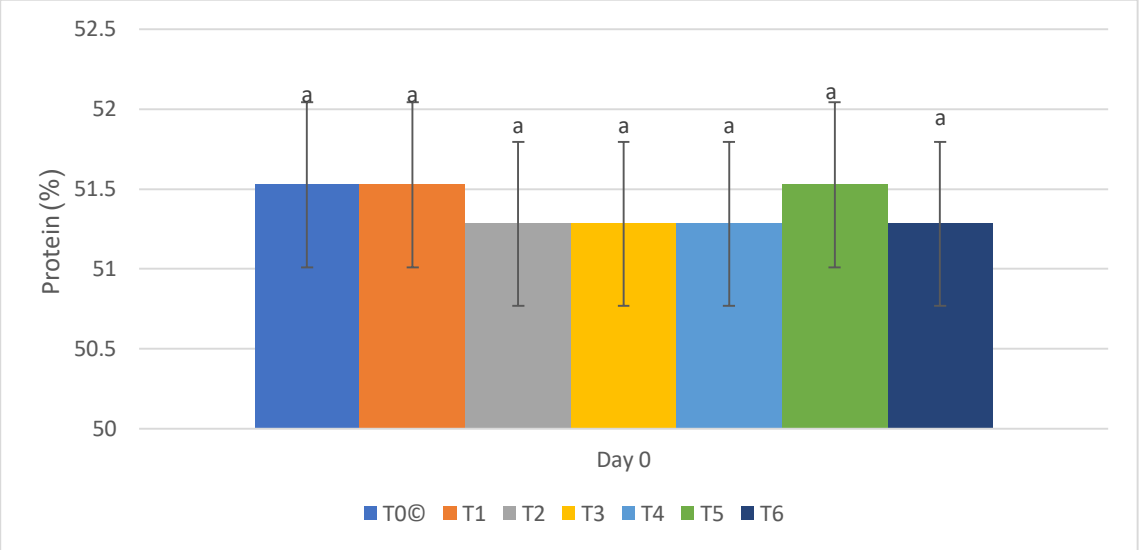

Fig. 14. Protein (%) of hamburger samples containing free and encapsulated essential oils of E. platyloba and Basil**.**
Different letters indicate significant differences between treatments ($p<0.05$).
Results for protein are expressed on a dry weight basis.
T0 (C): Control, T1: Treatment containing 0.2% free essential oil of E. platyloba, T2: Treatment containing 0.2% free essential oil of Basil, T3: Treatment containing 0.2% nanoencapsulated essential oil of E. platyloba with chitosan, T4: Treatment containing 0.2% nanoencapsulated essential oil of Basil with chitosan, T5: Treatment containing 0.1% essential oil of E. platyloba and 0.1% free essential oil of Basil, T6: Treatment containing 0.1% essential oil of E. platyloba and 0.1% nanoencapsulated essential oil of Basil with chitosan.

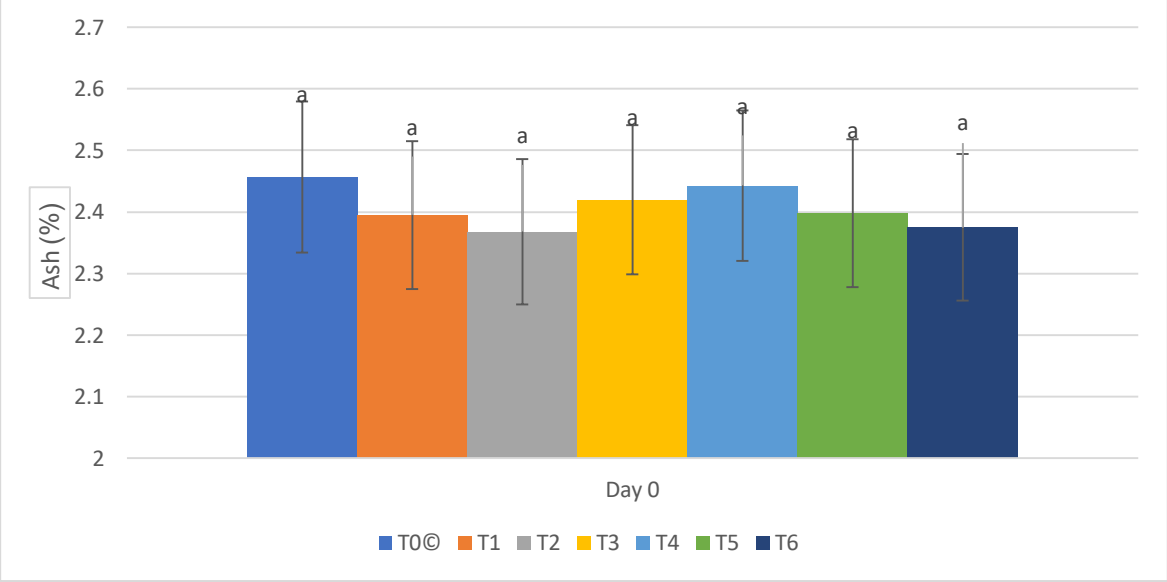

Fig. 15. Ash (%) of hamburger samples containing free and encapsulated essential oils of E. platyloba and Basil**.**
Different letters indicate significant differences between treatments ($p<0.05$).
Results for ash are expressed on a dry weight basis.
T0 (C): Control, T1: Treatment containing 0.2% free essential oil of E. platyloba, T2: Treatment containing 0.2% free essential oil of Basil, T3: Treatment containing 0.2% nanoencapsulated essential oil of E. platyloba with chitosan, T4: Treatment containing 0.2% nanoencapsulated essential oil of Basil with chitosan, T5: Treatment containing 0.1% essential oil of E. platyloba and 0.1% free essential oil of Basil, T6: Treatment containing 0.1% essential oil of E. platyloba and 0.1% nanoencapsulated essential oil of Basil with chitosan.

The findings concerning the FRAP of hamburger samples are detailed in Figure 16. The results of the statistical analysis indicate that the treatments, storage duration, and their interaction significantly influenced the FRAP antioxidant properties of the hamburger samples ($p < 0.05$). The findings derived from the assessment of the FRAP antioxidant properties indicated that the hamburger treatments supplemented with essential oils of E. platyloba and basil exhibited enhanced FRAP antioxidant capacity. Furthermore, it was observed that the treatments incorporating E. platyloba essential oil demonstrated significantly superior FRAP antioxidant properties in comparison to those containing basil essential oil ($p < 0.05$). Furthermore, an increase in storage duration was associated with a decline in the FRAP antioxidant capacity across all samples. However, it was observed that the FRAP antioxidant capacity in the nanoencapsulated treatments remained higher than that of the control sample and the treatments containing free essential oil. Furthermore, throughout the storage duration, the control sample exhibited the lowest levels of Ferric Reducing Antioxidant Power (FRAP) antioxidant activity. In contrast, the treatments that incorporated nanoencapsulated essential oils of E. platyloba and basil with chitosan demonstrated the highest FRAP antioxidant activity. In the current investigation, the Ferric Reducing Antioxidant Power (FRAP) assay was employed due to its simplicity and efficiency as a method for assessing the antioxidant capacity of both pure compounds and natural products, including fruits and plants. In this experimental analysis, the samples exhibiting the highest concentration demonstrated a greater efficacy in the reduction of Fe^{3+} ions to Fe^{2+} ions in comparison to their capacity for the elimination of free radicals. The Ferric Reducing Antioxidant Power (FRAP) assay is commonly employed to assess the antioxidant activity of both aqueous and organic extracts that comprise hydrophilic and lipophilic compounds (Khalili *et al*., 2025). The elevated antioxidant activity observed in nanoencapsulated samples may be attributed to the capacity of slow-release nanocapsules to enhance both the shelf life and nutritional value of phytochemical constituents. Additionally, these encapsulation methods serve to mitigate the development of undesirable flavors in food products. Plant bioactive compounds are released in a regulated manner within the food matrix. The findings indicate that the release of phenolic compounds is positively correlated with the duration of storage. The stability of phenolic compounds has diminished over time, a phenomenon that may be attributed to the degradation of the capsule wall resulting from oxidative processes and the permeable nature of the capsule wall membrane. Moreover, the enhancement of lipid membrane fluidity associated with storage contributes to an increased permeability, resulting in the leakage of phenolic compounds (Solgi *et al*., 2024).

Researchers conducted an investigation into the antioxidant properties of basil essential oil and its impact on the cooking quality of chicken nuggets. In the present study, several methodologies, including the DPPH and FRAP assays, were employed to evaluate the antioxidant properties of basil essential oil. The findings indicate that the incorporation of bioactive compounds, particularly basil essential oil, can significantly enhance antioxidant activity (Nadeem *et al*., 2022).

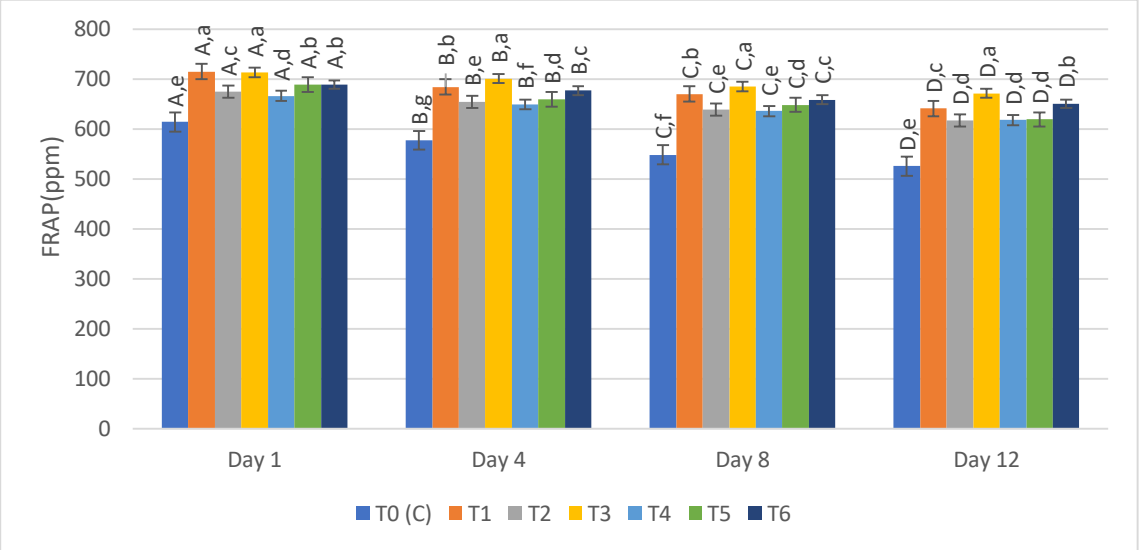

Fig. 16. FRAP (ppm) of hamburger samples containing free and encapsulated essential oils of E. platyloba and Basil. Different capital letters in each treatment indicate a significant difference between different days ($p<0.05$). Different lowercase letters in each day indicate a significant difference between different treatments ($p<0.05$). T0 (C): Control, T1: Treatment containing 0.2% free essential oil of E. platyloba, T2: Treatment containing 0.2% free essential oil of Basil, T3: Treatment containing 0.2% nanoencapsulated essential oil of E. platyloba with chitosan, T4: Treatment containing 0.2% nanoencapsulated essential oil of Basil with chitosan, T5: Treatment containing 0.1% essential oil of E. platyloba and 0.1% free essential oil of Basil, T6: Treatment containing 0.1% essential oil of E. platyloba and 0.1% nanoencapsulated essential oil of Basil with chitosan.

The results pertaining to the peroxide values of the hamburger samples are illustrated in Figure 17. The results indicated that there were statistically significant differences in the peroxide values among the various hamburger samples ($p < 0.05$). The measurement of peroxide values indicated that the hamburger treatments infused with essential oils of E. platyloba and basil exhibited a reduction in peroxide values. Furthermore, the treatments containing E. platyloba essential oil demonstrated significantly lower peroxide values compared to those with basil essential oil ($p < 0.05$). Furthermore, on the initial day of the study, no statistically significant differences were observed between the treatment groups ($p > 0.05$). Nonetheless, with an increase in storage duration, the peroxide values in all samples exhibited an upward trend. This increase was less pronounced in the nanoencapsulated treatments containing E. platyloba and basil essential oils compared to the control sample. Throughout the storage period, the control treatment exhibited the highest peroxide value, while treatments incorporating chitosan-encapsulated E. platyloba and basil essential oils demonstrated the lowest peroxide values. Fat oxidation serves as a pivotal factor influencing both the quality and shelf life of meat products. This chemical reaction results in the formation of undesirable color, taste, and odor characteristics in the resultant products. Peroxide value serves as a critical indicator of lipid oxidation, specifically quantifying the primary oxidation products, including hydroperoxides. These compounds are generated during the initial phases of oxidation through the reaction of molecular oxygen with the double bonds present in unsaturated fatty acids. Peroxide value is quantitatively defined as the milliequivalent of grams of peroxide or active oxygen contained in one kilogram of a given oil or fat sample. The peroxide value serves as a quantitative measure of

the extent of oxidative degradation in oils and fats. During the oxidation process, peroxides or reactive oxygen species are generated within these lipid media. The presence of peroxide in the oil serves as a catalyst that enhances the rate of oxidation processes. The peroxide value is widely recognized as the predominant method for quantifying the severity of oxidation during the initial stages of the oxidative process. Due to the tasteless and odorless nature of peroxides, consumers lack the ability to detect their presence. Nevertheless, the previously mentioned compounds facilitate the synthesis of secondary metabolites, including aldehydes, ketones, and alcohols. These secondary compounds exhibit enhanced stability under thermal processing conditions and are responsible for the development of off-flavors, which contribute to undesirable sensory attributes in the final product. During the storage period, lipid oxidation in meat leads to a deterioration in its quality. Free radicals present in meat generate aldehydes, which contribute to the development of rancid flavors in lipids and induce alterations in the color of the meat. The process of lipid oxidation in meat involves a multifaceted mechanism. Throughout this process, alongside the negative impacts on color and flavor, there is a notable decline in protein solubility, which ultimately diminishes the nutritional value of the product (Ghasemi *et al*., 2022; Shirvash & Najaf, 2024).

The findings indicated that the control hamburger samples exhibited the highest concentration of peroxide. The findings of the study indicated that the shelf life of the hamburger was significantly extended in the samples that included essential oils. In the present study, it was observed that hamburgers formulated with essential oils exhibited a lower concentration of peroxide. Furthermore, the incorporation of nanocapsules containing essential oils resulted in a significant reduction in peroxide levels. Phenolic compounds present in plant extracts and essential oils derived from plants and fruits exhibit significant antioxidant properties. This phenomenon can be attributed to the influence of phenolic compounds found within the essential oils of these plants (Mozafari *et al*., 2023). Essential oils and plant extracts are typically characterized by a diverse array of bioactive compounds, particularly phenolic compounds, including flavonoids and polyphenols. These compounds are distinguished by the presence of hydroxyl groups within their molecular structures. Consequently, they provide hydrogen to free radicals, effectively neutralizing these reactive species and subsequently decreasing the rate of lipid oxidation. Antioxidants effectively mitigate free radical chain reactions through the inactivation of free radicals (Ghasemi *et al*., 2022; Shirvash & Najaf, 2024). The gradual and controlled release of encapsulated essential oils facilitates the better preservation of bioactive compounds, thereby enhancing the antioxidant activity of the essential oils throughout the storage period (Shetta *et al*., 2019).

The permissible threshold for the peroxide index in meat products has been established at 5 milliequivalents per kilogram. In the current investigation, all hamburger samples remained within the acceptable limits up to day 12. However, on the final day of analysis, the samples that incorporated essential oil nanocapsules exhibited the lowest levels of peroxides (Shirvash & Najaf, 2024).

The study conducted an evaluation of the impact of nanoencapsulated peppermint essential oil on the shelf life of rainbow trout burgers during storage. The

findings indicated that, at the commencement of the storage period, there were no statistically significant differences in the peroxide index values among the various fish burger treatments. However, the incorporation of nanoencapsulated treatments, which contained essential oil, resulted in a reduction of peroxide levels in the fish burger samples over the course of storage (Shirvash & Najaf, 2024).

Researchers conducted an evaluation of the impact of plant essential oils on the physicochemical properties of chicken nuggets. Their findings indicated that essential oils with a higher concentration of phenolic compounds, specifically rosemary and clove, were more effective in reducing peroxide levels compared to other essential oils. This outcome aligns with the results observed in the current study (Ghasemi *et al.*, 2022).

The results regarding total volatile nitrogen bases (TVN) in the hamburger samples are illustrated in Figure 18. The analysis revealed that the concentration of total volatile nitrogen bases (TVN) in the various hamburger samples exhibited statistically significant differences ($p<0.05$). Hamburger treatments infused with essential oils derived from E. platyloba and basil resulted in a significant reduction in total volatile nitrogen (TVN) levels. Additionally, treatments incorporating essential oils from E. platyloba exhibited lower TVN levels compared to those that included basil essential oil, with statistical significance ($p < 0.05$). Furthermore, on the initial day of observation, no statistically significant difference was identified between the treatment groups ($p<0.05$). As storage

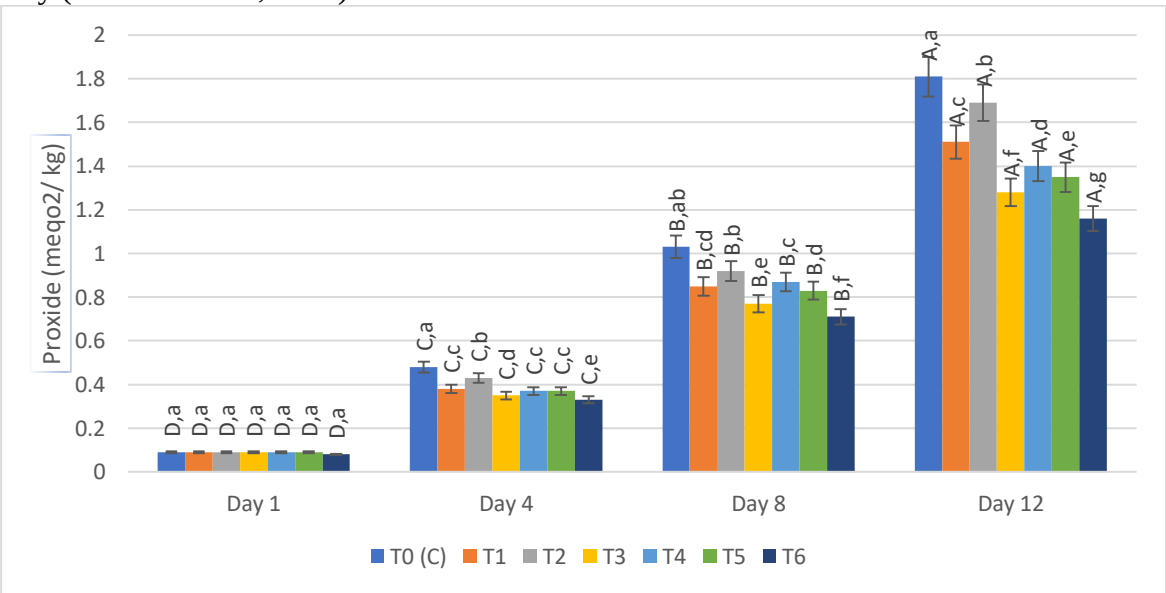

Fig. 17. Peroxide (meqO_2/kg oil) of hamburger samples containing free and encapsulated essential oils of E. platyloba and Basil.
Different capital letters in each treatment indicate a significant difference between different days ($p<0.05$). Different lowercase letters in each day indicate a significant difference between different treatments ($p<0.05$). T0 (C): Control, T1: Treatment containing 0.2% free essential oil of E. platyloba, T2: Treatment containing 0.2% free essential oil of Basil, T3: Treatment containing 0.2% nanoencapsulated essential oil of E. platyloba with chitosan, T4: Treatment containing 0.2% nanoencapsulated essential oil of Basil with chitosan, T5: Treatment containing 0.1% essential oil of E. platyloba and 0.1% free essential oil of Basil, T6: Treatment containing 0.1% essential oil of E. platyloba and 0.1% nanoencapsulated essential oil of Basil with chitosan.

duration increased, the total volatile nitrogen (TVN) levels exhibited an upward trend across all samples. Notably, the increase in TVN was less pronounced in the treatments incorporating nanoencapsulated essential oils of E. platyloba and basil with chitosan, which demonstrated lower TVN levels compared to the control group. Throughout the storage period, the control sample exhibited the highest total volatile nitrogen (TVN) level, whereas the treatments that incorporated E. platyloba essential oil and basil nanoencapsulated with chitosan demonstrated the lowest TVN levels.

Total volatile base nitrogen (TVB-N) refers to the nitrogenous compounds, specifically ammonia and amines, that are generated from the degradation of proteins present in animal feed. This breakdown process is facilitated by the action of enzymes and bacteria. An elevation in total volatile nitrogen (TVN) levels serves as an indicator of meat spoilage, which may result from the accumulation of non-protein compounds and various enzymatic processes. These processes include the deamination of free amino acids, nucleotide degradation, and amine oxidation (Sun *et al*., 2021; Shahbazi *et al*., 2018). The noted elevation in Total Volatile Bases (TVN) can be ascribed to various biochemical processes. These include the deamination of amino acids, the activity of spoilage bacteria and endogenous enzymes, the proteolytic degradation of proteins mediated by proteolytic enzymes, the oxidation of amines, and the degradation of nucleotides (Varmazyar *et al*., 2024). The group of volatile basic compounds encompasses methylamine, dimethylamine, trimethylamine, and ammonia, all of which contribute to the development of off-flavors. The deamylation of amino acids constitutes a contributing factor to the augmentation of this parameter (Moghimi *et al*., 2016). The observed reduction in Total Volatile Nitrogen (TVN) levels in treatments containing essential oils, in comparison to the control sample, can be ascribed to two primary factors. Firstly, the presence of essential oils within the inner layer matrix appears to exert a substantial inhibitory or bactericidal effect on the bacteria residing on the surface of the samples. This action consequently contributes to a postponement of the protein degradation process. An additional factor contributing to this phenomenon may be attributed to the hydrophilic nature of the materials, which enhances their capacity to absorb water on the surface of the samples. Consequently, this leads to the formation of a microenvironment characterized by low water activity surrounding the sample surfaces. This specific microenvironment inhibits bacterial proliferation, mitigates the degradation of proteins and amino acids, and subsequently enhances the antibacterial efficacy of plant essential oils. The significance of plant essential oils stems from the presence of phenolic compounds, which contribute to their antibacterial properties. The chemical structure of phenolic compounds significantly influences their antimicrobial mechanisms. Furthermore, the presence of hydroxyl groups in these compounds plays a critical role in determining the antimicrobial properties of plant essential oils. The existence of the active hydroxyphenolic group facilitates the formation of hydrogen bonds with the active sites of enzymes in these compounds (Bagheri & Aryaee, 2020).

Throughout the storage period, there was a notable increase in the total volatile nitrogen (TVN) content. This increase is likely attributable to the accumulation of volatile nitrogenous compounds that arise

from the bacterial decomposition of proteins during the initial phases of meat spoilage. Concurrently, this bacterial activity contributes to an elevation in pH levels. This phenomenon enhances and elevates the activity of various enzymes, including endogenous cathepsin B and L, thereby expediting the decomposition and degradation of proteins. Consequently, this results in a significant increase in the total volatile nitrogen (TVN) content (Zhang *et al*., 2023; Zhang *et al*., 2021). The optimal concentration of total volatile nitrogen bases (TVN) in meat and its derived products has been established at 25 mg per 100 g of meat. According to the findings observed on the final day of the treatment phases (specifically T_3, T_5, and T_6), the TVN levels remained within the permissible limits. Notably, the treatments utilizing nanoencapsulated essential oils exhibited the lowest levels of TVN among all examined conditions (Varmazyar *et al*., 2024; Khazaei *et al*., 2017).

Researchers conducted an investigation into the effects of chitosan, in conjunction with basil seed gum and nettle essential oil, on the microbial, chemical, and sensory properties of fresh hamburgers. The findings indicated that the incorporation of plant essential oils resulted in a reduction of volatile nitrogenous bases in the hamburger samples. Furthermore, the duration of storage influenced this parameter, which was found to be lower in treatments incorporating essential oils compared to the control group. This observation aligns with the findings of the present study (Bagheri & Aryaee, 2020). The researchers conducted an assessment of the influence of nanocapsules containing extracts derived from mango and eggplant peels on the physicochemical, oxidative, microbial, and sensory characteristics of refrigerated beef hamburgers throughout the storage period. In support of the findings presented in the current study, it was reported that the incorporation of plant essential oils led to a reduction in the levels of volatile nitrogenous bases in the hamburger treatments. Furthermore, the preservation of phenolic compounds within the nanocapsule treatments incorporating essential oils contributed to a measurable reduction in the concentration of nitrogenous bases during storage, in comparison to both treatments utilizing free essential oils and the control sample (Varmazyar *et al*., 2024).

The findings regarding the texture hardness of the hamburger samples are delineated in Figure 19. The results obtained indicate that there were statistically significant differences in texture hardness among the various hamburger samples ($p<0.05$). Hamburger formulations incorporating E. platyloba and basil essential oils demonstrated an increase in texture hardness. Conversely, the treatments that utilized nanoencapsulated E. platyloba essential oils exhibited significantly greater texture hardness compared to those containing non-encapsulated basil essential oils ($p<0.05$). As the duration of storage increased, a general decline in texture hardness was observed across all samples. However, samples treated with E. platyloba and basil essential oils exhibited a comparatively greater texture hardness. Furthermore, throughout the storage period, the control treatment demonstrated the lowest texture hardness. In contrast, treatments that included nanoencapsulated E. platyloba and basil with chitosan exhibited the highest texture hardness. The textural properties of meat and meat products constitute significant attributes that influence both the visual appeal of the final product and consumer acceptance. Additionally, these characteristics exert a

direct impact on other sensory factors, such as the chewing experience. The modulation of color and flavor can be effectively managed, as these attributes are influenced by a linear relationship among their contributing factors. In contrast, the incorporation of texture additives results in nonlinear effects on textural properties, thereby complicating the regulation of these characteristics. In numerous instances, particularly concerning soft foods, texture is often regarded as more significant than both taste and color, exerting a substantial influence on consumer perception. The hardness index is quantified in Newtons or grams and represents the maximal force necessary to compress samples utilizing the device probe (B. Zhang *et al*., 2021; Ghoturi *et al*., 2023). The hardness of meat during mastication is intricately linked to its tenderness. This serves as a critical indicator of consumer preferences, which are significantly influenced by the quantity and distribution of fat within the product (Zhang *et al*., 2021; Xu *et al*., 2017). Several factors, including the content of stromal protein, the quantity of extracted protein, the extent of comminution, and the types of additives incorporated into meat products, significantly affect the textural properties of meat and its derivates. Furthermore, the inclusion of additives in hamburger formulations significantly influences the textural properties, particularly the hardness, of the final product. Consequently, the incorporation of plant essential oils in this study yielded an increased hardness, particularly observed in samples that contained nanoencapsulated essential oils. Research has demonstrated that proteins, fats, and various other components significantly influence the textural properties of meat products by impacting their water-binding capacity and the states of lipid crystallization (Karslıoglu *et al*., 2024). The integrity of the physical structure of meat is upheld by a stable microstructural framework composed predominantly of protein. The deterioration of textural properties during storage may be attributed to lipid and protein oxidation, as well as the degradation of meat facilitated by endogenous enzymes and microbial activity. These processes contribute to alterations in the internal structure of the meat, subsequently impacting the quality of the samples. Given that plant essential oils possess antimicrobial properties, they can impede the degradation of tissue in hamburger treatments (Sun *et al*., 2021; Zhang *et al*., 2021; Xu *et al*., 2017). The retention of texture parameters in nanocapsule samples incorporating essential oils throughout the storage period may be attributed to the capacity of nanocapsules to preserve moisture (Ghadiri Amrei *et al*., 2023). Conversely, chitosan functions as a protective barrier against water loss, thereby assisting in the retention of moisture and the prevention of dehydration in hamburger samples (Mendes *et al*., 2023).

In a study investigating the impact of edible coatings formulated from a nanoemulsion containing fennel essential oil and cinnamaldehyde on the microbial characteristics of pork, researchers reported comparable findings. They concluded that the incorporation of plant essential oils enhanced the textural attributes of the pork; however, it was observed that the storage duration negatively influenced these parameters (Sun *et al*., 2021).

In a research study, investigators assessed the efficacy of chitosan coatings incorporated with flaxseed oil and green tea extract as an environmentally sustainable method for the preservation of

beef. In alignment with the findings of the current study, it has been reported that all textural parameters of the meat samples—including hardness, adhesion, cohesion, elasticity, springiness, gumminess, and chewiness—remained stable throughout the storage period. This phenomenon is likely attributable to the efficacy of the chitosan coating, combined with the bioactive components of green tea extract and flaxseed oil, in inhibiting enzymatic and microbiological processes. This protective effect contributes to the maintenance of textural integrity in the meat samples (Mendes *et al*., 2023).

In a research investigation focusing on the physicochemical, microbial, and sensory attributes of hamburgers fortified with turmeric and omega-3-containing nanoliposomes, the researchers indicated that the incorporation of these components resulted in an enhancement of the textural characteristics of the hamburger samples during storage. This improvement is attributable to the retention of moisture, a finding that is consistent with the results obtained in the current study (Ghadiri Amrei *et al*., 2023).

The findings pertaining to the evaluation of sensory characteristics—namely color, odor, taste, texture, and overall acceptance—of hamburger samples are systematically presented in Figures 20, 21, 22, 23, and 24. The sensory evaluation of various characteristics, including color, odor, taste, texture, and overall acceptance, across different hamburger samples revealed statistically significant differences ($p<0.05$). The organoleptic assessment of the sensory attributes, including taste, aroma, texture, and overall acceptability, was conducted for cooked hamburgers. The findings from the sensory evaluation indicated that the hamburger treatments incorporating essential oils

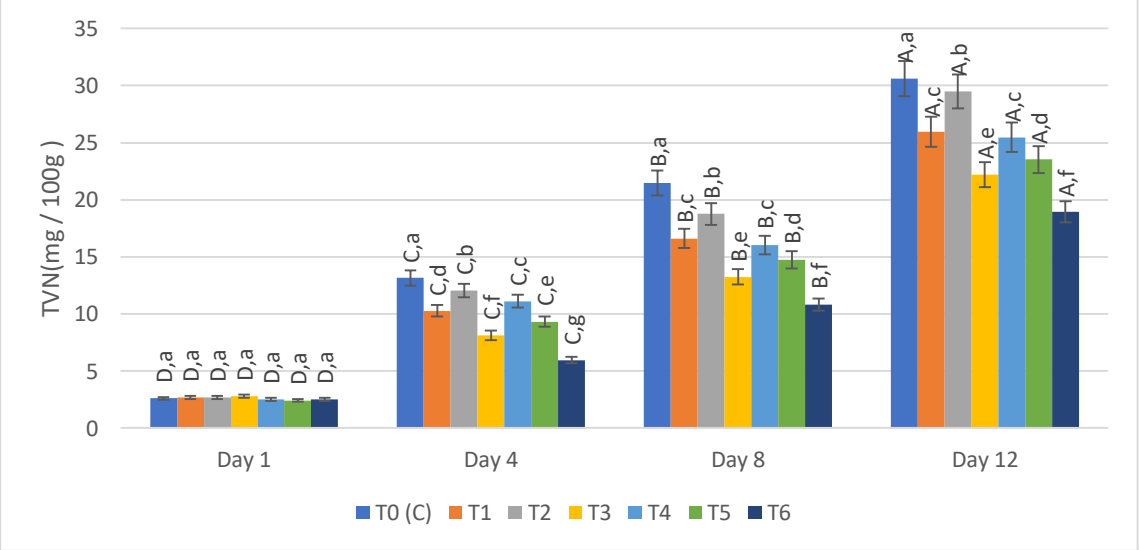

Fig. 18. Volatile nitrogenous bases (TVN) (mg/100gr) of hamburger samples containing free and encapsulated essential oils of E. platyloba and Basil.

Different capital letters in each treatment indicate a significant difference between different days ($p<0.05$). Different lowercase letters in each day indicate a significant difference between different treatments ($p<0.05$). T0 (C): Control, T1: Treatment containing 0.2% free essential oil of E. platyloba, T2: Treatment containing 0.2% free essential oil of Basil, T3: Treatment containing 0.2% nanoencapsulated essential oil of E. platyloba with chitosan, T4: Treatment containing 0.2% nanoencapsulated essential oil of Basil with chitosan, T5: Treatment containing 0.1% essential oil of E. platyloba and 0.1% free essential oil of Basil, T6: Treatment containing 0.1% essential oil of E. platyloba and 0.1% nanoencapsulated essential oil of Basil with chitosan.

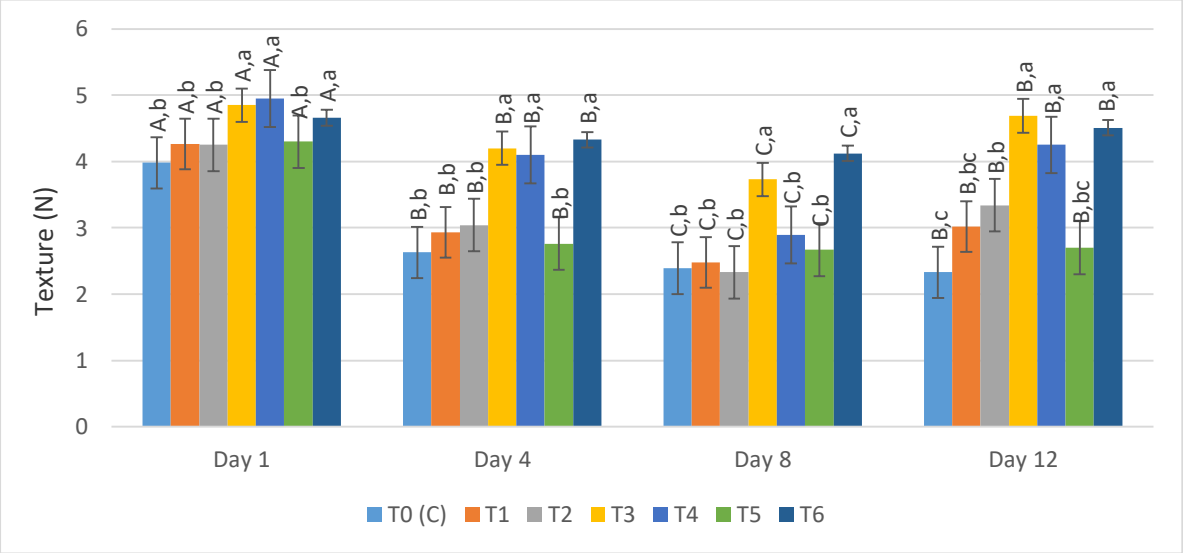

Fig. 19. texture hardness (N) of hamburger samples containing free and encapsulated essential oils of E. platyloba and Basil.
Different capital letters in each treatment indicate a significant difference between different days ($p<0.05$). Different lowercase letters in each day indicate a significant difference between different treatments ($p<0.05$). T0 (C): Control, T1: Treatment containing 0.2% free essential oil of E. platyloba, T2: Treatment containing 0.2% free essential oil of Basil, T3: Treatment containing 0.2% nanoencapsulated essential oil of E. platyloba with chitosan, T4: Treatment containing 0.2% nanoencapsulated essential oil of Basil with chitosan, T5: Treatment containing 0.1% essential oil of E. platyloba and 0.1% free essential oil of Basil, T6: Treatment containing 0.1% essential oil of E. platyloba and 0.1% nanoencapsulated essential oil of Basil with chitosan.

derived from E. platyloba and basil exhibited enhanced sensory attributes, including color, odor, taste, texture, and overall acceptance. Furthermore, the treatments infused with essential oils of E. platyloba receivedsignificantly higher sensory scores in these categories compared to those containing essential oils of basil ($p<0.05$). The sensory attributes of the samples assessed on the initial evaluation day exhibited no significant differences. However, an increase in storage duration correlated with a decline in sensory scores pertaining to color, odor, taste, texture, and overall acceptability across all samples. Notably, this decline was less pronounced in the treatments incorporating nanoencapsulated essential oils of E. platyloba and basil with chitosan compared to the control group. Furthermore, throughout the storage period, the control sample exhibited the lowest scores in color, odor, taste, texture, and overall acceptance. In contrast, the samples treated with nanoencapsulated essential oils of E. platyloba and basil in chitosan demonstrated the highest sensory scores. Moreover, the sensory evaluation of taste was conducted up to day four. Subsequently, a decline in the sensory quality of taste was observed, leading the evaluators to abstain from assigning scores to this parameter. This observation is corroborated by the findings from the microbial and chemical analyses. The results indicate that the total microbial count in the hamburger samples on day eight surpassed the permissible standards. Consequently, the evaluators refrained from assigning a score for this parameter.

The incorporation of plant-derived essential oils has markedly influenced the palatability of meat products, a factor that can substantially impact their marketability. Given that both texture and flavor are critical determinants of

consumer satisfaction, this enhancement in palatability is of considerable significance in the context of product acceptance. Plant essential oils significantly impact the sensory attributes of meat products. They possess the capacity to improve the overall flavor profile and aromatic qualities of meat products. The incorporation of plant essential oils that are abundant in antioxidants, polyphenols, and flavonoids has been shown to improve the sensory attributes of meat products while simultaneously prolonging their shelf life. These extracts have the potential to mitigate undesirable alterations in flavor and aroma, thereby enhancing the overall appeal of the product for consumers. Furthermore, plant extracts possess the capability to function as natural preservatives, thereby providing a viable alternative to synthetic additives, which may pose potential health risks (Moustafa *et al*., 2021; Kurcubic *et al*., 2023) (Ghorbani *et al*., 2024). One significant sensory alteration observed in hamburgers is the emergence of undesirable modifications in color, odor, texture, and taste. These changes can be attributed to microbial proliferation, oxidative chemical reactions, and the generation of volatile compounds (Pabast *et al*., 2018). The temporal decline in the textural and olfactory characteristics of hamburgers can be ascribed to the degradation and oxidation of protein molecules, as well as the subsequent formation of ammonia compounds. Lipid oxidation results in the generation of a diverse array of secondary metabolites, which include aldehydes, ketones, hydrocarbons, and alcohols. These compounds play a significant role in the progression of rancidity, a phenomenon characterized by the emergence of undesirable tastes and unpleasant odors in compromised products. The increase in microbial populations represents a significant factor that contributes to the decline in the sensory acceptability of meat products throughout the storage period. This phenomenon can primarily be ascribed to the enzymatic activities of the microorganisms involved, which facilitate enhanced protein degradation and subsequently lead to the production of various secondary odoriferous compounds. The observed decline in the color score of hamburgers over time can be attributed to the oxidative processes affecting myoglobin and oxymyoglobin. This oxidative degradation ultimately results in the formation of metmyoglobin. This biochemical transformation results in the development of a brown pigmentation in meat products. The reduction in moisture content over time may influence the observed variations in color and texture ratings of hamburgers during the storage period. The incorporation of essential oil-loaded nanocapsules within the formulation significantly improves the retention of sensory attributes of burgers during storage. This enhancement can be ascribed to the antioxidant and antimicrobial properties inherent to the essential oils utilized (Varmazyar *et al*., 2024).

In an investigation of the impact of plant polyphenols and ascorbic acid on the physicochemical properties of sausages, researchers have demonstrated that the incorporation of plant extracts into sausage formulations can substantially enhance their sensory attributes, thereby increasing consumer acceptability (Moustafa *et al*., 2021).

Researchers conducted an investigation into the antibacterial, antioxidant, and sensory properties of essential oils derived from *Rosmarinus officinalis* and *Ziziphora clinopodioides*, which were nanoencapsulated utilizing sodium

alginate within the context of raw burger formulations. The findings of the present study indicate that the integration of nanocapsules containing essential oils extracted from *Rosmarinus officinalis* and *Ziziphora clinopodioides* effectively maintained the sensory attributes of mutton (Karimifar *et al*., 2022).

Researchers conducted a study to investigate the effects of *Anethum graveolens L*. The impact of dill seed essential oil and gallic acid, in both free and nano-encapsulated forms, on the microbial, chemical, and sensory attributes of minced meat during storage at 4°C was investigated. The results demonstrated that the integration of dill seed essential oil and gallic acid nanocapsules into minced meat significantly contributes to the preservation of sensory properties (Anvar *et al*., 2023).

In a recent investigation, researchers examined the impact of microliposomes containing Ferula leaf extract on the shelf life of hamburgers stored under refrigeration. Consistent with the findings of the present study, the researchers reported that the incorporation of nanoencapsulated plant extract enhanced the sensory characteristics of the hamburger samples throughout the storage period (Solgi *et al*., 2024).

In a recent study, researchers investigated the effects of nanocapsules incorporating mango and eggplant peel extracts on the physicochemical, oxidative, microbial, and sensory properties of refrigerated beef burgers throughout the storage period. The findings demonstrated that, during the initial stages of storage, all

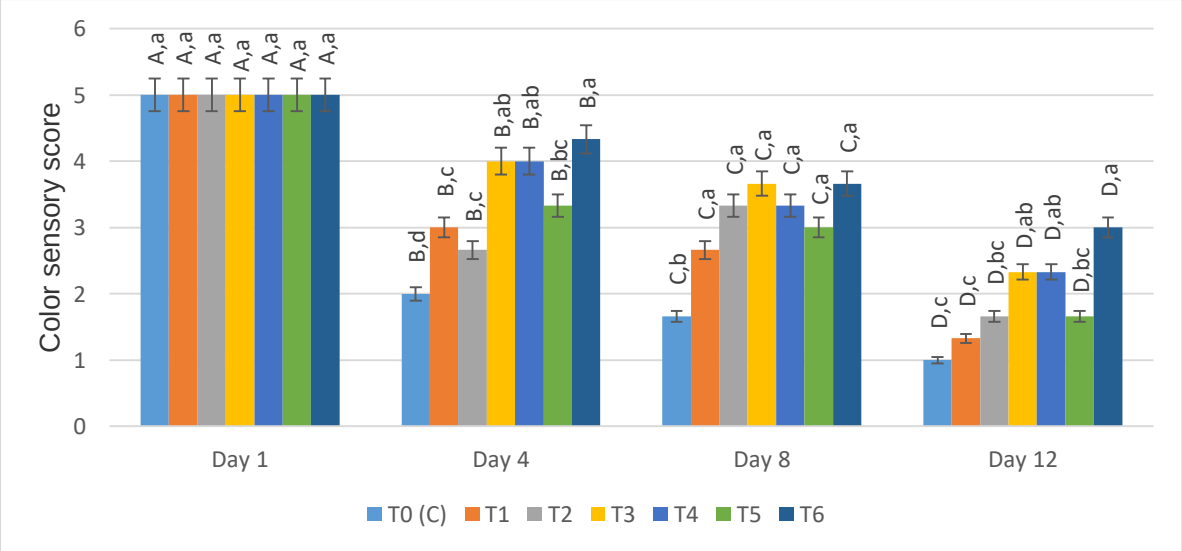

Fig. 20. Sensory color score of hamburger samples containing free and encapsulated essential oils of E. platyloba and Basil.

Different capital letters in each treatment indicate a significant difference between different days ($p<0.05$). Different lowercase letters in each day indicate a significant difference between different treatments ($p<0.05$). T0 (C): Control, T1: Treatment containing 0.2% free essential oil of E. platyloba, T2: Treatment containing 0.2% free essential oil of Basil, T3: Treatment containing 0.2% nanoencapsulated essential oil of E. platyloba with chitosan, T4: Treatment containing 0.2% nanoencapsulated essential oil of Basil with chitosan, T5: Treatment containing 0.1% essential oil of E. platyloba and 0.1% free essential oil of Basil, T6: Treatment containing 0.1% essential oil of E. platyloba and 0.1% nanoencapsulated essential oil of Basil with chitosan

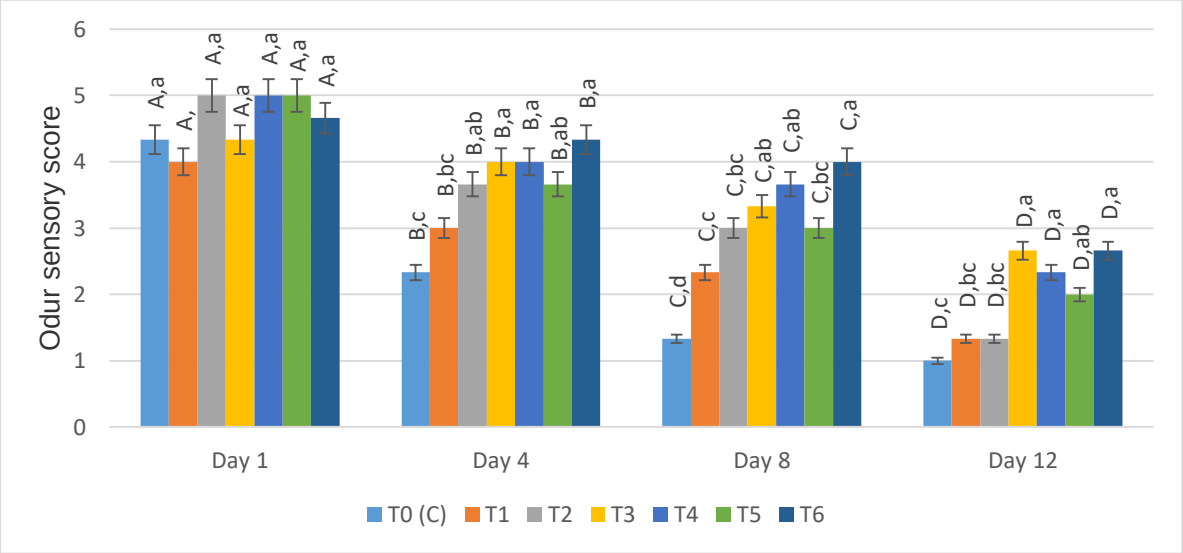

Fig. 21. Sensory odor score of hamburger samples containing free and encapsulated essential oils of E. platyloba and Basil.

Different capital letters in each treatment indicate a significant difference between different days ($p<0.05$). Different lowercase letters in each day indicate a significant difference between different treatments ($p<0.05$). T0 (C): Control, T1: Treatment containing 0.2% free essential oil of E. platyloba, T2: Treatment containing 0.2% free essential oil of Basil, T3: Treatment containing 0.2% nanoencapsulated essential oil of E. platyloba with chitosan, T4: Treatment containing 0.2% nanoencapsulated essential oil of Basil with chitosan, T5: Treatment containing 0.1% essential oil of E. platyloba and 0.1% free essential oil of Basil, T6: Treatment containing 0.1% essential oil of E. platyloba and 0.1% nanoencapsulated essential oil of Basil with chitosan.

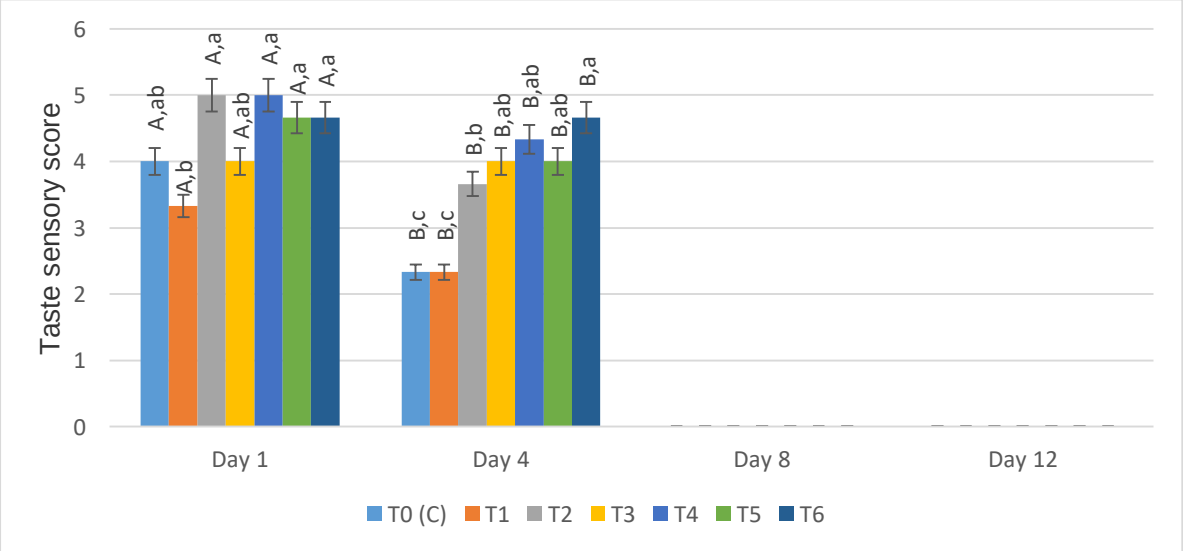

Fig. 22. Sensory taste score of hamburger samples containing free and encapsulated essential oils of E. platyloba and Basil.

Different capital letters in each treatment indicate a significant difference between different days ($p<0.05$). Different lowercase letters in each day indicate a significant difference between different treatments ($p<0.05$). T0 (C): Control, T1: Treatment containing 0.2% free essential oil of E. platyloba, T2: Treatment containing 0.2% free essential oil of Basil, T3: Treatment containing 0.2% nanoencapsulated essential oil of E. platyloba with chitosan, T4: Treatment containing 0.2% nanoencapsulated essential oil of Basil with chitosan, T5: Treatment containing 0.1% essential oil of E. platyloba and 0.1% free essential oil of Basil, T6: Treatment containing 0.1% essential oil of E. platyloba and 0.1% nanoencapsulated essential oil of Basil with chitosan.

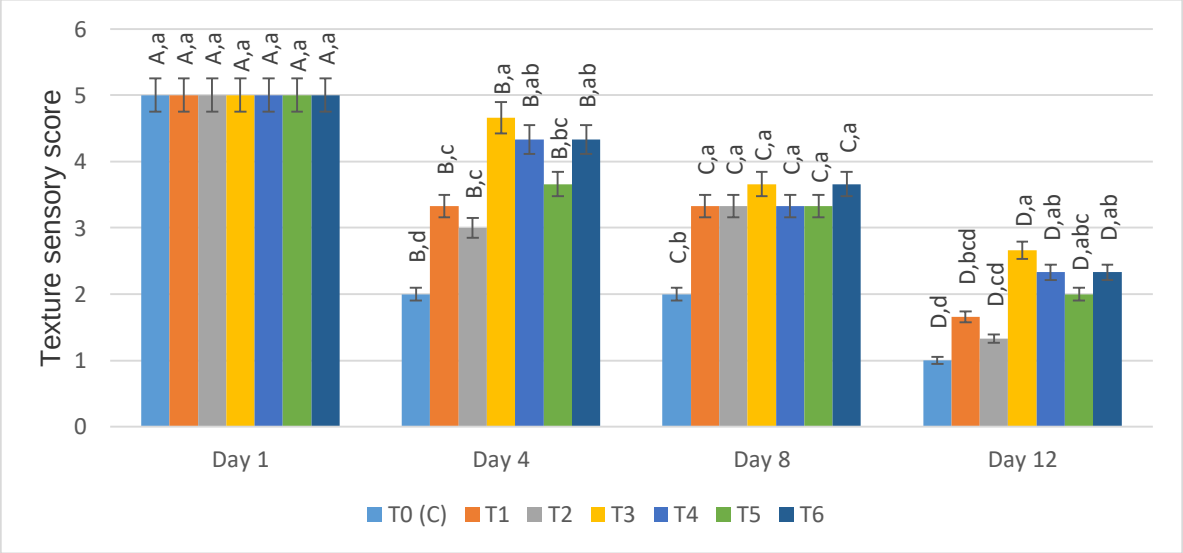

Fig. 23. Sensory texture score of hamburger samples containing free and encapsulated essential oils of E. platyloba and Basil.

Different capital letters in each treatment indicate a significant difference between different days ($p<0.05$). Different lowercase letters in each day indicate a significant difference between different treatments ($p<0.05$). T0 (C): Control, T1: Treatment containing 0.2% free essential oil of E. platyloba, T2: Treatment containing 0.2% free essential oil of Basil, T3: Treatment containing 0.2% nanoencapsulated essential oil of E. platyloba with chitosan, T4: Treatment containing 0.2% nanoencapsulated essential oil of Basil with chitosan, T5: Treatment containing 0.1% essential oil of E. platyloba and 0.1% free essential oil of Basil, T6: Treatment containing 0.1% essential oil of E. platyloba and 0.1% nanoencapsulated essential oil of Basil with chitosan.

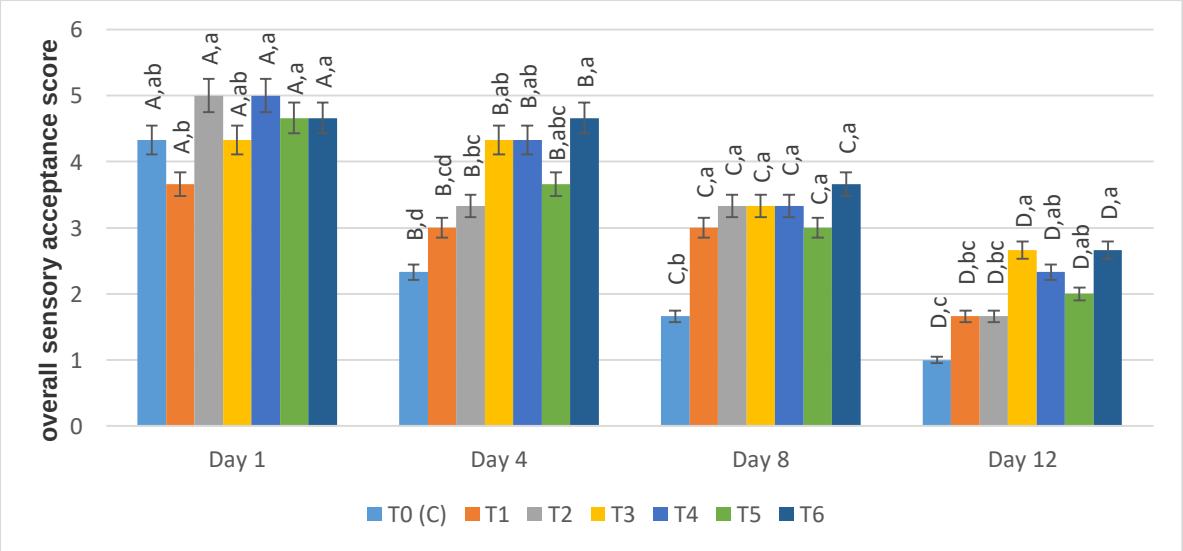

Fig. 24. Overall sensory acceptance score of hamburger samples containing free and encapsulated essential oils of E. platyloba and Basil.

Different capital letters in each treatment indicate a significant difference between different days ($p<0.05$). Different lowercase letters in each day indicate a significant difference between different treatments ($p<0.05$). T0 (C): Control, T1: Treatment containing 0.2% free essential oil of E. platyloba, T2: Treatment containing 0.2% free essential oil of Basil, T3: Treatment containing 0.2% nanoencapsulated essential oil of E. platyloba with chitosan, T4: Treatment containing 0.2% nanoencapsulated essential oil of Basil with chitosan, T5: Treatment containing 0.1% essential oil of E. platyloba and 0.1% free essential oil of Basil, T6: Treatment containing 0.1% essential oil of E. platyloba and 0.1% nanoencapsulated essential oil of Basil with chitosan.

burger samples were assigned elevated sensory scores. Nonetheless, over time, a progressive decline in the sensory evaluation scores of the samples was noted. It is important to highlight that the control sample exhibited the most significant reduction in sensory scores, whereas the nanocapsule treatments infused with plant extracts and essential oils achieved superior scores throughout the storage period (Varmazyar *et al*., 2024).

Conclusion

The findings of this study indicated that the incorporation of E. platyloba and basil essential oils, both in free and encapsulated forms, did not significantly affect the fat, protein, and ash content of the hamburger samples ($p > 0.05$). Furthermore, the incorporation of E. platyloba and basil essential oils, both in their free and encapsulated forms, significantly enhanced antioxidant properties as measured by the Ferric Reducing Antioxidant Power (FRAP) assay. Additionally, this inclusion resulted in improved texture hardness, sensory characteristics, and a reduction in peroxide value and total volatile nitrogen (TVN) levels. Increased storage duration was associated with a reduction in antioxidant properties, as measured by the Ferric Reducing Ability of Plasma (FRAP), as well as diminished textural hardness and sensory attributes. Conversely, a prolonged storage period led to an increase in peroxide value and total volatile nitrogen (TVN). Furthermore, based on the outcomes of the treatment designated as T_6, which incorporated 0. 1% essential oils of E. platyloba as well as 0. 1% basil essential oil nanoencapsulated with chitosan, this treatment was identified as the most advantageous among the assessed conditions. In conclusion, the incorporation of plant essential oils within the framework of nanocapsules presents a viable approach for the development of innovative, functional, and nutritionally advantageous products. Furthermore, owing to their inherent antimicrobial and antioxidant properties, these nanocapsulated essential oils contribute significantly to the prolongation of shelf life.

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