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Abstract

Nanotechnology in the food industry can increase the effectiveness of food ingredients. Nanotechnology can increase the bioavailability and absorption of bioactive compounds, enhance their stability, and improve the sensory quality of the product. Processed meat products are easily damaged due to bacterial activity. Advanced nanoemulsions as a meat preservative are nanoemulsions that can be used as preservative agents in meat products, particularly essential oil nanoemulsions, due to their antimicrobial and antioxidant properties. Its application is still limited to foods made from meat products. Therefore, this literature review examines nanoemulsion and its application in meat products and functionality improvement. Also, in the future, nanoemulsions in meat products must be made safe, and the government and businesses must work together to build consumer trust. It can be concluded that essential oil-based nanoemulsion has the potential to be used as an additive in meat products because it can kill bacteria, fight free radicals, improve flavor, and keep food fresh. Nanoemulsion is challenging in the meat industry because it can be toxic due to its tiny droplets (under 200 nm) and is expensive to produce.

Keywords: essential oils, nanoemulsion, natural preservative, meat product

INTRODUCTION

Food security is a problem in developing countries. This gap is an opportunity for researchers to use new technologies to improve the quantity and quality of food [1]. The increasing demand for safe and healthy products has attracted the use of nanotechnology as a new approach to improving food safety and quality [2]. Concerning the use of nanotechnology in the food industry, it can improve the quantity and quality of food and make it safer and healthier. It can do this by being better than traditional technologies at preventing microbial contamination and making food last longer [3] (Fig. 1). In fact, nanotechnology can be used for the development of food products with enhanced nutrients and sensory qualities [4].

Nanotechnology has an excellent opportunity to be applied in agriculture and food as a solution to the future challenges of food quantity and quality [5]. Nanotechnology in food focuses on developing novel materials with unique properties to boost production and preserve food products no larger than 100 nm in size[6]. Nanoemulsion (NE), a part of nanotechnology, can deliver bioactive compounds through food to the human body [7]. NEs consist of oil, water, and emulsifier phases which are mixed and will be dispersed to form tiny droplets [8].

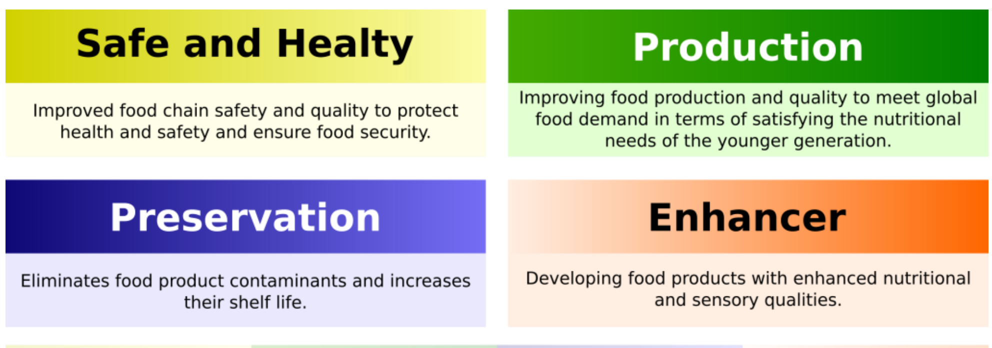

Fig. 1. Recent nanotechnology perspective in the field of sustainable and future food. Refers to and modifies from Onyeaka et al., Pateiro et al., and Shafiq et al. [3,4,6].

Pharmaceuticals, medicine delivery systems, cosmetics, and the food sector have extensively used Nes [9]. In the food industry, NEs can improve taste, texture, color, the bioavailability of active compounds, absorption, antimicrobial properties, protection of active compounds, delivery of active compounds, packaging materials with antimicrobial properties, and nanosensors for food safety detection [10]. NEs are renowned for using small particle sizes (1 nm is equivalent to 1.10^{-9} m). In particular, the optimal scale for application typically consists of oil droplets dispersed in water with an average diameter of less than 200 nm [11,12].

The surface qualities of the substance will be determined by the nano-delivery method applied. In the food industry, many types of nano-delivery include liposomes, nanoemulsions, solid-lipid nanoparticles, and biopolymeric nanoparticles [13]. In practice, NEs can be composed of oil-in-water or water-in-oil treatments; Fig. 2 depicts the NE structure. Bioactive chemicals that are either hydrophilic or lipophilic are wrapped in a stabilizer to maintain the integrity of the NE's structure [14]. The NE manufacturing approach may employ low- or high-energy techniques [15]. For food-grade NEs, the high-energy approach is favored because it requires less surfactant (Fig. 3). But high-pressure homogenization, ultrasonication, and microfluidization are necessary [16]. NEs have several benefits, including particle size reduction, a sufficient zeta potential value, increased stability, and others [17]. The small particle size of NE enhances the surface area and imparts a transparent appearance [9]. NE stability can be attained within a few hours to several years, depending on the underlying components and methods [18]. The commercial use of NEs in the pharmaceutical, pharmacology, and food sectors attempts to deliver active chemicals to the target and minimize the dosage of active compounds. Nanomaterials are effective due to their nanoscale particle size and large surface area [15].

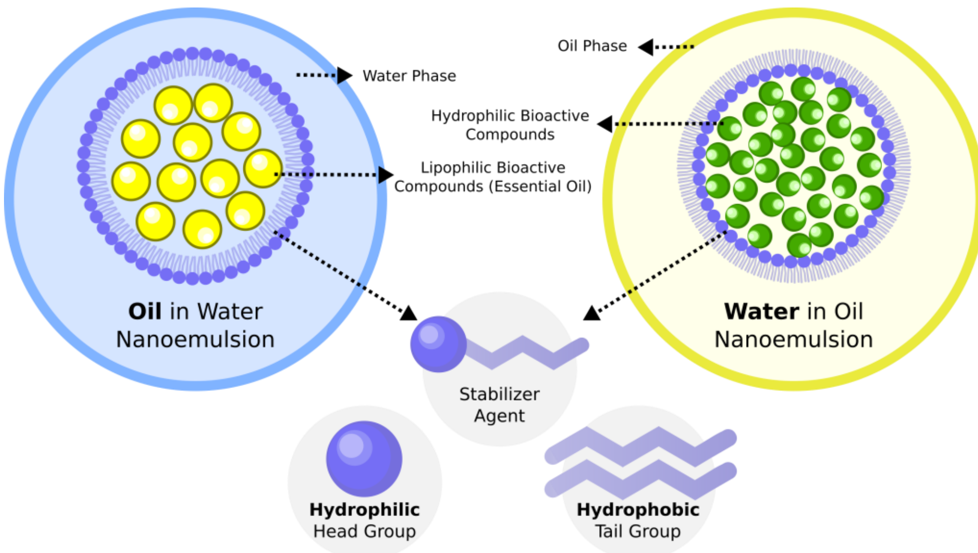

Fig. 2. The nanoemulsion structure in the water and oil phases.

Reworked form Aswathanarayan and Vittal [19].

Increased interest in plant-based natural food preservatives since they are relatively harmless to human health [20]. The food processing industry's goal for enhancing shelf life is to investigate natural preservatives rather than synthetic preservatives and simple formulation procedures [21]. Essential oil (EO) can be extracted from various plant parts, including leaves, stems, roots, flowers, bark, and grass [12]. EOs can suppress harmful microorganisms in food, but their hydrophobic nature limits their applicability [22]. NE can enhance the EOs' solubility [23]. Several considerations in the NE preparation process are solubility, bioavailability, and polarity [24]. EOs can be added to meat and animal products using NE as an alternative [25]. EO-NEs can act as antioxidant molecules that decrease the oxidation of food products and increase their storability [26]. Interestingly, EO-NEs can reduce the need for heat processing in the food industry for bacterial deactivation [27].

This literature review focuses on improving the quality of meat and meat products due to using NEs of bioactive compounds from plants. On the issue of the review, collected 3082 publications between 2017 and 2022. In the interim, the search terms "nanoemulsion," "essential oil," "meat product," "functionality", and "antimicrobial properties" were employed. The detailed description of the NE treatment, including its source, synthesis method, application, and meat products, served as the basis for this review.

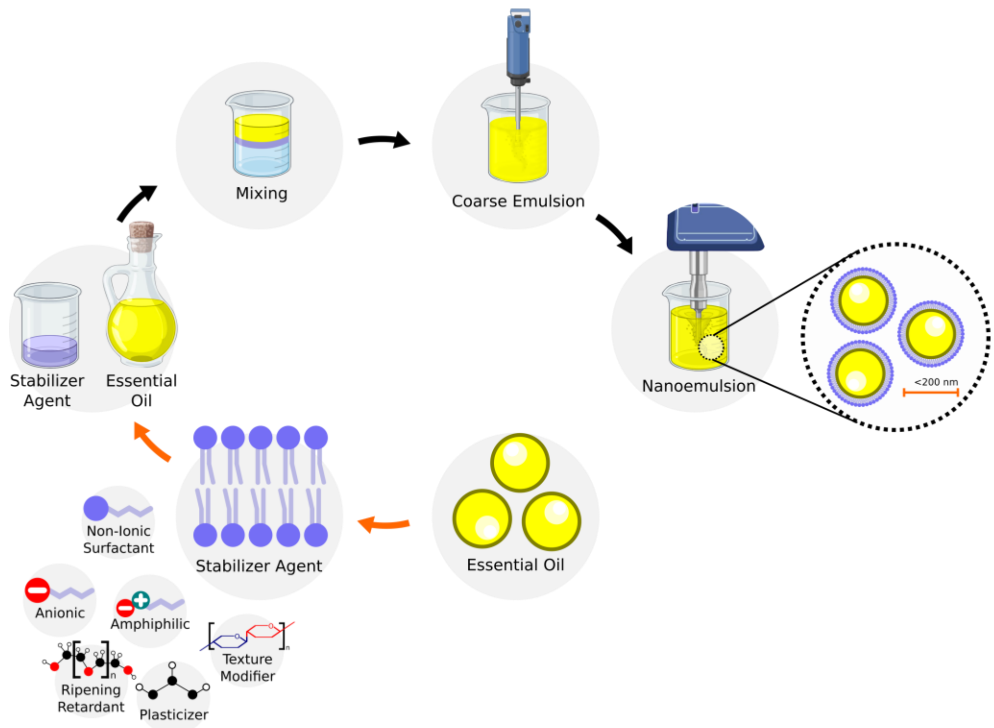

Fig. 3. Production of nanoemulsions using the high-energy method. Modified from Zhao et al. [28].

The type of NE employed and the assorted variety of meat products. The exact effects of the NE were derived from the reference materials; it is utilized to treat. Most NEs studied were derived from plant EOs containing secondary metabolites such as cinnamaldehyde, geraniol, linalool, quercetin, and tocopherols. Among the features of this EO are its nano-size, ability to preserve meat quality, ability to add value to meat products, and inhibitory activity against specific spoilage and disease bacteria (Fig. 4).

Numerous reviews on nanotechnology or NE in the food industry have been studied, especially ones highlighting food safety [29], preservation of meat products [19], enrichment of nutrients as functional food [30], and modification of specific active components for healthy food products [31]. Consequence, this work focuses primarily on applying NEs in meat products, their functional properties, and their future potential. This literature review aimed to explore active compounds from plants, especially EOs, and their preparation using nanotechnology to improve meat products' quality and shelf life and their derivates.

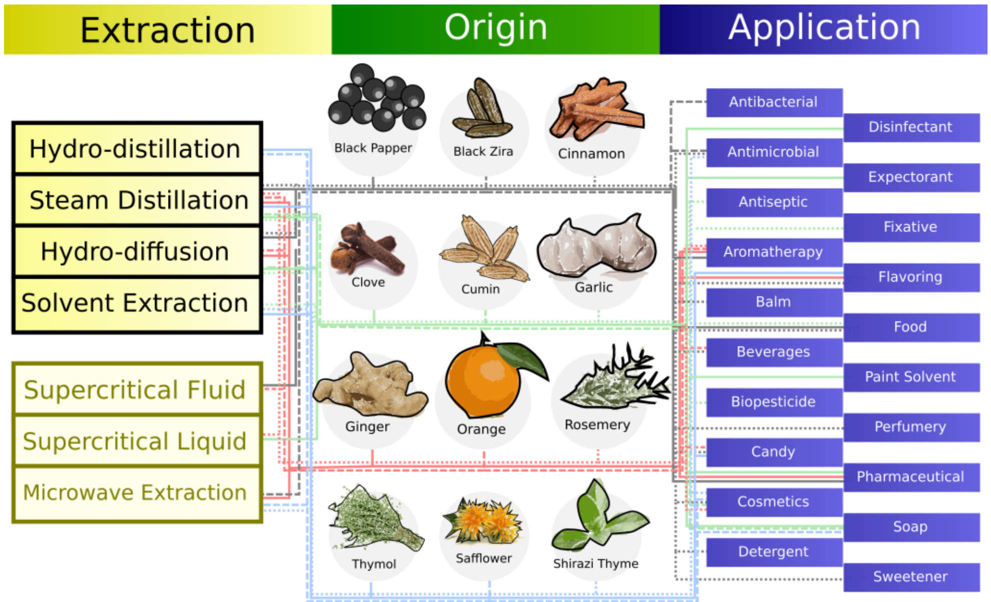

Fig. 4. Essential oil, its extraction method, and its use in the food, health, and cosmetic industries, among others. Adapted from Kant et al. [32].

NANOEMULSION AND ITS APPLICATION IN MEAT PRODUCT

As stated by the FAO, almost one-third of human food (1,300,000,000 tonnes) is wasted [33]. Extending the shelf life of food products is one of the food industry's research priorities. Due to food safety concerns, numerous initiatives have been implemented [34]. NE is one of the promising technological alternatives to extend food product shelf life [35]. NEs in the food industry may include water, oil, surfactants, and other additives such as bioactive compounds, preservatives, flavors, and colors [36]. Though, the accurate design of nanocarriers is critically required for consumer health and safety [37]. Using NE in meat products purposes to keep the physicochemical quality, prevent oxidation, eliminate pathogenic microbes, and improve the flavor. Various NEs have been utilized to preserve meat products and their derivatives. According to reports, herbal NEs can preserve meat's flavor and shelf life [33].

Physicochemical quality

NE preserved meat products commonly maintain their cooking loss, fat binding, water-holding capacity (WHC), and textural features [14,29]. The main factors that cause the meat to spoil are pH changes and total volatile base nitrogen (TVB-N), both of which can be reduced via NE. Trimethylamine-nitrogen (TMA-N) synthesis is another thing that can be repressed [29]. The mechanism of the NE in preserving the physicochemical properties of meat includes: i) lowering the permeability of oxygen from the environment and lowering or inhibiting its spread in meat products [30]; ii) lowering the permeability of water vapor [38]; iii) lowering the transfer of nutrients from meat to the environment [39]; iv) lowering the transfer of energy from the environment to meat which can be damaging [37].

Oxidative stability

The majority of the NEs active compounds are EOs or other phenolic compounds, which are found to have a high affinity as antioxidants [40]. Sunflower and *Zataria multiflora* EOs have been seen to prevent the oxidation and hydrolysis of free fat and lipids in meat (called "marbling") [41–43]. Antioxidants like caryophyllene, citronellal, citronellol, citronellol acetate, linalool, and sabinene in kaffir lime can inhibit oxidation and radical formation [44,45]. NEs maintain oxidative stability at the nanoscale with a large reaction area [29,30]. As a result, antioxidant substances (EOs) become more vulnerable to oxidizing agents like oxygen gas.

Antimicrobial activity

Most NEs modify the microenvironment of meat products to extend their shelf life by limiting the growth of pathogens. Fig. 5 demonstrates the mode of action of NEs against pathogenic microbes. Because their size is less than 1200 nm, the encapsulated EOs are carried across cell membranes through a passive transport mechanism [46]. This passive diffusion destroys or deforms the cell membrane, producing cell toxicity [47]. Inside pathogenic cells, NE causes four significant damages: a). damaging DNA integrity (inhibiting transcription and translation processes), b). interfering with the function of ribosomes in protein synthesis, c). triggering the formation of reactive oxygen species (ROS), and d). inhibiting energy production in mitochondria [48].

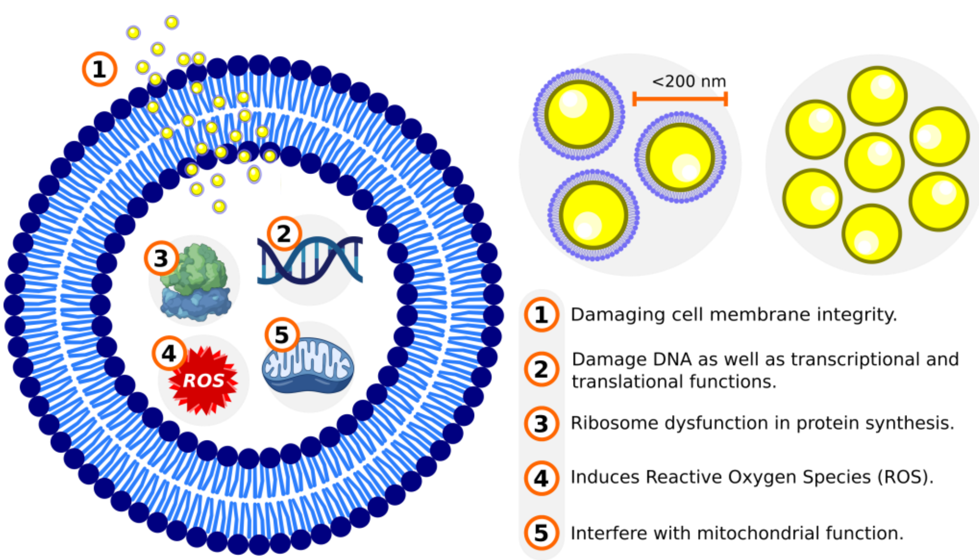

Fig. 5. The mechanism of nanoemulsion inhibits the pathogen microbe. Modified from Perumal et al. [48].

Sensory quality

NE has a significant role in minimizing the odorous products of meat production. Olive oil can eliminate unpleasant odors in fish sausage and fillet products and other sensory aspects, such as texture and flavor [49,50]. Nanoparticle technology produces a large surface area, enhancing the active compound's affinity [24]. NE improves the flavor of meat by establishing an environment low in radical molecules by chelating them [39], limiting the exchange of aromatic compounds (free fatty acids and volatile acids) from meat [29], and minimizing marbling damage caused by free radicals [2,51].

Current use of nanoemulsion in meat product

Consumer demand for animal products, especially meat, is increasing [52]. In contrast, consumers' desire for various types of healthy meat products has affected the marketing of meat products. In recent decades, modifications have been made to beef products [53]. The EOs can be classified based on the type of meat they were administered, including chicken, beef, lamb, plant-based meat, and cultured meat. Describes various EOs used as bioactive chemicals in NEs (Fig. 6).

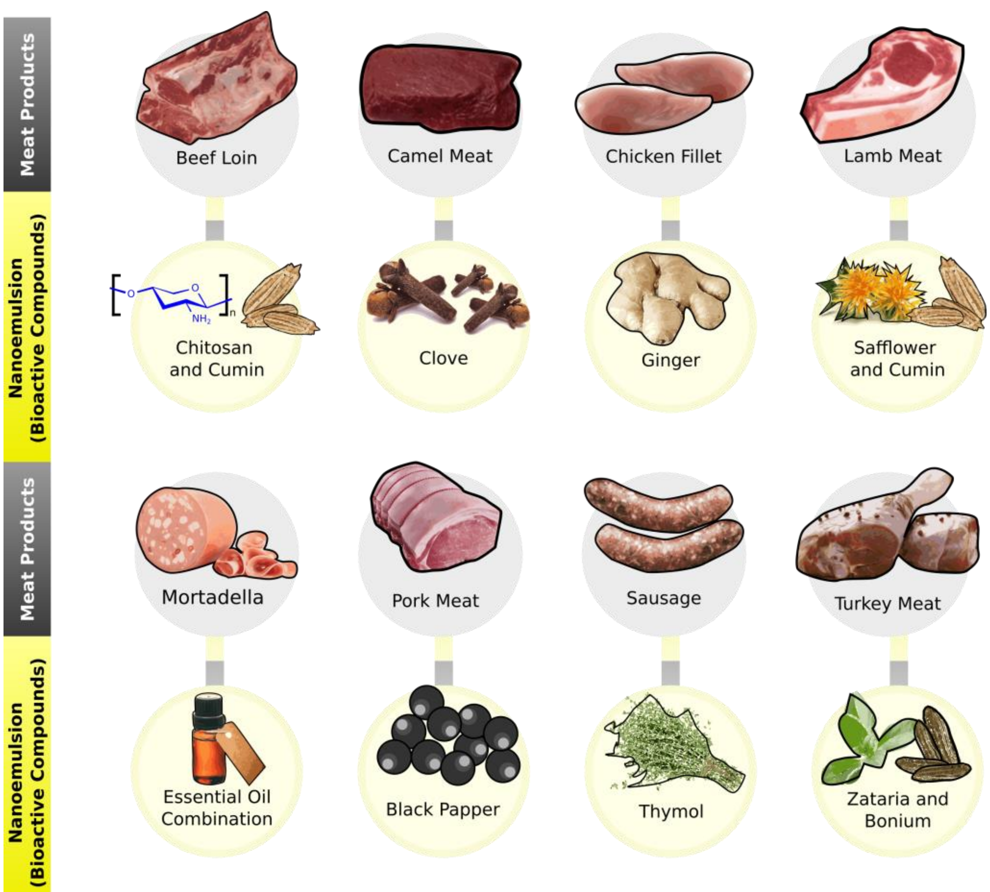

Fig. 6. Bioactive compounds of nanoemulsions are currently used in meat products and their derivatives.

The main impact of NE application should be to improve meat's nutritional quality and properties. Several issues exist where EOs as bioactive compounds in NEs affect meat and meat products (Table 1).

Table 1. Effects of nanoemulsion on meat products

Impact of food enhancement	Bioactive compounds	Stabilizer agents	Meat products	Size (nm)	Ref.
Antibacterial					
Exhibits antibacterial activity against *Escherichia coli* and *Salmonella typhimurium*	Gallic acid, curcumin, and quercetin	Carrageenan and gelatin	Fresh broiler chicken	98.2 ± 0.36	[54]
Growth retardation of psychrotrophic, mesophilic bacteria, lactic acid bacteria, and Enterobacteriaceae	Virgin olive oil and ajowan	Tween 80	Lamb loins	181 ± 1.71	[55]
Increase antimicrobial activity	Rosemary extract	ε-poly-L-lysine	Carbonado chicken	257	[56]
Increase antimicrobial activity against psychrotrophic bacteria, *Listeria monocytogenes*, Enterobacteriaceae, lactic acid bacteria, and molds	*Zataria multiflora* EO	Tween 80	Fresh chicken	177 – 185	[43]
Inhibit the growth of *Listeria innocua, Escherichia coli* K12, and *Pseudomonas lundensis*	Geraniol and linalool	Tween 80	Fresh meat	68.2–174	[57]
Inhibit the growth of *Listeria monocytogenes* and *Salmonella enteritidis* bacteria	*Zataria multiflora* Boiss and *Bunium persicum* Boiss EOs	Tween 80	Turkey meat	342 – 507	[42]
Inhibit the growth of pathogenic microbes	Cumin EO	Chitosan	Beef loins	89.6	[58]
Inhibit the growth of psychrotrophic, mesophilic, lactic acid bacteria, and Enterobacteriaceae bacteria	Safflower and cumin EOs	Polysorbate	Lamb meat	121 ± 1.53	[59]
Inhibit the growth of *Salmonella enterica* and *Escherichia coli* in infected fresh meat	Black pepper EO	Tween 80	Pork meat	18	[60]

Impact of food enhancement	Bioactive compounds	Stabilizer agents	Meat products	Size (nm)	Ref.
Inhibited the growth of *E. coli*, *S. aureus*, and *C. perfringens*	Thymol	Tween 80	Sausage	86.4	[61]
Inhibition of microbial population growth in sausages inoculated with *Escherichia coli*, *Staphylococcus aureus*, and *Clostridium perfringens*	Cinnamaldehyde	Tween 80	Sausage product	146	[62]
Prevent microbial proliferation	Clove EO and polylysine	Carboxymethyl chitosan	Donkey meat	110 ± 0.45	[63]
Reduce psychrophilic bacteria, total plate count, and mold	Curcumin, cinnamon, garlic EO, and sunflower oil	Tween 80 surfactant	Chicken fillet	9 - 130	[41]
Reduce the population of *Campylobacter jejuni*	Carvacrol	Tween 80	Broiler chicken skin	507 ± 101	[64]
Reduced *Clostridium sporogenes* vegetative cells	Combined EO from oregano, cinnamon, Tahiti lemon, cardamom, and Chinese pepper	Non-ionic surfactant soybean lecithin	Processed mortadella meat products	45.5 – 47.3	[65]
Reduces the population of psychrophilic bacteria	Ginger EO	Tween 80	Chicken fillet	57.4	[66]
Antioxidant					
Antioxidant activity	Gallic acid, curcumin, and quercetin	Carrageenan and gelatin	Fresh broiler chicken	98.2 ± 0.36	[54]
Delaying lipid oxidation	Tocopherol	Octenyl succinate anhydride	Fish sausage	252	[67]
Increase antioxidant activity	Clove EO	Tween 80	Camel meat	242 – 770	[68]
Increase antioxidant activity	Orange EO and cactus fruit	Liquid soya lecithin	Emulsified meat	73 ± 6	[69]
Increasing antioxidant activity	Cinnamon	Chitosan	Fish fillet	11.8	[70]

Impact of food enhancement	Bioactive compounds	Stabilizer agents	Meat products	Size (nm)	Ref.
	perilla				
Inhibits lipid oxidation	Tocopherol	Tween 80	Fish sausages	477 – 593	[50]
Inhibits the decline in meat quality due to oxidation and bacteria	Thyme	Chitosan	Pork	-	[51]
Protects against lipid oxidation	Quercetin	Tween 80 or Brij 30	Chicken pâtés	180-200	[71]
Providing antioxidant effects	Combined EO from oregano, cinnamon, Tahiti lemon, cardamom, and Chinese pepper	Non-ionic surfactant soybean lecithin	Processed mortadella meat products	45.5 – 47.3	[65]
Improvement					
Improving the quality without changing the texture	Tocopherol	Octenyl succinate anhydride	Fish sausage	252	[67]
Control the release of active compounds	Rosemary extract	ε-poly-L-lysine	Carbonado chicken	257	[56]
Reduce protein and fat oxidation	Clove EO and polylysine	Carboxymethyl chitosan	Donkey meat	110 ± 0.45	[63]
Preservative					
Extend shelf life	Olive oil	Surfactant-tween 80	Fish fillets	308 – 541	[49]
Extends the shelf life	Gallic acid, curcumin, and quercetin	Carrageenan and gelatin	Fresh broiler chicken	98.2 ± 0.36	[54]
Increase the shelf life	Orange EO and cactus fruit	Liquid soya lecithin	Emulsified meat	73 ± 6	[69]
Maintains the natural pH of the meat	Cinnamon, unknown EO, and soluble polysaccharides	Soy protein isolate and lecithin	Meat	141 – 145	[72]

Impact of food enhancement	Bioactive compounds	Stabilizer agents	Meat products	Size (nm)	Ref.
	from soybeans				
Prolonging shelf life	Combined EO from oregano, cinnamon, Tahiti lemon, cardamom, and Chinese pepper	Non-ionic surfactant soybean lecithin	Processed mortadella meat products	45.5 – 47.3	[65]
Stabilize pH	Clove EO and polylysine	Carboxymethyl chitosan	Donkey meat	110 ± 0.45	[63]

Ref, references.

An in vitro study utilizing clove (*Syzygium aromaticum*) EO-NE on minced camel meat during storage (20 days at 4℃) demonstrated more antioxidant activity than when no NE was applied [68]. The combination of cumin (*Cuminum cyminum*) EO-NE-containing chitosan film and gamma irradiation prevented the growth of pathogenic microbes and increased the life span of beef loins [58]. Adding olive oil under NE can increase the shelf life of fish fillets [49]. Cinnamon (*Cinnamomum zeylanicum* L.) EO under NE with soluble polysaccharides from soybeans can maintain the meat's natural pH for 8 days [72]. The combination of safflower (*Carthamus tinctorius*) and cumin (*Cuminum cyminum*) EOs inhibited the growth of psychrotrophic, mesophilic, lactic acid bacteria, and Enterobacteriaceae over 20 days of deep freeze [59]. Under NE, rosemary (*Rosmarinus officinalis* L.) extract and ε-poly-L-lysine inhibited the surface release of active chemicals. This technique can also increase antibacterial activity; thus, its implementation has the potential to improve the quality and safety of processed beef products [56]. EOs from *Zataria multiflora* Boiss and *Bunium persicum* Boiss can suppress the growth of Listeria monocytogenes and Salmonella enteritidis on turkey meat to increase its life – span [42].

Using edible coating based on NE with 6% ginger EO reduces the population of psychrophilic bacteria in chicken fillets [66]. The addition of antioxidant compounds from orange EO and cactus fruit with NEs can increase antioxidant activity and improve the shelf life of emulsified meat. In addition, it also reduces lipid oxidation and malonaldehyde [69]. The addition of tocopherol NE in fish sausage affects delaying lipid oxidation and improves the quality of fish sausage without changing the texture [50]. A combination of EO-NE (cinnamon, cardamom, Chinese pepper, Tahiti lemon, and oregano) effectively reduced *Clostridium sporogenes* vegetative cells in processed mortadella meat products, in addition to providing antioxidant effects without changing product characteristics and prolonging shelf life [65]. The addition of thymol-NE in sausages effectively inhibited the growth of *E. coli*, *S. aureus*, and *C. perfringens* bacteria [73]. Fresh chicken treated with *Zataria multiflora* EO-NE coated with starch increased antimicrobial activity against psychrotrophic bacteria, *Listeria monocytogenes*, Enterobacteriaceae, lactic acid bacteria, and molds [43]. Chicken fillet coated with pectin-coated NE (curcumin and cinnamon EO), (curcumin and garlic EO), (curcumin and sunflower oil) can reduce psychrophilic bacteria, total plate count, and mold [41].

Geraniol and linalool NEs are effective and safer to use as preservatives for fresh meat and have an inhibitory mechanism against *Listeria innocua*, *Escherichia coli* K12, and *Pseudomonas lundensis* [57]. Quercetin NE with Tween 80 and Brij 30 can maintain flavonoid content and inhibit lipid oxidation in chicken pâtés [71]. Tocopherol NE has good antioxidant activity, inhibits lipid oxidation, and does not change the texture of fish sausage during storage [50]. Black pepper EO-NE contains important components such as -α-pinene, β-pinene, β-caryophyllene, D-limonene, and 3-carene. It has antibacterial activity inhibiting the growth of *Salmonella enterica* and *Escherichia coli* in infected fresh pork meat [60].

Cinnamaldehyde NE increased the antimicrobial effect against *Escherichia coli*, *Staphylococcus aureus*, and *Clostridium perfringens* in sausages. However, cinnamaldehyde's antibacterial activity compared with cinnamaldehyde's NE did not show any significant difference [62]. The addition of virgin coconut oil and ajowan EO (*Carum copticum*) NE resulted in a delay in the growth of psychrotrophic, mesophilic bacteria, lactic acid bacteria, and Enterobacteriaceae. In addition, it slows down the oxidation of proteins and lipids, the formation of metmyoglobin, and the loss of color [55]. Gallic acid NE, curcumin, and quercetin encapsulated with carrageenan and gelatin, has antioxidant activity and shows antibacterial activity against *Escherichia coli* and *Salmonella typhimurium*, with the best result being curcumin NE which can extend the shelf life of fresh broiler chicken meat up to 17 days while in control 10 days [54].

Thymol NE added to sausage samples inoculated with bacteria up to 600 mg/kg effectively reduced the population of *C. perfringens*, *E. coli*, and *S. aureus* bacteria [61]. Carvacrol NE up to 2% level can reduce the population of *Campylobacter jejuni* in broiler chicken skin samples and potentially be an alternative for washing postharvest chickens [64]. Chitosan NE containing thyme EO reduced the decrease in meat quality due to oxidation and inhibited the growth of Pseudomonas bacteria [51]. Cinnamon-perilla EO-NE with collagen emulsifier can preserve fish fillets by increasing antioxidant activity [70]. Clove EO-NE with polylysine and carboxymethyl chitosan was able to stabilize pH, prevent microbial proliferation, reduce protein and fat oxidation, inhibit discoloration, maintain cohesiveness, maintain cohesiveness, and inhibit the decrease in elasticity in donkey meat [63].

Pros and cons of nanoemulsion application for meat products

Pros: The use of NE in the food industry is the preferred preparation. Thermodynamic stability, dispersibility, and transparency of NEs can improve food's chemical, sensory, and texture qualities [74]. In addition, it also improves the microbiological quality of food [75], enhances essential activities such as antioxidants [76] and can prevent foodborne disease [77]. NE can be used as an antimicrobial agent with a safe dose [78]. **Cons**: Studies of EO-NEs on meat and its products are still limited, their application in complex matrix foods is a challenge [79]. Further research is needed regarding the toxicity of NEs in the food sector for consumers and the environment [80]. The absorption of nanomaterials and their metabolism in the body are essential factors in designing safe NEs for consumers [13]. Future NE designs are suggested to use materials that are safer for the environment [1].

FUNCTIONALITY IMPROVEMENT OF MEAT PRODUCT

Increased consumer interest in processed meat products without synthetic additives has encouraged the food processing industry to innovate in providing healthy meat with additives that are safe and beneficial for health. Plant bioactive compounds can be used for meat preservation [38]. Synthetic preservatives such as butyrate hydroxyanisole (BHA), butyrate hydroxytoluene (BHT), and tertiary butyl hydroquinone (TBHQ), when consumed in excess amounts, can cause gene mutations and carcinogenic effects [12]. In addition, the FDA recommends using environmentally friendly ingredients and reducing chemicals in food products [81]. Natural ingredients were chosen as an alternative to synthetic preservatives and to ease concerns about resistance to microbial pathogens [82]. Thymol NE can be used as an alternative to replacing nitrite as a preservative in sausages [73].

Currently, there is an increasing demand for adding ingredients from plants into meat products such as nuggets, steaks, and sausages to increase the product's functionality [83]. The shelf life of meat can be affected by the presence of microbes, decreased sensory quality, and the addition of other ingredients [84]. In addition, NEs can be used as softening agents in the meat processing industry [85]. The advantages of using NE applications in meat products include: improving quality, inhibiting lipid oxidation, reducing physicochemical changes in storage, inhibiting microbial growth and development, and extending the shelf life of meat products [2] (Fig. 7). NEs preserve nutrients and enhance the quality of meat. Several components in meat, including protein, amino acids, lipids (for marbling), vitamins, and minerals, are protected from degradation (Fig. 8).

Meat proteins are quickly degraded, decreasing their nutritional content; NE can minimize the rate of protein breakdown. Carbonyl levels are markers of protein degradation. In conformity with Zixiang et al. [63], the carbonyl content of donkey meat treated with NE (a combination of clove EO and carboxymethyl chitosan-coated ε-polylysine) was lower than that of controls. Utrera and Estévez [86] elucidated the effectiveness of NE in inhibiting proteolysis. The hydroxyl groups of phenolic NE compounds can scavenge free radical compounds, resulting in the gradual oxidation of proteins. Moreover, from a particle size viewpoint, NEs (98.2 to 258 nm) can minimize protein damage more effectively than macroemulsions (370 to 460 nm) Zixiang et al. [63] and Khan et al. [54] due to the high surface area for free radical binding and starting a chelating response against it.

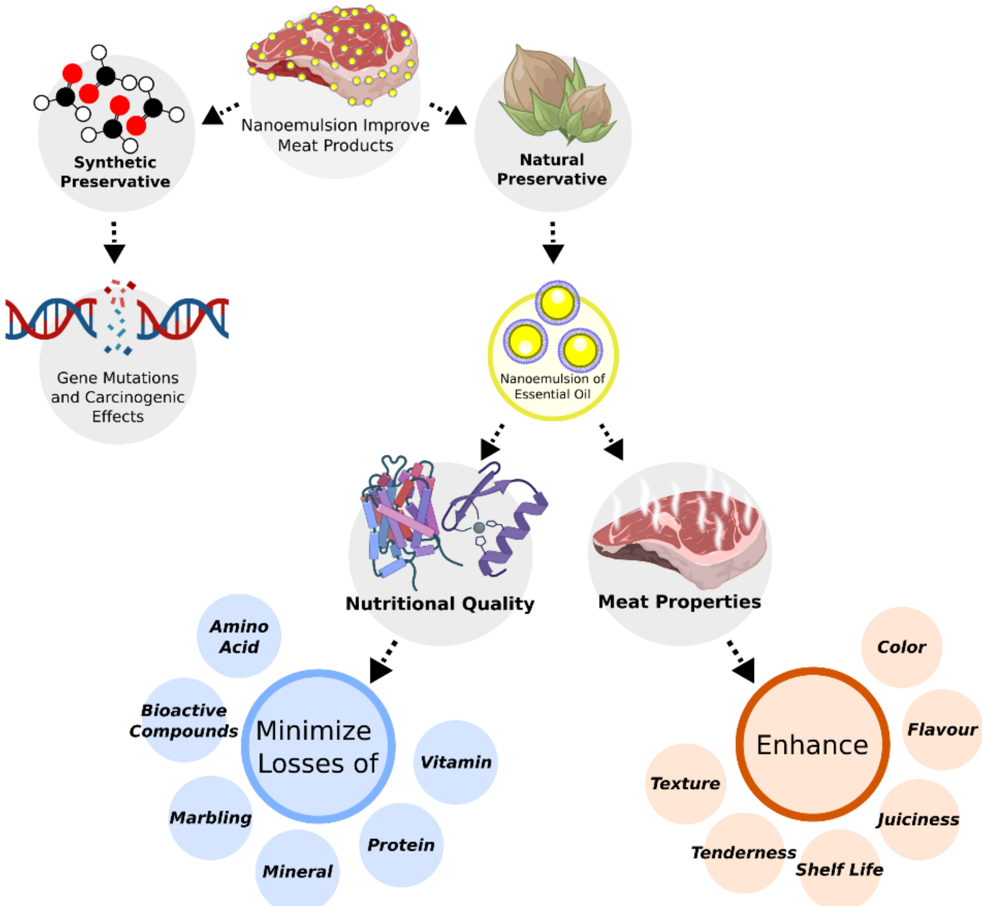

Fig. 7. Improvement mechanism of meat product affected by nanoemulsion.

The thiobarbituric acid reactive substance (TBARS) in lamb meat is reduced significantly by NEs (chitosan and Satureja) [87]. The function of NE as an antioxidant is to slow down the lipid oxidation process by limiting the availability to free radicals such as ROS to biologically active sites [50,67], absorbing energy and electrons [39], blocking the formation of ROS by binding metal ions [88], and directly eliminating ROS (mainly ascorbic acid compounds, tocopherols, flavonoids) [34]. The primary function of NE with lipophilic bioactive from an EO is to reduce oxygen exposure in meat products [14,89]. The oxygen absorption process generated by nanoparticles has been discovered to be more efficient than that caused by macroparticles; the nano-size also enhances the penetration of active substances when reacting with ROS targets [88].

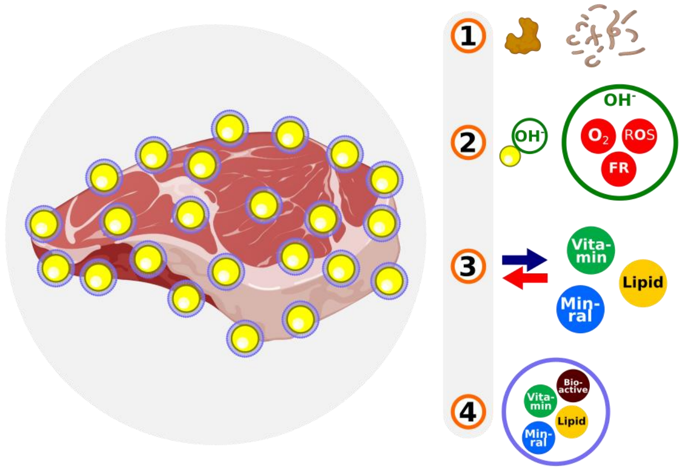

Fig. 8. Mode of action from nanoemulsion to improve the nutritional quality of meat products. Several advantages of nanoemulsion for enhanced meat products: 1. inhibit protein breakdown, 2. trap free radical, 3. prevent the nutrient transfer, and 4. add bioactive compound through encapsulated nanoemulsion.

The NE, as an enhancer, proposes to enrich meat products with specific bioactive compounds or add certain nutrients (such as lipids, minerals, and vitamins) to improve the quality of the product. In addition, fortified products have other benefits, including enhancing organoleptic criteria, such as flavor, aroma, texture, and tenderness. In other functions, NE can retain meat's nutrients such as fat, protein, minerals, and vitamins [29,88]. When the size gets smaller, the surface area gets more extensive. This process makes chemical reactions easier, like when antioxidants eliminate free radicals [90]. The effectiveness of the NE coating is also affected by its size; the expansion of the material from the NE causes the surface area to cover the meat to increase as well [88,91]. As a result, the effectiveness of the NE coating in reducing the mobility of bioactive compounds, minerals, and vitamins from inside and outside of the meat becomes more effective [52,92]. Furthermore, applying NEs in meat packaging can combat spoilage microbes, reduce lipid oxidation, and extend product shelf life [93].

FUTURE IMPLEMENTATION OF NANOEMULSION

In recent years, nanotechnology in food preservation (especially NE) has been increasingly in demand. This indicates that the application of nanotechnology in the food sector for preservation will develop rapidly in the future [94]. The application of EO in NE as a natural preservative for meat products needs further exploration regarding efficient dosage [95].

It is necessary to examine the limitations of nanoemulsion as a novel technology for preserving and enhancing meat products. Emphasis must be given to the nanoemulsion's toxicity [36]; the apparent nano-size can lead to consumer health issues [8]. The nanoscale size facilitates the nanoemulsion's absorption, particularly its penetration into cells [80]. Although there are no official findings about the relationship between the nano-size of essential oils and the activity of human cells [52], this matter must be addressed. Steps that can be taken to reduce and stop this toxicity include dosage restrictions, specialized nanoemulsion applications, the ideal nano-size design that does not promote material infiltration into cell organelles [96], and the use of health-safe stabilizers and bioactive substances [81]. Production of nanoemulsions utilizing high-energy technologies on a laboratory scale is not cost-effective for industrial use [19]. Alternative technologies, such as the low-energy approach, can serve as the primary substitute. The low-energy method requires a more significant amount of stabilizer agent than the high-energy method; this must be reconsidered, or a suitable stabilizer will be discovered to produce nanoemulsions (low-energy method) [97].

CONCLUSION

In conclusion, essential oils-based nanoemulsion has the potential to be applied as an additive in food because it has antimicrobial and antioxidant activity. However, nanoemulsion in meat products has yet to be widely used. The challenge for applying nanoemulsion in meat products is the concern about the adverse effects of its size at the nanoscale on health, such as the bioaccumulation of compounds, toxic products, and reduced excretion. Future research is expected to provide accurate dosage information so that it does not harm health. Using nanoemulsions in meat products with complex matrices is challenging in their application. Advanced research and regulation must ensure the safety of essential oil nanoemulsions application products and are necessary to build consumer confidence.

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