Innovative technologies for fruit extracts: Value-added opportunities in the meat industry

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Abstract. Consumers have concerns about the safety of synthetic antioxidants, and therefore, the use of natural antioxidants is increasing. Fruits are rich sources of various antioxidants that can be used in the meat industry as replacements for synthetic antioxidants. The naturally occurring antioxidants in fruit (e.g. polyphenols, carotenoids, vitamins) have attracted interest due to their bioactivity, to which many beneficial healthy effects are prescribed. It is well known that oxidation decreases the sensory and nutritive value of food products, whereas antioxidants added to foods can preserve the lipid components from quality deterioration. Therefore, the use of naturally extracted antioxidants from fruit could be useful to meet industry and consumers’ expectations of safe and high-quality products. Recently, innovative extraction methods have been developed in order to obtain highly valued extracts for further industrial use. In particular, non-thermal technologies showed many advantages over traditional conventional methods, and therefore, much attention is paid to optimizing these lower temperature processing parameters to obtain higher yields and higher quality extracts. Incorporation of fruit extracts consisting of various bioactive compounds in processed meat will result in value-added products with associated health benefits.

1. Potential of fruit as natural antioxidants in the meat industry

In recent years, a great deal of attention has been directed towards natural and safe food products that may offer multiple health benefits. Moreover, consumers’ considerable negative attention on the widely used synthetic antioxidants suggests that it is important to identify natural (functional) antioxidants to use in meat products [1].
Chemically synthesized antioxidant additives, such as butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), tertiary butyl hydroquinone (TBHQ), and gallates are usually added to food as antioxidants to prevent lipid peroxidation [2]. However, use of these antioxidants may lead to harmful side-effects, for example radiosensitization, increased toxicity of other chemicals, increased mutagen activity and increased risk of cancers [3, 4]. Therefore, alternative, plant-based antioxidants could have better biological and health effects in comparison to synthetic antioxidants, as the natural products exhibit better compatibility with human physiology [5].

Recent research has shown that fruits contain a wide variety of antioxidants (e.g. vitamins, polyphenols, carotenoids, chlorophylls) known for their health-promoting effects and nutritional values [6, 7]. To name a few sources, antioxidants can be extracted from plum (puree), prunes (dried plum), grape (skin, seeds, peel and pomace), berries (cakes and powder extracts), pomegranate (rind powder and juice), and most of the citrus fruits. Furthermore, agri-food waste and by-products provide a valuable source of various antioxidants. For instance, grape by-product extracts were effectively applied in the slowing down of meat discoloration and lipid oxidation [8]. When added to meat products, these molecules serve as a natural antioxidants and antimicrobial additives with the purpose of extending the quality and stability of foods [9].

The inhibitory effects of fruit extracts on meat oxidation are mainly attributed to the numerous bioactive compounds with \textit{in vitro} and \textit{in vivo} antioxidant activity. Correspondingly, a recent study highlighted the use of berry extracts, including bearberry (\textit{Arctostaphylos} sp.), blueberry (\textit{Vaccinium} sp.), blackberry (\textit{Rubus} sp.), blackcurrant (\textit{Ribes nigrum}), cranberry (\textit{Vaccinium} sp.), cloudberry (\textit{Rubus chamaemorus}), strawberry (\textit{Fragaria ananassa}), and grape berries (\textit{Vitis} sp.) for replacing/decreasing synthetic antioxidants in meat products [10]. These fruits are widely considered good sources of bioactive compounds, namely polyphenols (i.e., phenolic acids, flavonols, anthocyanins, tannins) and ascorbic acid that can act as strong antioxidants, able to decrease the damage caused by oxidative stress [11].

Additional to fruit extracts, fruit juices have also found their applications in the area of meat processing. In this regard, the addition of cornelian cherry juice as a functional additive in the production of beef burgers was found to effectively reduce lipid oxidation, and also allowed the maintenance of good sensory characteristics [12].

2. Innovative technologies for extraction of fruit antioxidants

Since liquid or dried fruit extracts are the most commonly used forms of natural antioxidants for incorporation in meat products, it is necessary to find the optimal extraction technique with respect to fruit type and targeted antioxidants [7]. The most frequently used techniques for obtaining extracts rich in antioxidants include conventional methods, due to their simplicity and wide range of applicability.

In this regard, some of the most common extraction methods from fruits using different solvent systems are based on Soxhlet, maceration, and hydrodistillation technologies. The effects of various extraction parameters in any type of extraction must be studied in order to achieve the highest yields and the highest quality extracts. In particular, the most important parameters for conventional extractions are referred to as being the solvent type, the polarity of target compounds, particle size, solid-to-solvent ratios, and extraction time [13]. However, the key disadvantages with conventional extraction techniques (compared with novel techniques) are reflected in the higher costs and environmental burden due to the use of large amounts of organic solvents, high energy consumption, extended extraction time, and higher extraction temperature, i.e., all those factors that can led to degradation of heat-sensitive antioxidants [14].

Alternative approaches to thermal processing of food started to gain importance, above all due to increased consumer demands for new methods of food manufacturing that retain the original nutritional content and overall quality of the food. Therefore, numerous new alternatives, including high pressure, ultrasound, microwave, supercritical fluid, electrotechnologies (e.g. cold plasma, pulsed
electric field, and high voltage electric discharge) have been developed in order to overcome the main drawbacks of conventional thermal techniques [15].

The basic principles of these innovative technologies for the extraction of bioactive compounds from fruits are given in Table 1. The beneficial aspects of these approaches are the elimination or reduction of organic solvents, decreased extraction time, lower operating temperatures (preventing thermal degradation), lower energy cost, high quality extracts, improved extraction yields and high product quality and purity, hence indicating their potential for energy-efficient and environmentally friendly food processing [14, 16-18]. Regardless of the extraction technique, all methods should be optimized for the best results in the economic and nutritional senses [19].

Several innovative technologies have already been applied to various industrial sectors, where the use of water and alcohol, which are well-known versatile and eco-friendly solvents, is on the rise. In particular, Pressurized Hot Water Extraction (PHWE) is gaining more attention and is recognized as the most favored environmentally friendly technology (green technology) that operates above the atmospheric boiling point of water (100°C/273 K, 0.1 MPa), but below the critical point of water (374°C/647 K, 22.1 MPa). Under these conditions, water largely changes its chemical and physical properties, which allows the dissolution of less polar compounds from fruit matrices. Hence, this technology provides the opportunity for extraction of antioxidants with various polarities that can synergistically act as additives in meat products.

Table 1. Innovative technologies for the extraction of bioactive compounds in fruits

| Article I. technique | Extraction technique | Article II. Basic principles | Article III. References |
|---------------------|----------------------|-----------------------------|------------------------|
| High Hydrostatic Pressure (HHP) | Operates at high pressures (100-1000 MPa) at 0 °C to less than 100°C for a short period. | [20-25] |
| Ultrasound assisted (UAE) | Ultrasound is a cyclic pressure wave that has a frequency of 20 kHz-10 MHz. Rapid changes of pressure in a liquid lead to the formation of small vapor-filled cavities – a phenomenon called cavitation. The production, growth, and collapse of the bubbles to form pores facilitate the extraction from the plant matrix. | [18, 26-31] |
| Microwave assisted (MAE) | Microwaves are electromagnetic radiation in the range of 300 MHz to 300 GHz. This method uses microwave energy to heat the solvent and facilitates the relocation of target compounds to the solvent. Two transport phenomena occur at the same time, namely heat and mass gradients. | [32-35] |
| Supercritical fluid (SFE) | Supercritical fluid extraction is characterized by changes in temperature and pressure (above its critical values) that transform a gas into a supercritical fluid. | [36-39] |
| Pressurized liquid (PLE) | The extraction occurs at elevated pressures (~10 MPa) and the solvent may remain in liquid state even when used at | [40-44] |
temperatures above their boiling points

Pulsed electric field (PEF) Method uses short pulses of electricity (µs to ms) under high intensity electric fields (0.1-20 kV/cm), number of pulses <100, which leads to the formation of pores (temporary or permanent) on the cell membranes, thereby improving the extraction and diffusion processes (a phenomenon called electroporation). [23, 31, 45-47]

High voltage electrical discharges (HVED) Electrotechnology that damages the cell structure and promotes the extraction of valuable cellular compounds, based on the phenomenon of electrical breakdown in water. Operates at electric pulse 40 kV/10 kA and number of pulses >100. [48-52]

3. Conclusions
In conclusion, addition of mixed (synergetic) polar/nonpolar antioxidants extracted from fruits to processed meat will result in less perishable but healthier products, due to decreased oxidation and associated health benefits. With some application of savvy food engineering, such products can be easily labeled as functional. These products are expected to aid in improving consumer health while providing economic benefits that follow from placing such high demand foods on the market.

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