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Review

Alternatives to nitrite in processed meat: Up to date

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Nitrite has been used in different meat products mainly to maintain their microbial quality, flavor, and color and to prevent lipid oxidation. Since consumer demand for organic or natural meat products has increased due to the concerns of health risk of synthetic additives, the meat industry is currently focusing on the development of nitrite alternatives. This paper reviews the potential alternatives to replace nitrite salts that are used completely or partially in the manufacturing of meat products.

Introduction

The consumption of animal products including meat and meat products has increased globally with an increase in the household income (Nam, Jo, & Lee, 2010). In parallel, the demand for safe and high quality meat and meat products has also increased with the novel concepts of all-natural and clean-label (Jayasena & Jo, 2013).

Spoilage by microbes, autolytic enzymes and lipid oxidation can cause deterioration of meat and meat products, which has considerable economic and environmental impact (Jayasena & Jo, 2013). Several thermal and non-thermal meat preservation techniques, including refrigeration, freezing, drying, and smoking, are presently being used in the meat processing industry (Sindelar & Milkowski, 2011).

Meat curing which includes the addition of salt, nitrite, and sometimes nitrate to fresh meat cuts, enables preservative effect by removing moisture and reducing the water activity of the meat (Parthasarathy & Bryan, 2012). In addition to the preservative action, particularly against *Clostridium botulinum*, the curing process imparts several other distinctive properties that are common to all cured meat products which is attributable to the sodium nitrite present in the curing mixture (Sindelar & Milkowski, 2011). These other properties include contribution to the formation of an unique color, texture, and flavor to cured meat products and protection of meat lipids from oxidation (Sindelar & Milkowski, 2011). In the modern meat processing industry, meat curing is a well-developed segment that uses advanced techniques. In addition, nitrite plays a vital role in normal human body functions (Sindelar & Milkowski, 2012).

However, over the years, great concerns have been expressed regarding the exposure of consumers to certain harmful products that may be formed in meat and meat products during and after curing. The foremost concern is that certain reaction products after curing may be carcinogenic to humans (Cassens, 1997a; Sen & Baddoo, 1997). This concern has led researchers to seek ways to reduce the risk of nitrosamine formation and alleviate potential human health concerns. One such way is the substitution of nitrite with alternative ingredients having comparable characteristics without causing any health hazards (Sindelar & Milkowski, 2011). Over the past several decades, studies have conducted to counter this difficult challenge; however, until date, these attempts remained unsuccessful in identifying an effective single replacement material possessing all the properties of nitrite (Sindelar & Milkowski, 2011). One possible approach to resolve this problem is the use of hurdle technology in meat curing; in this approach, low levels of sodium nitrite are combined with other

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compounds and/or other processing technologies. It is imperative that products treated with these secondary compounds or technologies be safe for human consumption.

This review provides an overview of the published data on the potential alternatives to completely or partially replace nitrite salt in meat and meat products.

Nitrite in processed meat

The precise discovery of meat curing may never be known, but it is generally accepted to be associated with preservation methods using salt as early as 3000 B.C. (Sindelar & Milkowski, 2011). With the invention of refrigeration and food packaging technologies, the original role of curing technology of meat and meat products gradually changed from that of preservative to that of development to diverse convenient products (Pegg, 2004).

The main functions of nitrite in cured meat include the formation of the characteristic reddish-pink color and flavor associated with cured meats in addition to serving as an effective antioxidant and antimicrobial agent alone or in combination with other ingredients (Pegg, 2004; Sindelar & Milkowski, 2011). Nitrate can be reduced to nitrite to perform the same function (Sindelar & Milkowski, 2011). Therefore, naturally present or artificially supplemented nitrate in brine solutions should be converted to nitrite by the meat microflora or by the addition of bacteria possessing nitrate reductase activity (Sebranek & Bacus, 2007).

Cured color

Nitrite – the true curing ingredient – is considered a multifunctional food additive that forms nitric oxide during the curing process. Formation of nitric oxide from the intermediates is facilitated by reductants such as ascorbate. It has been recognized that nitrous acid (HNO_2) is formed from nitrite under acidic conditions such as that in postmortem muscles (Pegg & Shahidi, 2000). According to Honikel (2004), dinitrogen trioxide (N_2O_3) is formed from nitrous acid and will subsequently form nitric oxide or will react with other substrates in meat.

Nitric oxide will react with iron of both myoglobin (Fe^{+2}) and metmyoglobin (Fe^{+3}) to form cured color (Pegg & Shahidi, 2000). Comminuted meat quickly turns into brown color with the addition of nitrite due to metmyoglobin formation since nitrite acts as a strong heme pigment oxidant and is, in turn, reduced to nitric oxide. Nitric oxide reacts with metmyoglobin and subsequent reduction reactions convert the oxidized heme to reduced nitric oxide myoglobin for typical cured color subjected to cooking (Pegg & Shahidi, 2000).

Nitric oxide reaction with myoglobin forms the nitrosylmyoglobin complex, which outline the basis for unique cured meat color (Parthasarathy & Bryan, 2012). Nitrosylmyoglobin is bright red in color (Parthasarathy & Bryan, 2012) and is an extremely unstable compound. During thermal processing, it is converted to a stable, attractive reddish-pink compound – nitrosohemochrome – because of the denaturation of the protein moiety of the myoglobin pigment (Parthasarathy & Bryan, 2012).

Although a minute amount of nitrite (2–14 ppm) is sufficient to develop a cured color in the meat, a higher amount is necessary to avoid non-uniform curing and to preserve the developed reddish-pink color throughout the meat's shelf-life (Sebranek & Bacus, 2007; Sindelar & Milkowski, 2011). As the residual nitrite levels in cured meat products gradually decline due to oxidation- and light-induced fading over the storage period (Cassens, 1997b), a residual nitrite level of 10–15 ppm is generally recommended as a reservoir primarily for the regeneration of cured meat color (Sindelar & Milkowski, 2011).

Cured flavor

The characteristic flavor of cured meat products can also be attributed to the chemical reactions of nitrite and its associated reactions as described above. Sensory evaluation revealed that a low level of nitrite (50 ppm) was sufficient to develop the unique flavor differences between cured and uncured meat. However, the principle mechanism and the compounds responsible for this unique flavor remain unknown (Sindelar & Milkowski, 2011). Shahidi (1998) proposed that this characteristic feature could be due to the nitrite-related suppression of oxidation products, which manipulates the development of rancid-flavor compounds. Sindelar and Milkowski (2011) suggested that cured meat flavor could be the result of a combination of nitrite-related flavors and aroma. Hydrocarbons, ketones, alcohols, phenols, esters, furans, pyrazines, aldehydes, and other nitrogen containing compounds, and increased carboxylic acids, sulfur, and nitrite/nitrate containing compounds have been found in cured meat compared to uncured meat (Ramarathnam, Rubin, & Diosady, 1993). Alcohols and phenols undergo nitrosation reactions and could impact volatile compounds as well. Increases in sulfur compounds could be attributed to S-nitrosothiol formation and reduction to disulfide bonds during meat curing (Ramarathnam *et al.*, 1993).

Antioxidant effect

Another remarkable property of nitrite is its ability to retard the development of rancidity during storage and the subsequent warmed-over flavors developed upon heating of meat and meat products (Parthasarathy & Bryan, 2012; Pegg & Shahidi, 2000). The antioxidant activity of nitrite is attributed to the potential of nitric oxide to bind to and stabilize heme iron of meat pigments during the curing process. Oxygen and other reactive oxygen species rapidly react with, and are sequestered by nitric oxide (Ford & Lorkovic, 2002). Nitric oxide, as a free radical, can also terminate lipid autooxidation (Pegg & Shahidi, 2000). In addition, it binds free irons and stabilizes heme iron (Bergamaschi & Pizza, 2011) which can reduce lipid oxidation by limiting prooxidant activity of iron. This lowers the amount of free iron released during cooking