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A comprehensive approach to formulation of seaweed-enriched meat products: From technological development to assessment of healthy properties

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ABSTRACT

Meat consumption is influenced by various kinds of factors, among them health implications. Different strategies can be effective in developing meat-based functional foods. These basically entail reducing the presence of compounds with negative health implications and enhancing the presence of beneficial compounds. This article reviews a comprehensive model for the development of meat-based functional foods based on a presentation of the research achieved in terms of the design and development of qualitatively and quantitatively modified meat products (frankfurters, patties and restructured steaks). These were reformulated to incorporate nutrients associated with three different seaweeds (wakame–*Undaria pinnatifida*; nori–*Porphyra umbilicalis;* and sea spaghetti–*Himanthalia elongata*) as sources of bioactive substances, while simultaneously reducing sodium and fat and improving fatty acid profiles. Those seaweeds were chosen, because in terms of composition and health implications, abundance on Spanish coasts, relatively widespread consumption, and suitability in terms of flavour and colour they are better suited than others for use as ingredients in new products. It also discusses the consequences of the use of this type of meat-based functional foods (combination of pork meat and 5% of each seaweed with or without hypercholesterolaemic agent included in the diets) on growing animals (Wistar male rats), and their effects on different aspects of lipoprotein metabolism, oxidative stress and liver structure. This article, then, reports a comprehensive approach to the production of seaweed-enriched meat products, considering aspects of technological development aimed at achieving the functional effect.

1. Introduction

Meat and meat products are essential components of the diet which supply valuable amounts of the nutrients (protein, fatty acids, vitamins, minerals and other bioactive compounds) needed for a healthy, balanced diet. However, like any other food they also contain constituents which, when consumed in inappropriate quantities, may enhance the risk of some of the major degenerative and chronic diseases (ischaemic heart disease, cancer, etc.). The growing understanding of the relationship between diet and health, combined with consumer interest in healthy, nutritious foods with additional health promoting functions, is driving the development of functional foods, which presents a challenge for the future of the meat industry. Meat-based functional foods offer an interesting opportunity to address consumer needs and to update recommendations regarding nutritional and dietary goals (Jimenez-Colmenero, 2007a). Consumers' unwillingness to change their dietary habits suggests that there is a considerable potential market for frequently-consumed foods such as meats that have been designed to produce health benefits. Also, owing to the broad range of available presentations and the possibility of modifying their composition using non-meat ingredients, high consumer acceptability, etc., meat products are an excellent vehicle for delivery of bioactive compounds in the diet while complying more closely with dietary recommendations.

In general, the design and development of meat-based functional foods basically seeks to reduce the presence of compounds with negative health implications and increase the presence of beneficial compounds. Approaches based on animal production practices (genetic and nutritional) and meat transformation systems (reformulation process) are the most promising strategies for introducing qualitative and/or quantitative modifications in meat and meat derivatives (Arhiara, 2006; Jimenez-Colmenero, 2007b; Jimenez-Colmenero, Carballo, & Cofrades, 2001). Reformulation has been widely used to remove, reduce, increase, add and/or replace different bioactive components and obtain specific meat-based designs with certain attributes that confer health-promoting properties (Olmedilla-Alonso, Jimenez-Colmenero, & Sánchez-Muniz, 2013). Healthy meat products have

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been prepared using a variety of ingredients, chiefly of plant origin (soy, walnut, oils, oats, rice, wheat, carrot, etc.) to improve fat content, incorporate antioxidants, prebiotics and dietary fibre, enrich with minerals, etc. (Olmedilla-Alonso et al., 2013). In this connection, marine plants such as seaweeds offer interesting new avenues for exploration. Seaweeds are commonly consumed in Asia and are gradually becoming accepted in Western countries. Although with wide variations depending on species, habitat, state of maturity, etc., seaweeds contain substantial amounts of different bioactive compounds (dietary fibre, high-quality protein, abundant minerals, vitamins, large proportions of unsaturated essential fatty acids, polyphenols, carotenoids, tocopherols, etc.) with potential benefits for health (Bocanegra, Bastida, Benedi, Ródenas, & Sánchez-Muniz, 2009; Fleurence, 1999; Plaza et al., 2010; Ruperez, 2002). In addition, seaweeds possess useful technological properties, largely associated with the dietary fibre they contain. Seaweeds are, then, an ingredient with considerable potential for use in the development of functional foods.

In view of the interest noted above and the scant research in this direction to date (Cofrades, Lopez-Lopez, & Jimenez Colmenero, 2011; Cofrades, Serdaroğlu, & Jimenez-Colmenero, 2013), we set up a multidisciplinary research group to undertake a series of studies for the purpose of i) designing and developing functional meat products with added seaweed, and ii) assessing (in laboratory animals) the effects of sustained consumption on intermediate markers of peroxidative and lipoproteic risks of particular importance in degenerative diseases (e.g. cardiovascular diseases-CVDs) and of apoptotic induction in hepatocytes. This article reports a comprehensive approach to the production of seaweed-enriched meat products, considering aspects related to technological development, to achieve functional effects.

2. Seaweeds as sources of nutrients and bioactive ingredients

Although seaweed consumption is not as common in Europe as in Asia, seaweeds have gained popularity for human consumption as they may be a good natural source of biologically active compounds. Seaweeds contain several bioactive substances, which is why they are gaining a reputation as the new "superfood" (Hotchkiss & Trius, 2010). Nowadays, seaweeds are very attractive to consumers and the food industry due to their low calorie content and high content of key nutrients such as carbohydrates, vitamins, minerals and dietary fibre. Also, they are a rich source of health-promoting compounds capable of acting on a wide spectrum of disorders and/or diseases. Several investigations have indicated that the regular consumption of macroalgae can help prolong life expectancy and reduce the risk of CVDs (Shimazu et al., 2007).

Subject to different factors, seaweeds can contain high concentrations of protein (as much as 24%, given as gram of protein per 100 g of alga) and low percentages of lipids (about 1% in all cases) (Sánchez-Machado, Lopez-Cervantes, Lopez-Hernandez, & Paseiro-Losada, 2004). Interestingly, although these algae contained low lipid levels, they possessed high levels of polyunsaturated fatty acids (PUFAs). Thus, seaweed can be particularly rich in the long chain (LC) n-3 PUFAs, eicosapentaenoic acid and α-linolenic acid, as well as the n-6 fatty acids, linoleic acid, along with relatively high levels of oleic and palmitic acids. The n-3 fatty acids have for instance, demonstrated their effect on the reduction of risk of coronary diseases (Bocanegra et al., 2009; Sánchez-Muniz, Bocanegra de Juana, Bastida, & Benedí, 2013).

Seaweeds are a source of vitamins, mainly from group B. For instance, they contain vitamin B_{12}, which is particularly recommended in the treatment of the effects of ageing, of chronic fatigue syndrome and anaemia. Vitamin B_{12} is found in red macroalgae (e.g., *Porphyra tenera*) and in certain green seaweeds (Burtin, 2003; Nisizawa, 2006). Interestingly, red and brown algae can also contain high levels of folic acid and folate derivatives including 5-methyl-tetrahydro-folate, 5-formyl-tetrahydro-folate and tetrahydro-folate. For instance, concentrations as high as 150 μg of total folic acid per 100 g of dry seaweed have been detected in *Undaria pinnatifida* (Plaza, Cifuentes, & Ibáñez, 2008).

Algae generally present a wide variety and high levels of minerals (8–40%) (Bocanegra et al., 2009), with higher concentrations than edible terrestrial plants and animal products. *U. pinnatifida* could be used as a food supplement to help meet the recommended daily intake of some minerals, macro elements (Na, K, Ca, Mg, ranging from 8.1 to 17.9 mg/100 g) and trace elements (Fe, Zn, Mn, Cu ranging from 5.1 to 15.2 mg/100 g) (Ruperez, 2002). Additionally, seaweeds are one of the most important vegetable sources of calcium. Calcium content may be as high as 7% of dry weight in macroalgae and up to 25–34% in the chalky seaweed lithothamnion (Burtin, 2003). Thus, seaweed consumption may also be useful to those at risk of calcium deficiency, namely expectant mothers, adolescents and the elderly. However, although some minerals are necessary for health, others are harmful (e.g. heavy metals such as As, Cd, Cu, Hg and Pb), so that their presence (high concentrations) in a seaweed could limit its use (Ruperez, 2002).

Among various chemical compounds isolated from algae, polysaccharides are the most well-established and have been the subject of a number of studies due to their extensive bioactivities (Ahmadi, Zorofchian Moghadamtousi, Abubakar, & Zandi, 2015). Typical polysaccharides occurring in red algae varieties are floridean starch, cellulose, xylan and mannan, and the water soluble fibre fraction is composed of sulphur containing galactans such as agar and carrageenan. Major soluble fibres include alginate from brown macroalgae and carrageenan and agar from red macroalgae, which overall can represent up to half of a seaweed's dried weight. This is important in that human consumption of fibre-enriched products from macroalgae has been shown to promote health benefits, including the prevention of colon cancer, type II diabetes, obesity and CVDs. Standard polysaccharides in brown algae are fucoidan, laminaran, cellulose, alginates and mannitol, while the fibres are mainly cellulose and insoluble alginates. Most of these polysaccharides are not digestible by the human gastrointestinal tract and can therefore be regarded as dietary fibres. Fucoidans are a complex series of sulphated polysaccharides commonly found in the cell walls of brown macroalgae. Fucoidans are reported to possess numerous physiological and biological properties, including anticoagulant, antiviral, antithrombotic, hypotensive, antitumor and antioxidant activities, as well as having an effect on the inflammatory and immune systems (Bocanegra et al., 2009; de Jesus Raposo, de Morais, & de Morais, 2015; Lordan, Ross, & Stanton, 2011). Ikeda et al. (2003) reported that the possible preventive effect of *U. pinnatifida* on cerebrovascular diseases could be partially due to its content in fucoxanthin as an antioxidant fibre, which could protect against ischaemic neuronal cells death. These authors investigated the effect of fibre from this alga on risk factors for cardiovascular diseases (hypertension and hypercholesterolaemia). Another sulphated polysaccharide, porphyran, one of the main components of the red macroalga *Porphyra*, has reported uses as a gelling agent, a nutritional supplement and as an antioxidant (Jimenez-Escrig & Sánchez-Muniz, 2000).

Over the years, a number of biologically active peptides derived from marine algae have been identified. Bioactive peptides usually contain 3–20 amino acid residues and their activities are based on their amino acid composition and sequence (Kim & Wijesekara, 2010). These peptides are reported to be involved in various biological functions such as antihypertensive, immunomodulatory, antithrombotic, antioxidant, anticancer and antimicrobial activities, in addition to nutrient utilization (Kim & Wijesekara, 2010). In particular, peptides derived from the brown seaweed *U. pinnatifida* (wakame) and the red seaweed *Porphyra yezoensis* have been shown to be potent angiotensin-I-converting enzyme inhibitors (Suetsuna, Maekawa, & Chen, 2004; Harnedy & Fitzgerald, 2011). Some bioactive peptides have demonstrated multifunctional activities based on their structure and other factors including hydrophobicity, charge or microelement binding properties. In particular phycobiliproteins (protein-pigment complexes) are one of the most important groups of proteins from algae. Several studies have shown

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