Meat Science 120 (2016) 54–59

Contents lists available at ScienceDirect

Meat Science

journal homepage: www.elsevier.com/locate/meatsci

New insights into meat by-product utilization

Fidel Toldrá [a,*], Leticia Mora [a], Milagro Reig [b]

[a] Instituto de Agroquímica y Tecnología de Alimentos (CSIC), Avenue Agustín Escardino 7, 46980 Paterna, (Valencia), Spain
[b] Instituto de Ingeniería de Alimentos para el Desarrollo, Universidad Politécnica de Valencia, Camino de Vera s/n, 46022 Valencia, Spain

ARTICLE INFO

Article history:
Received 26 January 2016
Received in revised form 13 April 2016
Accepted 18 April 2016
Available online 19 April 2016

Keywords:
Animal by-products
Meat by-products
Offal
Skin
Bones
Trimmings
Bioactive peptides
Hydrolyzed proteins
Biodiesel

ABSTRACT

Meat industry generates large volumes of by-products like blood, bones, meat trimmings, skin, fatty tissues, horns, hoofs, feet, skull and viscera among others that are costly to be treated and disposed ecologically. These costs can be balanced through innovation to generate added value products that increase its profitability. Rendering results in feed ingredients for livestock, poultry and aquaculture as well as for pet foods. Energy valorization can be obtained through the thermochemical processing of meat and bone meal or the use of waste animal fats for the production of biodiesel. More recently, new applications have been reported like the production of polyhydroxyalkanoates as alternative to plastics produced from petroleum. Other interesting valorization strategies are based on the hydrolysis of by-products to obtain added value products like bioactive peptides with relevant physiological effects as antihypertensive, antioxidant, antidiabetic, antimicrobial, etc. with promising applications in the food, pharmaceutical and cosmetics industry. This paper reports and discusses the latest developments and trends in the use and valorisation of meat industry by-products.

1. Introduction

Meat industry generates large volumes of by-products like blood, bones, meat trimmings, skin, fatty tissues, horns, hoofs, feet, skull and viscera among others that are costly to be treated and disposed ecologically (Ryder, Ha, El-Din Bekhit, & Carne, 2015). These costs can be balanced through innovation to generate added value products that increase its profitability. On the other hand, unappropriated treatment or handling of such by-products raised relevant crisis in the past such as the spread of the spongiform encephalopathies. The European Commission published the Regulation (EC) 1069/2009 laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) 1774/2002. Later, the European Commission published the Regulation (EC) 142/2011 that was implementing the Regulation 1069/2009. Rules were also provided by the Food and Drug Administration (FDA) in 2004 to prevent the establishment and spread of bovine spongiform encephalopathy (BSE) in the United States, including a prohibition on the use of high-risk, cattle-derived materials that can carry the BSE agent which are defined as specified risk material. This means that adequate disposal of by-products may increase the cost to processors and makes necessary to produce new substances or products capable to cover the disposal costs (Toldrá, Aristoy, Mora, & Reig, 2012).

It must be taken into account that certain meat by-products can be considered as foods of interest depending on the country and local traditions while in other places they can be considered as inedible foods (Ockerman & Basu, 2004a). In fact, some by-products with high nutritional value like the blood, liver, lung, heart, kidney, brains, spleen and tripe constitute part of the diet and culinary recipes in many countries worldwide (Nollet & Toldrá, 2011). Of course, the nutritional composition depends on each particular type of by-product and the animal species from which they are obtained (Honikel, 2011). Other by-products like lard may be used for cooking.

Meat by-products may constitute a valuable resource if handled properly to produce added value substances or products (Zhang, Xiao, Samaraweera, Lee, & Ahn, 2010, Toldrá & Reig, 2011). Efficient use of by-products may arise up to 11.4% and 7.5% of the gross income of beef and pork (Jayathilakan, Sultana, Radhakrishna, & Bawa, 2012). There is a large variety of meat by-products but, in general, most of them contain good amounts of nutrients like essential amino acids, minerals and vitamins (Aristoy & Toldrá, 2011; Honikel, 2011; Kim, 2011), constituting good valorization opportunity for the meat industry (Valta et al., 2015). There are numerous applications based on new or improved technologies for processing meat by-products like edible food ingredients for the food, feed and pet food industry (see Fig. 1). Meat by-products can be considered as raw materials for the generation of biomolecules of interest like protein hydrolysates with relevant bioactivities or enzymes (Lasekan, Abu Bakar, & Hashim, 2013), extracts with functional properties (Chernukha, Fedulovaa, & Kotenkovaa,

* Corresponding author.
E-mail address: ftoldra@iata.csic.es (F. Toldrá).

http://dx.doi.org/10.1016/j.meatsci.2016.04.021

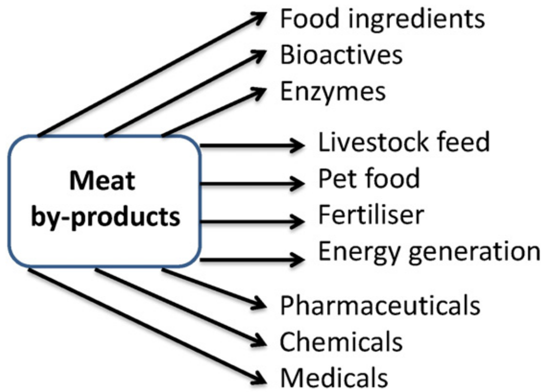

Fig. 1. Flow diagram of main routes of applications for meat by-products.

2015) or bioactive peptides (Mora, Reig, & Toldrá, 2014; Martínez-Alvarez, Chamorro, & Brenes, 2015).

Other applications are addressed towards inedible products like fertilizers, substances of interest for the chemical or pharmaceutical industry or energy generation (see Fig. 1).

Energy generation is an active area mainly focused on the biodiesel production from waste animal fats (Banković-Ilić, Stojković, Stamenković, Veljkovic, & Hung, 2014; Adewale, Dumont, & Ngadi, 2016) or even a second generation of bioderived diesel fuel, also known as bio gas oil (Baladincz & Hancsók, 2015).

This manuscript reports and discusses the latest developments and trends in the use and valorization of meat industry by-products.

2. Food applications

2.1. Applications as functional ingredients

Bioactive peptides are sequences usually between 2 and 20 amino acids that exert a biological function in one or several of the physiological systems in human being. In this sense, hypocholesterolemic, antioxidant and antithrombotic peptides have been described to modulate the cardiovascular system whereas mineral binding and immunomodulatory peptides act in gastrointestinal and immune systems, respectively. Some groups of peptides are able to participate in multiple system reactions. Thus, opioid agonist and antagonists can act on nervous, gastrointestinal, and immune systems, whereas antimicrobial peptides can modulate gastrointestinal and immune systems (Lafarga & Hayes, 2014).

Bioactive peptides need to be liberated from their origin protein in order to exert the biological function as they are inactive within the parent protein (Vercruysse, Van Camp, & Smagghe, 2005). Some bioactive peptides are released during food processing either in fermentation or curing stages, whereas others are generated during gastrointestinal digestion. The main problem of naturally generated peptides is the difficulty in controlling the hydrolysis conditions because many endogenous enzymes are acting at the same time and a wide profile of peptides showing different sizes and characteristics is generated (Mora et al., 2015). For this reason, the digestion of protein extracts under controlled hydrolysis conditions using known enzymes such as alcalase, pepsin, thermolysin, and trypsin, allows the control of the generated bioactive peptides as well as the obtention of more homogeneous batches.

The use of by-products as a source of bioactive peptides has been extensively studied during the last years. In this sense, the blood and collagen, very important by-products from slaughterhouses and meat industry, have been the most assayed (Ryder, El-Din Bekhit, McConnell, & Carne, 2016).

Blood is a rich source of proteins where hemoglobin, an iron-containing protein, is the most abundant complex (Ofori & Hsieh, 2014). It is obtained all around the world and even though it is used as food ingredient in Europe, Asia, and Africa, its production is more copious than needed. Its value as a source of bioactive peptides has been studied in both the cellular fraction (hemoglobin cells) and the plasma fraction, and their hydrolysates have been described to exert antimicrobial, antioxidant, ACE-inhibitory, and opioid activities (Chang, Wu, & Chiang, 2007). However, antimicrobial peptides derived from hemoglobin hydrolysates have been the most studied (Nedjar-Arroume et al., 2006; Adje, Balti, Kouach, Dhulster and Guillochon, 2011b; Nedjar-Arroume et al., 2008). Bovine hemoglobin hydrolysate obtained with pepsin in the presence of 30% ethanol resulted in the novel identification of 67–106, 73–105, 99–105, and 100–105 fragments of the α-chain of bovine hemoglobin. These peptides exert an antibacterial activity against *Kocuria luteus A270*, *Listeria innocua*, *Escherichia coli*, and *Staphylococcus aureus* with a MIC between 187.1 and 35.2 μM as well as an ACE inhibitory activity with IC_{50} values from 42.55 to 1095 μM (Adje, Balti, Kouach, Guillochon, & Nedjar-Arroume, 2011a). On the other hand, Hu et al. (2011) identified the peptide VNFKLLSHSLLVTLASHL from α-chain bovine hemoglobin showing antimicrobial activity against *E. coli*, *S. aureus*, and *Candida albicans* when assessed. The minimal peptide sequences necessary to show antimicrobial activity after a pepsin enzyme digestion of α- and β-chain hemoglobin proteins have been described to be KYR and RYH, respectively, and were studied against *E. coli*, *Salmonella enteritidis*, *L. innocua*, *Micrococcus luteus*, and *S. aureus* (Catiau et al., 2011a; Catiau et al., 2011b). The sequences obtained from blood protein hydrolysates in recent years are shown as Table 1.

The generation of bioactive peptides depends to a high extent on the enzymes and substrate used in the hydrolysis. In fact, the hydrolysis degree determines the extent of hydrolysis whereas the digestion conditions (temperature, pH, and time) are very important to obtain the bioactive peptides. On the other hand, peptide size and amino acid sequences are crucial for the bioactive potential of the peptides (Yu et al., 2006). As an example, antimicrobial peptides have been shown to be mostly hydrophobic as higher hydrophobicity is necessary in the affinity with the outer membrane of microbials. In fact, there is an interaction with negatively charged membrane phospholipids by tyrosine residues together with arginine and lysine which can act as peptide anchors in membranes (Lopes, Fedorov, & Castanho, 2005). ACE-inhibitory peptides, also well-studied in hemoglobin hydrolysates, have been described to contain proline, lysine or aromatic residues. In fact, ACE binding is influenced by a proline residue at any of the three last positions of the C-terminal site. Antimicrobial and ACE-inhibitory peptides derived from bovine and porcine hemoglobin and plasma have been described in Table 1. Some opioid peptides with potential to have an effect on nervous and gastrointestinal systems have also been described from animal blood sources (Zhao, Garreau, Sanier, & Piot, 1997; Zhao, Sannier, Garreau, Guillochon, & Piot, 1994; Kapel et al., 2003; Froidevaux, Vanhoute, Lecouturier, Dhulster, & Guillochon, 2008). However, there is a lack of studies about the antioxidant capability of hemoglobin-derived peptides.

Collagen is the most abundant protein in many by-products obtained from meat industry. In fact, it is the main constituent in skin, hide, bones, and cartilages. The nutritional value of collagen is very low because it lacks essential amino acids but, on the other hand, collagen is very useful as a source of bioactive peptides (Saiga et al., 2008, Herregods et al., 2011). Despite many recent studies have been focused on the bioactive properties of collagen hydrolysates, most of the published studies have been focused on fisheries by-products. In collagen hydrolysates, ACE-inhibitory and antioxidant activities resulted to be the most relevant when enzymes such as alcalase, trypsin, chymotrypsin, neutrase, flavourzyme, pepsin, bromelain and papain were used (Saiga et al., 2008; Gómez-Guillén, Giménez, López-Caballero, & Montero, 2011; Di Bernardini et al., 2012). In this sense, Herregods et al. (2011) reported that thermolysin hydrolysate showed the highest in vitro ACE inhibitory activity as well as an important in vivo antihypertensive effect in spontaneously hypertensive rats. Recently, a MALDI-