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Review Article

Meat and meat byproducts derived bio-active peptides and their importance on human health

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Abstract

Meat and meat byproducts are a rich source of bioactive peptides, which are small protein fragments that possess various biological activities. These peptides are released during digestion or can be obtained by enzymatic hydrolysis of meat proteins. Various researches demonstrated that bioactive peptides derived from the above sources have potential health benefits, including antihypertensive, antioxidant, anti-inflammatory, anti-cancer and antimicrobial activities. These peptides can also improve immune function and aid in the prevention and treatment of various chronic diseases, such as cardiovascular disease, diabetes, and obesity. This paper aims to review the current literature on meat and its by-products-derived bioactive peptides and their importance on human health, highlighting their potential applications as functional food ingredients and nutraceuticals.

Keywords: Bioactive peptides, Enzymatic hydrolysis, Human health, Meat byproducts, Nutraceuticals

Highlights

- Meat and its byproducts derived bioactive peptide sequence has several functional and physiological effects on human health.
- Bioactive peptides exhibit a wide range of physiological functions.
- Bioactive peptides have potential applications as functional food ingredients and nutraceuticals.
- Bioactive peptide generation from slaughterhouse waste can reduce environmental pollution.

INTRODUCTION

Animal-based products are regarded as valuable sources of proteins, vitamins, minerals, fibers and antioxidants for humans. Non-vegetarian population around the world prefers meat and fish for their protein intake. Additionally, the proteins found in meat and fish have the potential to serve as a significant source of bioactive peptides for human health. Meat is derived from both domestic and wild animals, including mammals such as cattle, sheep, goats, pigs, buffaloes, camels, and birds such as chicken, duck and goose (Xing *et al.*, 2021). Due to the large number of proteins found in meat with high biological value, it is an excellent source of essential amino acids (Stadnik and Keska, 2015).

The concept of food-derived bioactive peptides was first introduced in 1950 by Mellander, who suggested that casein-derived phosphorylated peptides improved bone calcification in babies with rachitic disease (Mellander, 1950). Recently, researchers have discovered that meat and its byproducts are a rich source of bioactive peptides, including protein-derived peptides, creatine, carnosine, glutathione, L-carnitine, conjugated linoleic acid, and taurine, as well as peptides found in protein hydrolysates (Liu *et al.*, 2016). Unlike proteins, bioactive peptides are short chains of 2-20 amino acids with various nutritional and physiological effects on the human body (Rezaharsamto and Subroto, 2019). These peptides are initially inactive within the parent protein sequence and become active after proteolytic digestion. Methods used for proteolytic digestion include hydrolysis using plant and bacterial proteases, digestive enzymes, and microbial fermentation processes (Ryan *et al.*, 2011). There are two types of bioactive peptides: exogenous peptides, which are artificially produced by enzyme hydrolysis or synthetic synthesis, and endogenous peptides, which are spontaneously released from the

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host protein through food aging or gastrointestinal digestion (Bechaux *et al.*, 2019). Exogenous peptides have the same biological effects as endogenous peptides and can be delivered to people. The amino acid order and structure of the peptide chain, as well as its weight, length, N- and C-terminal characteristics, charge, and spatial organization, affect the physiological activity of bioactive peptides (Xing *et al.*, 2021). To understand the physiological regulating function of bioactive peptides in the human body, the peptide sequence must first be analyzed.

In meat industry, different activities (slaughtering, cutting, processing, etc.) generate numbers of byproducts viz. blood, bone, fat, red and white offal, leather, etc. (Bechaux *et al.*, 2019). The generation of bioactive peptides would vary according to the species, breeds, and gender of meat resources. Even within the same breed, the bioactivities in the organs vary depending on the metabolic process. Additionally, it is believed that byproducts of meat processing are an excellent source of bioactive peptides, particularly blood and bones, which may be exploited to create functional ingredients for the food business (Toldrá *et al.*, 2018). Industries nowadays are working hard to turn wastes and byproducts into sources of both edible and non-edible items, creating lucrative new products and functional components with a considerable added-value and/or a great economic potential. In this recent era, researchers are trying to utilize these byproducts as an edible source by the production of protein hydrolysates, which can be used as emulsifiers, flavor enhancers, water-binding capacity enhancers and as an excellent source of nutrients like essential amino acids, minerals and vitamins as well as a good source for functional food ingredients like bioactive peptide (Mora *et al.*, 2014). This makes the possibility of using these leftovers as a cheap raw material for creating bioactive peptides appealing (Lafarga and Hayes, 2014).

Bioactive peptides derived from meat and its byproducts have been shown to have various physiological functions, such as antithrombotic, anticancerogenic, antioxidant, antihypertensive, antimicrobial, and immunomodulatory effects, as well as positive effects on digestion and blood circulation (Kang *et al.*, 2019).

Meat industry derived bioactive peptides or muscles derived bioactive peptide

Muscle proteins in meat can be classified into three categories based on their solubility: myofibrillar, sarcoplasmic and stromal. These categories make up approximately 55%, 30% and 15%, respectively, depending on the species and carcass portions (Xiong, 2018). The characteristics of each species' meat vary, including protein content, digestibility, and nutritional value. Skeletal muscle proteins of cattle, pigs, chickens, and sheep differ in their isoelectric point, molecular weight, and peptide content following meat digestion (Martini *et al.*, 2019).

However, not all peptides released from meat protein chains are biologically active. The biological activity of some peptide sequences liberated from parent proteins has functional or physiological effects on human health (Rezaharsamto and Subroto, 2019). Meat byproducts can be utilized to create functional food ingredients, including protein hydrolysates that serve as emulsifiers, flavour enhancers, and water-bonding capacity enhancers. They are also a good source of essential amino acids, minerals, vitamins, and bioactive peptides (Mora *et al.*, 2014).

The production of bioactive peptides from meat and its byproducts offers a wide range of potential applications for improving human health. Fig. 1 displays the major sources of animal-derived bioactive peptides.

Although animal protein beef, in particular, is an

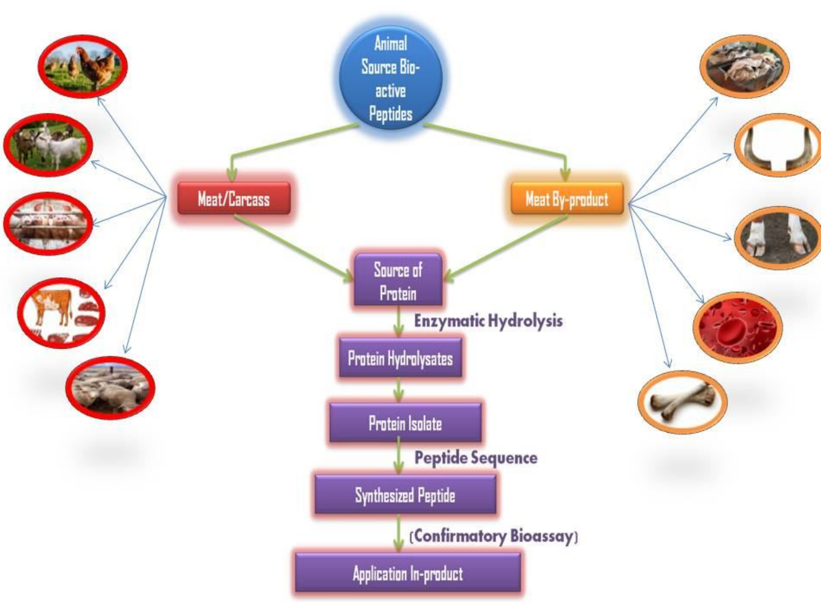

Fig. 1. Major sources of animal-derived bioactive peptides (Adapted from: Arihara, 2006)

excellent source of high-quality dietary proteins for humans due to its amino acid composition and bioactive components. The bioactive peptides in beef meat are influenced by its fiber composition and muscle activity (Ribas-Agustí *et al.*, 2019). Recent studies using LC-MS/MS chromatography have identified approximately 452 peptides in the semimembranosus muscle of beef, out of which 62 peptide sequences have shown greater bioactive potentiality with a score of > 0.5 (Keska *et al.*, 2019). The peptide sequences and angiotensin-converting enzyme (ACE) inhibitory effect of these bioactive peptides were determined using thermolysin and proteinase A (Jang and Lee, 2005). In another study, the bioactive peptides in fermented beef were extracted, and the efficacy of ACE inhibition was further tested using various protein hydrolyzate fractions. The hexapeptide VLAGYK has been found to have a significant ACE inhibitory effect, among others (Xing *et al.*, 2021).

The level of peptides in chicken meat is influenced by factors such as the type of flesh or portion of the carcass, breed of chicken, and cooking methods used. Carnitine, carnosine, betaine, and anserine are some of the bioactive peptides found in chicken meat. Carnosine and anserine are known to prevent oxidation, maintain intracellular pH, and carry out neurotransmitter functions (Rezaharsamto and Subroto, 2019). Chicken breasts have 2-3 times more carnosine and anserine than leg meat. Antihypertensive, antioxidant and antibacterial properties have been found in bioactive peptides from chicken muscle (Zhang *et al.*, 2010b). For example, an octapeptide derived from chicken collagen has been shown to have ACE inhibitory activity in hypertensive rat trials. Chicken meat-derived bioactive peptides such as CATH3 and β-defensin 4 have also demonstrated antibacterial effects against *E. coli* (Mukhopadhyay *et al.*, 2010). Antioxidant activity has also been observed in chicken muscle, and α-chymotrypsin and flavorzyme have been used to produce protein hydrolysates with antioxidant activity (Centenaro *et al.*, 2014). The same antioxidant activity has also been observed in duck muscle.

Pork is a source of various physiologically effective bioactive peptides that can be derived from different parts of the animal, including myofibrillar protein, sarcoplasmic protein, bone, blood, collagen, and dry-cured ham. These bioactive peptides have been shown to possess antioxidative, anti-inflammatory, and antihypertensive properties (Borrajo *et al.*, 2019). To obtain these peptides, raw pork protein is hydrolyzed with proteolytic enzymes, and the resulting peptide fragments are analyzed for their potential health benefits (Xing *et al.,* 2021). Studies have identified specific bioactive peptides derived from pork that possess antihypertensive activity. For example, swine flesh digestion led to the discovery of peptide sequences Pro-Thr-Pro-Val-Pro and Lys-Ala-Pro-Val-Ala from titin, as well as Arg-Pro-Arg from nebulin, which were shown to have antihypertensive activity *in vitro* (Escudero *et al.*, 2012b). Peptide sequences RMLGQTPTK derived from porcine skeletal muscle protein troponin by hydrolysis with pepsin also showed ACE inhibitory activity (Katayama *et al.*, 2003). In another study, peptides sequences EELDNALN, IEAEGE, VPSIDDQEELM, DSGVT, and DAQEKLE derived from pig myofibrillar proteins exhibited strong action in DPPH scavenging assay and chelating activity of metal ions (Saiga *et al.*, 2003b). Peptides with antioxidant, anti-hypertension, and anti-inflammatory properties have been found in both dry-cured ham and the muscle proteins of pigs. Peptides from Spanish dry-cured ham have been reported to exhibit antihypertensive and antioxidant properties and bioactive peptides generated from Spanish dry-cured ham (Escudero *et al.*, 2012a; Borrajo *et al.*, 2019; Toldrá *et al.*, 2020). Overall, pork is a potential source of bioactive peptides that could be used to develop functional foods and nutraceuticals with various health benefits.

Bioactive peptide derived from meat industry byproducts

The meat industry has been able to convert trimming and cutting into a valuable secondary meat product, as they are a good source of bioactive peptides. Trimming is the portion of meat that remains after cutting the primal cut from the carcass, and it generally includes fat, glister, and meat (Mora *et al.*, 2014). Blood, which represents approximately 4% of animal body weight, is also a valuable source of protein as well as bioactive peptides. However, due to the significant daily blood production at the slaughterhouse, it can cause significant environmental problems. Researchers have used various concentrations of trypsin for hydrolysis of serum albumin, and the peptide sequence has been demonstrated for antioxidation, DPP-IV inhibition, and ACE inhibition activity (Arrutia *et al.*, 2016). Antimicrobial, antihypertensive, antioxidant, and opioid activity has been evaluated from haemoglobin and plasma hydrolysates. Peptide sequences derived from the α-chain and β-chain of porcine haemoglobin have shown ACE-inhibitory activity after hydrolysis with papain enzyme. Bioactive peptide sequences derived from bovine haemoglobin have also been identified, such as VTLASHLPSDFTP

AVHASLD-KFLANVSTVL, which has the potential to work as an antimicrobial agent against *E. faecalis*, *Staphylococcus saprophyticus*, *Staphylococcus simulans*, and *Bacillus cereus* (Daoud *et al.*, 2005). Other peptide sequences, such as LDDLPGALSELS DLHAHKLRVDPVNFKLLSHSL,LLSHSL,TKAV EHLDDLPGALSELSDLHAHKLRDPVNFKLLSHSLL, and KLLSHSL, have been reported from the α-chain of bovine haemoglobin and exhibit antimicrobial as well as ACE inhibitory effects. VNFKLLSHSLLVTLASHL antimicrobial peptide sequence was also derived from the α-chain of bovine haemoglobin and showed the greatest effect against *Staphylococcus aureus*, *Candida albicans*, and *Escherichia coli* (Hu *et al.,* 2011). Additionally, some opioid-active peptide sequences were determined by researchers from bovine blood hydrolyzed, such as LVVYPWTQR, LVVYPWTQRF, and LVVYPWT (Collinder *et al.*, 2005).

The slaughter industry produces large amounts of bone, horn, and hoof each year, which are commonly used as soil fertilizers or feed materials. However, the collagen found in bone has been identified as a valuable source of bioactive peptides that offer potential health benefits for consumers. Studies have shown that antioxidative peptide sequences, such as AADNANELFPPN, QYDQGV, and YEDCTDCGN, can be extracted from water buffalo horns and have a remarkable effect on DPPH scavenging assays (Liu *et al.*, 2010). Similarly, 13 ACE-inhibitory peptides were generated and purified from bovine bone collagen, and among them, RGM-(Hyp)-GF and RGL-(Hyp)-GL peptide sequences were found to reduce systolic blood pressure after oral administration in spontaneously hypertensive rats (Cao *et al.*, 2020). Proteins derived from chicken leg bones have also been found to exhibit ACE inhibitory activity (Cheng *et al.*, 2009). Furthermore, a bioactive peptide derived from chicken bones has been shown to protect against atherosclerosis by lowering the production of inflammatory cytokines (Zhang *et al.*, 2010a). These findings demonstrate the potential for using waste materials from the slaughter industry to produce valuable bioactive peptides with various health benefits (Zhang *et al.*, 2010a). Collagen is an important byproduct derived from animal slaughterhouses and is the most abundant protein found in mammalian connective tissue, bones, cartilage, and skin (Gomez-Guillen *et al.*, 2011). Despite having relatively little nutritional value due to its high concentration of non-essential amino acids such as Gly, Pro, and Hyp, collagen is still significant in the food industry as a source of bioactive peptides (Mora *et al.*, 2014). Pharmaceutical companies use collagen as a source of protein to produce bioactive peptides, which have been shown to exert beneficial effects on bone metabolism as well as calcium absorption (Mizuno *et al.*, 2000). Chicken leg collagen-derived peptides have the potential to improve mineral density in bone and prevent osteoporosis in rats (Mari *et al.*, 2010). Moreover, hydrolysates derived from chicken bone collagen have been demonstrated to have the potential to lower total plasma cholesterol and triglycerides in the liver, hepatic cholesterol, and prevent atherosclerosis by inhibiting inflammatory cytokines (Zhang *et al.*, 2010a). In addition, Saiga *et al.* (2008) found that chicken skin collagen hydrolysate treated with an Aspergillus-derived enzyme identified four ACE inhibitory peptides. Furthermore, Li *et al.* (2007) identified four antioxidant peptides with the peptide sequence Gln-Gly-Ala-Arg after protease treatment in hydrolyzed porcine skin, showing remarkable effects in DPPH scavenging assays. From bovine Achilles tendon collagen, two ACE-1 inhibitory peptides with the peptide sequences PAGNPGADGQPGAKGANGAP and AKGANGAPGIAGAPGFPGARGPSGPQGPSGPP were identified, having a molecular weight range of 1.5–3.5 kDa (Banerjee and Shanthi, 2012). These findings suggest that collagen and its derived peptides have great potential in the food and pharmaceutical industries, as well as in improving bone health and preventing diseases such as atherosclerosis.

Generation and identification of bioactive peptides from meat sources

Bioactive peptides are frequently obtained from muscle proteins sourced from pigs, goats, cattle, sheep, and chickens. The various meat processing methods, such as curing, drying, salting, fermentation, storage, freezing, and cooking, can easily damage the structure of proteins. Protein structure can be disrupted or peptide chains can be broken down by altering temperature and pH levels. Additionally, endogenous enzymes in meat encourage the breakdown of protein chains and the production of tiny peptides during the post-ageing process of the carcass (Lafarga *et al.*, 2014). The creation of bioactive peptides is also dependent on temperature and duration of storage during the freezing storage of meat products. Peptides may be produced during this process (Leygonie *et al.*, 2012).

Enzymatic hydrolysis is the most widely used method for producing bioactive peptides, which involves breaking down the protein structure. Various digestive enzymes such as pepsin, trypsin, pancreatin, alcalase, chymotrypsin, thermolysin, papain, and flavorzyme are used in this process (Mora *et al.*, 2014; Liu *et al.*, 2016). Pepsin, trypsin, and pancreatin are the most commonly used enzymes for simulating gastrointestinal digestion in research, especially in the hydrolysis of meat products such as dry-cured hams, chicken breast muscles, duck, porcine muscles, bovine brisket muscles, and deer muscles (Bednarski and Lynch, 1996). Cathepsins and calpains are the main enzymes responsible for protein degradation, with calpain enzymes capable of breaking down proteins into long strands of peptide chains depending on the location of the protease activity. Peptidases such as aminopeptidases, peptidylpeptidases, and carboxypeptidases encourage the production of small chain peptides and free amino acids (Toldrá *et al.*, 2020). Alcalase, flavorzyme, and protamex are frequently used in the food sector to create peptides from duck, chicken, porcine protein, goat, and bacon (Mirdhayati *et al.*, 2016). Collagenase and a combination of several enzymes are also used to sequentially hydrolyze proteins in gelatin. Furthermore, bacteria such as *Streptococcus thermo philes* and *Aspergillus proteases* can produce collagen proteins and peptides in chicken breast flesh (Saiga *et al.*, 2003a). The types of muscle, curing techniques, and processing factors such as time, temperature, humidity, and salt content all have an impact on the generation of peptides. During the curing process, cathepsin B, L, and D play a key role in degrading myofibrillar proteins, following peptidyl peptidase and aminopeptidase (Mora *et al.*, 2011).

In recent years, predictive analysis *in silico* has become a popular technique for identifying and predicting bioactive peptides from various proteins due to advances in bioinformatics. Bioinformatics tools such as BIOPEP database, ProtParam, Blast, and Peptide Cutter are commonly used for in silico analysis. This technique helps to track the release of peptides from parent proteins and predict their potential bioactivity based on the sequences of the released peptides (Lafarga and Hayes, 2014).

During the bioinformatics analysis of beef, 1743 peptides and 71 meat proteins were discovered, and the cooking temperature had a significant impact on protein digestion (Sayd *et al.*, 2016). High-performance liquid chromatography, ion exchange chromatography, size exclusion chromatography, reversed-phase chromatography, and ultrafiltration are the most common purification techniques. Reversed-phase high-performance liquid chromatography (RP-HPLC), which can be combined with mass spectrometry (MS) to break down peptide sequences by molecular weight, is a frequently used method for characterizing bioactive peptides. To produce bioactive peptides on a large scale, the combination of immobilized enzymes and membrane separation techniques was found to be more efficient (Korhonen and Pihlanto, 2006). Enzymatic hydrolysis is a widely used method for generating bioactive peptides in general, as shown in below Fig. 2.

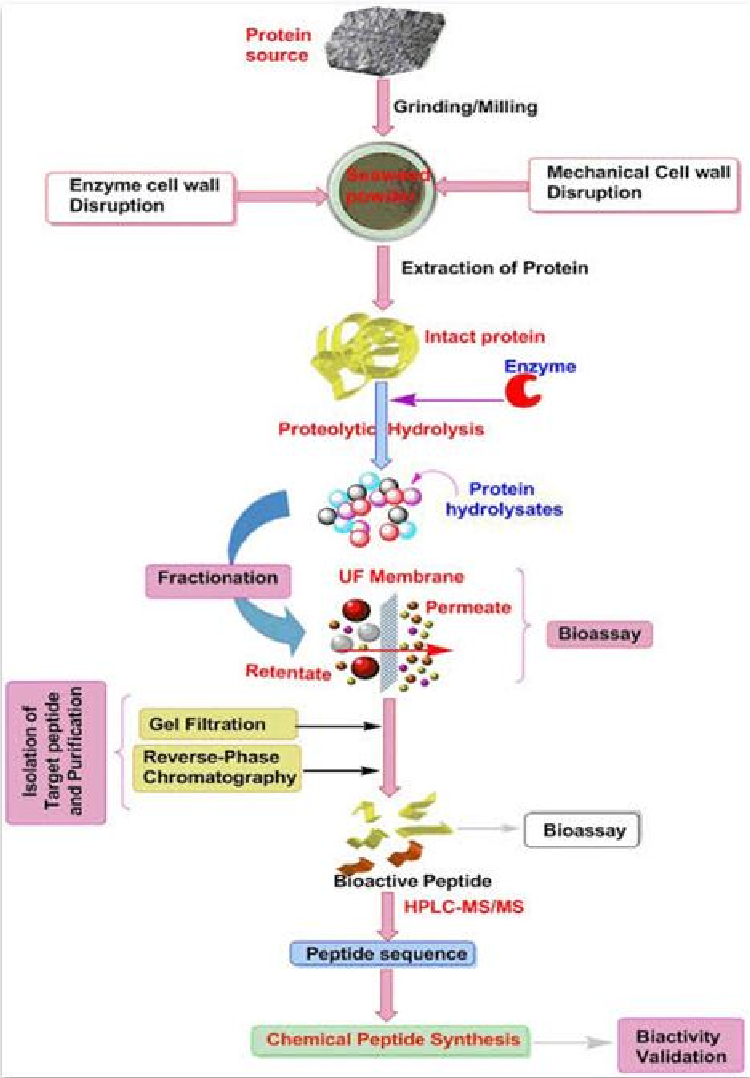

Fig. 2. Enzymatic hydrolysis for bioactive peptide generation (Adopted from: Admassu *et al.*, 2018)

Pharmacological effect of bioactive peptide on human health

Meat and its byproducts are rich sources of bioactive peptides with various beneficial physiological functions, making them potential candidates for the development of functional foods and pharmaceutical products. These bioactive peptides have been found to exhibit antioxidative, antimicrobial, antihypertensive, anti-thrombotic, and anti-inflammatory effects. Among these, antihypertensive, antimicrobial, and antioxidative bioactive peptides have been more widely studied by researchers. The efficacy of bioactive peptides mainly depends on various factors, including the location of the peptides in the protein structure, protein extraction techniques, the degree of hydrolysis, hydrophobicity, enzymes utilized, peptide concentrations, and the amino acid composition of the peptides (Stadnik and Keska, 2015).

Overall, meat and its byproducts are a rich source of bioactive peptides with various health benefits. As research continues, new bioactive peptide sequences will likely be discovered, and their potential roles in human health will be further understood. However, before their use as functional ingredients, it is important to evaluate their efficacy, dosage response, and safety through *in-vivo* methods.

Antioxidative bioactive peptides: Antioxidant peptides derived from meat and meat byproducts have the potential to prevent or delay oxidation by inhibiting the production of free radicals or scavenging reactive oxygen species. Reactive oxygen species (ROS) are produced by the body during cell metabolism to defend itself from pathogenic assaults and serve as cell communication systems. Antioxidant peptides are composed of amino acids that serve as metallic ion chelators, as well as sulfhydryl and aromatic amino acids, which provide protons to free radicals (López-Barrios *et al.*, 2014). Excessive free radical activity can have detrimental effects on human health, including cancer, heart disease, and inflammatory diseases (Lobo *et al.*, 2010). Meat and meat byproducts are rich sources of antioxidant peptides, as listed in Table 1.

Antimicrobial bioactive peptide: Compared to conventional antibiotics, antibacterial bioactive peptides have different mechanisms of action. The antimicrobial peptide industry is rapidly growing due to its effectiveness against parasites, fungi, viruses, and bacteria, including both Gram-positive and Gram-negative strains. Antimicrobial peptides are able to disrupt the membrane integrity of microorganisms by interacting with negatively charged cell membranes and specific intracellular targets. This results in microbial cell death due to inhibition of protein, DNA, and RNA synthesis (Kumar *et al.*, 2018).

Antimicrobial peptides are classified into three

Table 1. Antioxidative bioactive peptide derived from meat industry

Source	Peptide sequences	References
Chicken	HVTEE, PVPVEGV	Wu *et al.*, 2005
Duck	LQAEVEELRAALE, IEDPFDQDDWGAWKK	Wang *et al.*, 2015
Bovine muscle	AKHPSDFGADAQ, AKHPSDFGADAQA	Di Bernardini *et al.*, 2012
Buffalo horn	AADNANELFPPN, QYDQGV, YEDCTDCGN	Liu *et al.*, 2010
Bovine collagen	VGPV, GPRGF	Fu *et al.*, 2016
Venison muscle	MQIFVKTLTG, DLSDGEQGVL	Kim *et al.*, 2009
Sheep abomasum	LEDGLK, IDDVLK	Liu *et al.*, 2018
Porcine muscle	AEEEYPDL, SNAAC	Gallego *et al.*, 2018
Porcine muscle	GLAGA, SAGNPN	Escudero *et al.*, 2013b
Porcine muscle	DSGVT, IEAEGE, DAQEKLE, EELDNALN, VPSIDDQEELM	Saiga, *et al.*, 2003b
Porcine muscle	ALTA, SLTA, VT	Arihara, 2006
Porcine muscle	HNGN	Liu *et al.*, 2010
Porcine muscle	QGAR, LQGM, LQGMH, HC	Li *et al.*, 2007
Porcine muscle	GKFNV, LPGGGHGDL, LPGGGT and HA	Zhu *et al.*, 2016
Porcine muscle	DLEE	Xing *et al.*, 2016
Porcine muscle	QYP	Ohata *et al.*, 2016

categories based on their structural features. The first category includes disulfide-bridged cyclic and open-ended cyclic peptides, while the second category consists of peptides with a high content of certain amino acid residues, such as proline, glycine, or histidine. The third category is composed of α-helical linear peptides. To interact with anionic cell walls and membranes of microorganisms, most of these peptides develop an amphipathic structure with both cationic and hydrophobic properties (Pimenta and De Lima, 2005).

The scientific study of antimicrobial peptides is strongly encouraged due to the fast rise in antibiotic resistance to conventional treatments with antibiotics. Meat and slaughterhouse-derived antimicrobial bioactive peptides and their actions against various organisms are listed in Table 2. As the demand for alternative antimicrobial agents increases, antimicrobial peptides derived from meat and its byproducts could offer a promising solution for the prevention and treatment of microbial infections.

Antihypertensive bioactive peptides: The activity of antihypertensive peptides depends on the parent protein from which they are derived. These peptides have the ability to act on the renin-angiotensin system, inhibiting the action of both renin and angiotensin-converting enzymes, which are involved in controlling blood pressure. Hypertension is closely linked to cardiovascular diseases, including congestive heart failure, and is one of the three most common diseases affecting people today, along with cancer and cerebrovascular disease.

The renin-angiotensin system is a physiological mechanism that plays a critical role in controlling blood pressure. Angiotensin, a peptide hormone, is naturally converted to angiotensin I (Ang I) during the regulation of blood pressure. Ang I is subsequently transformed by angiotensin I converting enzyme (ACE) to produce angiotensin II (Ang II), which causes vasoconstriction and can lead to hypertension (Xing *et al.,* 2021). Therefore, inhibiting ACE activity is a key strategy for the prevention and management of hypertension and related cardiovascular disorders.

Numerous antihypertensive peptides have been identified from animal meats and their byproducts, as shown in Table 3. These peptides have the potential to be used as functional ingredients in the development of nutraceuticals and functional foods for the prevention and management of hypertension and related cardiovascular diseases.

Table 2. Anti-microbial bioactive peptide derived from meat industry

Source	Peptide sequences	Antimicrobial activity	References
Bovine muscle	GFHI, DFHING, FHG, GLSDGEWQ	*Escherichia coli*, *Salmonella typhimurium*, *Listeria monocytogenes*, *Pseudomonas aeruginosa*, *Bacillus cereus* and *Staphylococcus aureus*	Jang *et al.*, 2008
Bovine haemoglobin	VLSAADKGNVKAAWGK VGGHAAE	*M. luteus* A270 and fungal strains	Froidevaux *et al.*, 2001
Bovine haemoglobin	FLSFPTTKTYFPHFDLSH GSAQVKGHGAK	Gram-positive bacteria and fungi strain	Fogaça *et al.*, 1999
Bovine haemoglobin	VTLASHLPSDFTPAVHAS LDKFLANVSTVL	*Listeria innocua*, *M. luteus* A270, *Bacillus cereus*, *Enterococcus faecalis*, *Staphylococcus simulans* and *Staphylococcus saprophyticus*	Daoud *et al.*, 2005
Bovine haemoglobin	VNFKLLSHSLLVTLASHL	*Candida albicans*, *Escherichia coli* and *Staphylococcus aureus*	Hu *et al.*, 2011
Bovine haemoglobin	VTLASHLPSDFTPAVHA SLDKFLANVSTVL TSKYR; TSKYR, STVLTSKYR, QADFQKV VAGVANALAHRYH	*Listeria innocua*, *M. luteus* A270, *Bacillus cereus*, *Enterococcus faecalis*, *Staphylococcus simulans* and *Staphylococcus saprophyticus*	Nedjar-Arroume *et al.*, 2006
Bovine h aemoglobin	YSKYR	*Escherichia coli*, *Salmonella enterica* or *Staphylococcus aureus*	Przybylski *et al.*, 2016

Table 3. Antihypertensive bioactive peptide derived from meat industry

Source	Peptide sequences	References
Chicken	KPLLCS, ELFTT, KPLL	Sangsawad *et al.*, 2017
Chicken collagen	AHyp	Iwais *et al.*, 2009
Chicken	LKP, GFHypGTHypGLHypGF	Saiga *et al.*, 2003a
Chicken bones	YYRA	Nakade *et al.*, 2008
Chicken legs collagen	GAXGLXGP, GAXGPAGPGGIXGERGLXG, GLXGSRGERGERGLXG, GIXGSRGERGPVGPSG	Saiga *et al.*, 2008
Chicken muscle	GFXGTXGLXGF	Saiga *et al.*, 2006
Chicken muscle	LKA, LKP, LAP, FKGRYYP, FQKPKR, IKW	Fujita *et al.*, 2000
Chicken	LKA, FQKPKR, LAP, IVGRPRHQG, IKW, LKP, FKGRYYP	Fujita *et al.*, 2000
Bovine gelatin	RGL-(Hyp)-GL, RGM-(Hyp)-GF	Cao *et al.*, 2020
Bovine collagen	VGPV, GPRGF	Fu *et al.*, 2016
Bovine tendon collagen	AKGANGAPGIAGAPGFPGARGPSGPQGPSG PP, PAGNPGADGQPGAK	Banerjee and Shanthi, 2012
Bovine brisket muscle	INDPFIDLHYM, RGDLGIEPAEKVF	Di Bernardini *et al.*, 2012
Bovine	GFHI, DFHING, FHG, GLSDGEWQ	Jang *et al.*, 2008
Bovine	VLAQYK	Jang and Lee, 2005
Bovine gelatin	GPL, GPV	Kim *et al.*, 2001
Bovine myosin and collagen	APPH, IFY, DFY	Lafarga and Hayes, 2014
Bovine blood	TKAVEHLDDLPGALSELSDLHAHKLRVDP, VNFKLLSHSL, LDDLPGALSELSDLHAHKLR VDPVNFKLLSHS, KLLSHSL, LLSHSL	Adje *et al.*, 2011
Bovine muscle	LSW, FGY, YRQ	Choe *et al.*, 2019
Bovine serum albumin	YY	Lafarga and Hayes, 2017
Bovine blood haemoglobin	HF, KR, YF	Lafarga *et al.*, 2015
Porcine muscle	MNPPK, MNPPK	Arihara *et al.*, 2001
Porcine skeletal muscle	RPR, KAPVA, PTPVP	Escudero *et al.*, 2012a
Porcine skeletal muscle	FISNHAY	Castellano *et al.*, 2013
Porcine	AAATP	Escudero *et al.*, 2013a
Porcine	NLLPP, DEP, DAVLP	Zuo *et al.*, 2017
Porcine muscle	EKERERQ, KRQKYDI, VKKVLGNP, RMLGQTPTK	Katayama *et al.*, 2003; Katayama *et al.*, 2008
Porcine muscle	KRVIQY, KRVIQY	Muguruma *et al.*, 2009
Porcine blood	LGFPTTKTYFPHF, VVYPWT	Yu *et al.*, 2006
Porcine liver	LHI	Inoue *et al.*, 2013
Porcine skin collagen	GFGP	Mora *et al.*, 2018
Goat	FQPS	Mirdhayati *et al.*, 2016

Conclusion

Bioactive peptides have been discovered in a variety of animal meats and byproducts, and research has shown that these peptides can serve a range of physiological functions. For example, some bioactive peptides have antioxidant, antihypertensive, and antimicrobial properties, among others. These peptides may be applied in the production of nutraceuticals as a strategy for the prevention, management, and possible treatment of disorders related to a sedentary lifestyle. Various techniques can be used to generate bioactive peptides from meat sources, such as enzyme hydrolysis, microbial fermentation, acid-base hydrolysis, and unconventional hydrolysis techniques like sub-critical water hydrolysis and isoelectric solubilisation/

precipitation. However, it is important to note that the efficacy, dosage response, and safety of these bioactive peptides should be evaluated prior to their usage as functional ingredients. Although *in vitro* methods have been used to study meat-derived bioactive peptides, these methods may not be sufficient to determine their activity in the human body following digestion. Therefore, it is essential to apply peptides through *in-vivo* methods for a better understanding of their potential roles in human health.

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Author's contributions: AKD: conceptualization; SN, SM, SS, AP: Writing- original draft preparation; AKD, PKN, AD: Writing, review and editing. All the authors have read and agreed to the published version of the manuscript.

Data availability statement: Data is contained within the article.

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