REVIEW

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Study on the current research trends and future agenda in animal products: an Asian perspective

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Abstract

This study aimed to analyze the leading research materials and research trends related to livestock food in Asia in recent years and propose future research agendas to ultimately contribute to the development of related livestock species. On analyzing more than 200 relevant articles, a high frequency of studies on livestock species and products with large breeding scales and vast markets was observed. Asia possesses the largest pig population and most extensive pork market, followed by that of beef, chicken, and milk; moreover, blood and egg markets have also been studied. Regarding research keywords, “meat quality” and “probiotics” were the most common, followed by “antioxidants”, which have been extensively studied in the past, and “cultured meat”, which has recently gained traction. The future research agenda for meat products is expected to be dominated by alternative livestock products, such as cultured and plant-derived meats; improved meat product functionality and safety; the environmental impacts of livestock farming; and animal welfare research. The future research agenda for dairy products is anticipated to include animal welfare, dairy production, probiotic-based development of high-quality functional dairy products, the development of alternative dairy products, and the advancement of lactose-free or personalized dairy products. However, determining the extent to which the various research articles’ findings have been applied in real-world industry proved challenging, and research related to animal food laws and policies and consumer surveys was lacking. In addition, studies on alternatives for sustainable livestock development could not be identified. Therefore, future research may augment industrial application, and multidisciplinary research related to animal food laws and policies as well as eco-friendly livestock production should be strengthened.

Keywords: Future agenda, Animal products, Meat analog, Dairy products, Cultured meat

INTRODUCTION

The livestock industry is the most prominent agricultural sector in most countries, and it has a strong bearing on food supply issues, environmental issues, and human health owing to population growth

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Authors' contributions
Conceptualization: Hur SJ.
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[1]. In particular, livestock products account for more than 40% of the total agricultural output in Korea. Moreover, while the livestock industry is considerably important, its negative perception is also quite significant. As the livestock industry involves the large-scale breeding and utilization of animals, it potentially infringes on animal welfare. In particular, Asia possesses the largest population among the world's continents, and its livestock market is expanding rapidly owing to the growth of emerging economies [2]. Unlike North America and Europe, where the livestock market has already reached its peak, the rapid growth of the Asian livestock market is considerably likely to have a significant impact on changes in the international livestock market by increasing the demand for livestock products and feed crops worldwide. In recent years, the growing interest in cultured meat and plant-based alternatives to traditional livestock products has led to the expected growth and development of novel food groups as well as increased conflict with the traditional livestock industry [3]. Therefore, analyzing key research topics related to livestock food production not only charts the direction for academic advancement in this area and the development of related industries but also enables the prediction of complementary points in the real-world livestock industry and the need for improvement at an institutional level. Therefore, this study aimed to analyze research topics and materials related to livestock food production published by authors from major Asian economies, including Korea, China, and Japan, to assess the current status of Asian livestock food-related technology and predict the future research agenda for the livestock food industry.

CURRENT RESEARCH TRENDS IN ANIMAL PRODUCTS

Research trends according to livestock breed and material

As shown in Fig. 1 and Table 1, the most dominant livestock species in the Asian livestock sector are pigs, cattle, chickens, and sheep, and the most studied animal products are pork, beef, chicken, milk, and eggs. In fact, our study demonstrates that out of more than 200 livestock food-related research topics, pork is the most frequently studied livestock product, with over 30 studies, followed by beef and chicken, with more than 20 studies. In addition, milk and dairy products have been

Fig. 1. **Bigdata analysis for research materials in animal products.**

Table 1. Research article and keyword categories

Animals, animal products or by-products, or raw materials	Research keywords	References
Animal products	Animal products; detection; invA gene; lateral flow dipstick; loop-mediated isothermal amplification; minimum inhibitory concentration; natural production preservatives	[6], [7], [8]
Beef	Adipogenesis; adulteration; anaerobic glycolysis; atmospheric pressure plasma; backfat thickness; bactericidal effect; beef; beef discoloration; beef jerky; beef quality; beef tenderness; bovine; brine injection; calpain system; calpastatin; capillary electrophoresis time-of-flight mass spectrometry; carcass chilling; chemometric analysis; Chikso; collagen; collagen solubility; cull cow beef; degree of doneness; dry aging; dry aging methods; drying characteristics; duck fat; empal gentong; ethylene vinyl alcohol; fat; fatty acids; fat replacement; feed energy level; feeding regime; rheological property; freezing/thawing; fresh beef tumbling; front-face fluorescence spectroscopy; genetic merit for marbling; grain; gram-negative bacteria; grass; Hanwoo; health; hemi-castration; hierarchical clustering; high-intensity ultrasound; hot-air drying; instrumental color; Japanese Brown; lipid oxidation; long-term aging; marbling; meat; meat products; meat quality; metabolites; metabolomics; metagenome; metmyoglobin reducing activity; microbial safety; microstructure; multivariate analysis; myogenesis; net income; nisin; oxidative stability; packaged dry-aged beef; pasture; phosphate; physicochemical analysis; physicochemical properties; polyvinylidene chloride; postmortem aging; pre-cooking; principal component analysis (PCA); protein solubility; purchasing preference; quality characteristic; quality grade; quality properties; quality traits; ready-to-eat; satellite cell; semitendinosus; sensory attributes; short-term fattening; single nucleotide polymorphisms; sous-vide; supplementation; temperature abuse; tenderness; testosterone; texture; κ-carrageenan	[9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [30], [31], [32]
Blood	Aflatoxin; angiotensin-I-converting enzyme (ACE) inhibitory activity; antioxidant; antioxidant activity; biochemistry; blood by-product; blood metabolites; blood parameter; broiler; carcass characteristics; chicken; conventional; cytokines; duck blood; enzyme hydrolysis; fibrosis; flutriafol; freeze drying; Hanwoo; heat stress; hemi-castration; hot-air drying; illite; immunity; laying hens; leukocyte; light intensity; meat quality; metal chelating activity; mycotoxin; net income; octacosanol; organic chromium; performance; pig; piglet performance; reproductive performance of sows; residue levels; salicylic acids; short-term fattening; spray drying; stress; stress index; survival rate; tebuconazole; testosterone; thermal discomfort; toll-like receptor; triticale sprout; vacuum drying; villus height; welfare; zeolite	[9], [33], [34], [35], [36], [37], [38], [39], [40], [41], [42], [43]
Carcass	AutoFom III™; backfat thickness; bedding; blood removal; carcass; carcass chilling method; carcass traits; carcass weight; coco peat; correlation; food safety; growth performance; Hanwoo; heteroscedasticity; market weight; meat color; meat grading; non-destructive inspection method; pig carcass grade; porcine carcass; primal cuts; regression; slaughter age; yield grade	[44], [45], [46], [47], [48]
Casein	Acid-induced gelation; casein derivative; delivery system; docosahexaenoic acid; sodium caseinate	[49]
Cell	Adipogenesis; amino acid transport; apoptosis; cell viability; chicken; dairy cow; DF-1; Hanwoo beef cattle; heat stress; hyperthermia; inflammation; innate immunity; intramuscular fat; lysine; mammary alveolar cell-T; milk-protein synthesis; pancreatic pro-genitor cell differentiation and proliferation factor; prolactin; stromal vascular cells; toll-like receptor 3; 5-hydroxytryptamine	[50], [51], [52], [53]
Cell-cultivated meat	Blood; chicken satellite cell; cultured meat; cultured meat taste; cultured muscle tissue; fetal bovine serum; muscle cells; pre-plating; pre-plating time; purification; satellite cell; scaffolds; taste characteristics; temperature; umami intensity	[54], [55], [56]
Cheese	Antimicrobial resistance; biofilm; cheese brine; cheese starter culture; foodborne pathogen; growth curve; *Kocuria salsicia*; *Lactococcus lactis*; bacteriocin; *Listeria monocytogenes*	[57], [58]
Chicken carcass	*Campylobacter* spp.; carcass condemnation; chicken; dermatitis; gold nanoparticle; hock burn; inspection line; polymerase chain reaction; slaughterhouse	[59], [60]
Chicken meat	Adulteration; antimicrobial; antioxidant; *Bacillus subtilis*; black garlic; broiler; *Campylobacter* spp.; carcass characteristics; carcass condemnation; chemometric analysis; chicken; chicken breast; chicken breast sausages; chicken meat quality; chicken thigh; chicken wings; coccidiosis; cold storage; consumer behavior; conventional; dermatitis; detoxification; dietary protein source; dipeptides; elderly digestion; enzymatic hydrolysis; fat substitute; Flavourzyme®; free amino acids; front-face fluorescence spectroscopy; fruit juices; garlic; genome-wide association study; glutamate-ammonia ligase; gold nanoparticle; growth performance; heat stress; heat-equivalent non-thermal technology; high hydrostatic pressure; hock burn; illite; information effect; inosine monophosphate; inosine-5'-monophosphate; inspection line; Jingyuan chicken; Korean native chicken; leukocyte; light intensity; lipid oxidation; marinade; marination; meat quality; meat science; microbial quality; modified atmosphere packaging (MAP); native chicken; natural phosphate alternatives; nucleotides; occurrence; organic chromium; oxidative stability; packaging methods; performance; phosphate; phosphodiesterase 10A; physiochemical and rheological properties; polymerase chain reaction; poultry breast fillets; prebiotic; PCA; protein digestibility; quality; red ginseng marc; *Rhus verniciflua*; riboflavin; RNA-seq; ross 308; Samgyetang; sensory evaluation; slaughterhouse; slaughtering age; stress; survival rate; sustainable consumption; taste properties; thermal discomfort; thiobarbituric acid reactive substance; total volatile basic nitrogen; ultraviolet light-emitting diode; vacuum packaging; welfare; white striping; wooden; zeolite	[1], [24], [34], [35], [38], [40], [61], [62], [63], [64], [65], [66], [67], [68], [69], [70], [71], [72], [73], [74], [75]

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Table 1. Continued

Animals, animal products or by-products, or raw materials	Research keywords	References
Doenjang	Animal model; immune response; probiotics	[76]
Duck	Digestibility; enzyme; hardness; liver sausage; pressure	[77]
Duck meat	Abdominal fat; carcass traits; duck; duck meat; energy level; growth performance; inulin; meat quality; muscle fiber type; proteolysis; sausage; soy protein isolate	[25], [78], [79], [80]
Edible insect	Edible insects; entomophagy; expanded polystyrene; food resources; food safety; functional; functional properties; *Hermetia illucens*; insect protein; optimal pre-treatment method; protein characteristics; protein cross-linking; sausages; sensory; soluble protein; subacute toxicity; *Tenebrio molitor*	[81], [82], [83], [84]
Egg	Antioxidant activity; blood parameter; chukar partridge; egg; egg position; egg production; egg quality; egg yolk protein; electronic nose; fatty acid; flavor analysis; gas chromatography–mass spectrometry; ginsenoside; hen-day egg production; HepG2; immunity; immunomodulatory activity; inflammatory cytokine; laying hens; lipid oxidation; liquid smoke; natural carotenoids; non-fasting molting; octacosanol; performance; productivity; rosemary extract; salted duck egg; salted egg; saponin; splenocyte; storage period; triticale sprout; tumor necrosis factor alpha; turning frequency; zinc oxide	[41], [85], [86], [87], [88], [89], [90], [91], [92]
Feces	Anti-listerial; bacteriocin; canine; lactic acid bacteria; *Ligilactobacillus agilis*; *Limosilactobacillus fermentum*; *Pediococcus pentosaceus*; probiotics	[93], [94]
Fermented sausages	Fermented sausages; lactic acid bacteria; quality control; starter culture	[95]
Goat	Emulsifier; gelatin extraction; goat skin; Korean native black goat; response surface methodology	[96]
Goat meat	Alfalfa; anti-muscular atrophy; antioxidant activity; apoptosis; black goat meat; carnosine; concentrate; extract; goat meat; goaty flavor; indole; Korean native black goat; sexes; water-soluble metabolites; α-glucosidase inhibitory activity	[97], [98], [99]
Goose meat	*Acremonium terricola* culture; conventional characteristics; flavor substances; hortobágy geese; meat quality	[100]
Honey	Biofilm; *Enterococcus faecalis*; *Hovenia* monofloral honey; inflammation; mitogen-activated protein kinases; toll-like receptor-2	[101]
Human breast milk	Gut health; infant formula; microbiota; probiotics; short-chain fatty acids	[102]
Kimchi	Animal model; anti-obesity; aryl hydrocarbon receptor; Caco-2 cells; differentially expressed gene; genomic DNA; immune response; immunostimulatory effect; inflammation; lactic acid bacteria; *Lactiplantibacillus plantarum*; *Latilactobacillus curvatus* BYB3; *Lipopolysaccharide*; macrophage; nuclear factor kappa B; *Pediococcus acidilactici*; *Periodontitis*; *Porphyromonas gingivalis*; postbiotics; probiotic property; probiotics; tight junctions	[76], [103], [104], [105], [106], [107], [108]
Lamb	Branched-chain fatty acids; carcass evaluation; carcass traits; cold shortening; different types of meat cut; fattening system; fatty acid profile; feedlot lambs; feedlot performance; ferulic acid; flavor; hot-boned; Hulunbuir sheep; Jamuna basis lambs; lamb quality; lipid oxidation; *Lycium barbarum* polysaccharide; meat quality; multiple quality parameters; muscle morphometry; optical system; packaging time; phytochemicals; PCA; production traits; protein degradation; rapid detection; real-time polymerase chain reaction; sheep; slaughter traits; supplementary feeding; Tan sheep meatballs; vacuum packaging; visible and near-infrared; zeolite	[109], [110], [111], [112], [113], [114], [115]
Malt	Genomic DNA; inflammation; *Pediococcus acidilactici*; periodontitis; *Porphyromonas gingivalis*	[105]
Meat	Gut microbiota; meat; protein digestion; proteolytic enzyme; sous-vide	[116]
Meat products	Authentication; essential oils; lipidomics; liquid chromatography–mass spectrometry; low-salt meat products; low-sodium meat products; meat product; metabolomics; nanoemulsion; natural preservative; natural salt replacers; salt alternatives; salt-modifying; salt reduction	[117], [118], [119]
Meat supply chain	COVID 19; agriculture; consumer concern; economy; meat supply chain	[120]
Milk	Adulteration; agglomeration; ACE; inhibitory activity; antidiabetic; antihypertensive peptides; antioxidant; aroma compounds; big data; blood; metabolites; bovine milk; buffalo milk; camel milk; carrier; cheese; cheese fat composition; cheese lipolysis; climate change; colostrum; comprehensive quality; dairy cows; dairy goat; dairy products; digestion; dry-period length; economic assessment; environmental assessment; enzymatic hydrolysis; Etawah grade; extracellular vesicles; fatty acid profile; fatty acids; fermented milk; fluidized bed; food byproduct; Fourier-transform infrared spectroscopy; free radical; goat milk fermented; goat whey; gut health; health benefit; heat stress; high Fischer's ratio oligopeptides; human milk; hydrolysate; hypoallergenic; infant formula; infant nutrition; inulin; Jeminay; *Lactis* BD17; *Lc. lactis* ssp; lysozyme; Maillard conjugate; maltodextrin; milk; milk amino acid; milk cooling; milk fat globule membrane; milk fatty acid; milk performance; milk powder; milk production; milk protein concentrate; natural emulsifier; nutritional components; oligosaccharides; Parmigiano Reggiano; *Pediococcus acidilactici* BE; *Pediococcus pentosaceus* M103; probiotics; processing opportunities; proteolytic specificity; red grape pomace; response surface methodology; rheological analysis; rheological behavior; Ricotta; sarcopenia; sensory acceptance; sheep; sour cream; temperature–humidity index; therapeutics; volatile compounds; water-holding capacity; whey; whey protein; whipping cream; whipping property; yogurt	[121], [122], [123], [124], [125], [126], [127], [128], [129], [130], [131], [132], [133], [134], [135], [136], [137], [138], [139], [140]

Table 1. Continued

Animals, animal products or by-products, or raw materials	Research keywords	References
Mushroom	Hot-air drying; *Letinula edodes*; organoleptic properties; quality properties; rolled-dumplings	[141]
Pig tissues	Biochemistry; fibrosis; flutriafol; pig; residue levels; tebuconazole	[36], [37]
Pork	Aging methods; antibacterial activity; antimicrobial resistance; antioxidant; activities; antioxidants; ascorbic acid; *Bacillus licheniformis*; *Bacillus subtilis*; barrow; belly; Berkshire; biogenic amine; blackcurrant; breeding potential; calamansi pulp; charcoal; clean-label; collagen content; cooking loss; cooking time; correlation coefficient; cured pork loin; *Debaryomyces hansenii*; determination coefficient; digestibility; dissected value; dongchimi powder; dry-cured ham; drying characteristic; duck fat; economic trait; edible insect; electrical conductivity; electronic nose and tongue; emulsion-type sausages; enzyme; ethanol extracts; fat replacement; fermented dongchimi; fermented sausage; finishing pig; freshness; functional properties; gelatin; genotype; gilt; grade; graft reaction; ham; hardness; heterocyclic amines; initial moisture content; Korean fermented food; Landrace × Yorkshire × Duroc; liver sausage; loin; loquat leaf; meat quality; meat yield; microbiological; microorganisms; MAP; muscle; muscle architecture; muscle fiber characteristics; myofibril protein; myosin heavy chain 3; natural curing agent; natural materials; natural preservative; nitrite replacement; non-*aureus staphylococci*; nutrient digestibility; odor gas emission; off-odor; oxidation; parallel; *Penicillium nalgiovense*; pennate; perilla leaves; phosphate replacement; physicochemical; physicochemical characteristics; physicochemical property; pig; pig breeding; polycyclic aromatic hydrocarbons; pork; pork belly; pork large intestine; pork loin; pork patty; pork products; pork quality; pork sous-vide ham; post-rigor; pre-rigor; pressure; primal cut; probiotic; protein; phosphorylation; pulsed electric field; quality; quality and color properties; quality properties; radish powder; reduced-salt; reducing sugar; restructured jerky; retail pork; rheological property; saccharide; sarcoplasmic proteins; sausages; season; semi-dried; semi-dried restructured sausage; sensory; sensory attribute; sensory characterization; sensory properties; shear force; slaughter weight; slaughterhouse carcass; soluble protein; sonication; sous-vide; starter culture; stepwise algorithm; structure; sulfhydryl concentration; supercooling storage; temperature; vacuum-packed VCS2000; wet-aging; Woori-Heukdon; κ-carrageenan	[19], [25], [77], [84], [142], [143], [144], [145], [146], [147], [148], [149], [150], [151], [152], [153], [154], [155], [156], [157], [158], [159], [160], [161], [162], [163], [164], [165], [166], [167], [168], [169], [170]
Poultry	Antibiotics; growth performance; health; poultry feed; spore-forming probiotics	[171]
Probiotics	Animal model; anti-inflammation; anti-oxidation; bacteriocin-like inhibitory substance; biofilm; cell extracts; cognitive deficits; *Caenorhabditis elegans*; cognitive impairment; culture supernatant; cyclophosphamide; cytokines; dental caries; *Enterococcus faecium*; gamma-aminobutyric acid; gut-brain axis; immune; immunostimulation; immune promotion; *Lactiplantibacillus plantarum*; *Lactobacillus reuteri* MG5346; *Lactococcus lactis*; ligature-induced experimental periodontitis; microbiome; neurodegenerative disease; osteoclast specific gene expression; osteoclastogenesis; osteoporosis; ovariectomy; probiotics; receptor activator of NF-kB ligand; sialic acid; *Streptococcus mutans*; toll-like receptor; transcriptome; velvet antler	[172], [173], [174], [175], [176], [177], [178], [179]
Rabbit meat	Biological activity; factors affecting quality; meat quality; quality determinants; rabbit breeds	[180]
Satellite cell	Adipogenesis; AKT/AMPK signaling pathway; antimicrobial peptide; apolipoprotein H; blood removal; C2C12 myoblast cell; carcass chilling method; cell growth; chicken; CopA3; culture temperature; cultured meat; differentiation; fat; food safety; genetic analysis; growth factors; Hanwoo; myosatellite cell; hormone–lipid metabolism; meat color; meat quality; muscle satellite cells; myoblast; myofiber type; myogenesis; myogenic regulatory factors; myosin heavy chains; pig; proliferation; satellite cell; skeletal muscle; Wurank sheep	[30], [181], [182], [183], [184], [185], [186], [187]
Soybean protein	Chicken; partial meat replacement; quality properties; sausage; soybean	[188]
Traditional fermented Korean foods	Immunoglobulin A; interleukin-6; lactic acid bacteria; Peyer's patch; toll-like receptor	[189]
Turkey meat	Ground turkey breast; pink color defect; pink inhibiting ingredients; sodium tripolyphosphate	[190]
Velvet antler	ACE; animal-based functional food ingredients; antihypertensive effect; *Caenorhabditis elegans*; gamma-aminobutyric acid; immune promotion; probiotics; purified peptide; sialic acid; velvet antler	[179], [191]
Wax propolis	Antimicrobial; livestock products; natural preservative; propolis	[192]
Whey	Antioxidant; antitumor; dynamic balance; fermented whey protein; *Lactobacillus casei*; muscle strength; peptide; purification; separation	[106], [193]

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studied 20 times, blood 12 times, and eggs 9 times. Noteworthily, blood, which does not actually account for a portion of the livestock market, occupies a significant proportion of livestock product research, suggesting that efficient blood utilization is necessary. Research on cultured meat has been on the rise in recent years, with eight and three studies related to muscle satellite cell materials and cultured meat production, respectively. In fact, studies on specific technologies that produce cultured meat are lacking; considering the vast proportion of review articles related to cultured meat, specific technologies, and industrialization-related studies are predictably essential for the industrialization of cultured meat. Furthermore, several studies have examined lamb, duck, goat, and goose meats, while one study investigated rabbit and turkey meats. In addition, insect materials have increasingly been studied in recent years. On summarizing research trends according to livestock species, most studies were found to be on pork, which holds the most extensive livestock product market, followed by those for beef and chicken. Therefore, the scale or trend of research is almost consistent with the market size of livestock products. In other words, the number of studies and researchers involved is proportional to market size.

Nevertheless, the patent and supermarket criteria results (data not shown) reveal that the products studied have rarely been commercialized. In fact, although the authors of many studies have claimed that their studies may be of industrial importance, verifying whether their findings have been applied to animal products is challenging.

Research trends by keywords

Keyword analysis of more than 200 recently published animal food-related papers revealed the following results. The total number of keywords mentioned in the paper was approximately 900, which is considered to indicate considerable diversity. As shown in Fig. 2, "meat quality" was the most frequently mentioned (15 studies), followed by "probiotics" (nine studies) and "beef", "Hanwoo", and "pig" (five studies each), while "antioxidant activity", "growth performance", "heat stress", "lactic acid bacteria", "lipid oxidation", "pork loin", "quality properties", "satellite cell", and "tenderness" were each mentioned four times. In the field of livestock food, research on meat quality has remained predominant, while probiotics have recently drawn interest and become a frequent

Fig. 2. Bigdata analysis for research keywords in animal products.

study topic; moreover, research on antioxidants has also persisted. In addition, keywords related to cultured meat development, such as "cultured meat" and "myogenesis", as well as those related to animal food processing, such as "sous vide", "starter culture", and "hot-air drying", were also found to be substantially recurrent.

A more detailed breakdown of recent research trends indicated that a wide variety of topics have been pursued in pork research, including "aging methods", "antimicrobial activity", "antioxidants", "vitamin C", "biogenic amines", "heat reduction", "muscle fiber properties", "natural preservatives", "carcass weight", "breeding methods", "packaging methods", "meat production characteristics", and "source fiber proteins." In contrast, beef-related research topics, such as "adipogenesis", "glycolysis", "back-fat thickness", "beef quality", "tenderness", "calpain system", "collagen solubility", "dry aging", "fat replacement", "feed energy level", "lipid oxidation", "myoglobin", "myogenesis", "quality grade", and "short-term fattening", among others, have been studied more than those related to pork, such as "tenderness", "aging", "marbling", "meat color", and "fat oxidation." In particular, fat content and marbling are significant beef quality factors in the Korean and Japanese beef markets; therefore, numerous available studies are considered to have the potential to improve beef quality factors, such as fat, marbling, and aging. Chicken-related research topics, including "microbial quality and safety", such as that related to *Campylobacter*, "antimicrobial agents", "antioxidants", "chicken related processed meat products", "chicken storage", "heat stress", "packaging methods", "consumer behavior", "non-heating technologies", and "protein digestibility", exhibit greater diversity than those of beef.

Among milk-related research topics, several are related to digestive health and milk quality, including "antidiabetic properties", "antihypertensive peptides", "antioxidants", "aromatic compounds", "metabolites", "cheese fat", "cheese lipolysis", "climate change", "enzymatic hydrolysis", "fatty acid profile", "gut health", "health benefits", "heat stress", "natural emulsifiers", "nutritional components", "whey protein", and "probiotics." In particular, among dairy product research topics, those related to probiotics have been dominated by various studies on human health, focusing on anti-inflammatory properties, antioxidant activity, bacteriocin-like inhibitors, cognitive deficits, caries, cognitive impairment, immunostimulation, immune enhancement, the microbiome, neurodegenerative diseases, and osteoporosis.

Egg-related research topics have included "antioxidant activity", "egg quality", "immunomodulatory activity", "inflammatory cytokines", "lipid peroxidation", "carotenoids", "saponins", and "tumor necrosis factor." However, despite being one of the major animal food products, the quantity and diversity of egg-related research has remained lower than that of other animal food products. A significant amount of research has also focused on blood, which is a relatively underutilized byproduct of livestock food production possibly because it is more commonly used as a food product in Asia than in Europe or North America. In addition to research on blood function and components, such as aflatoxins, angiotensin-I-converting enzyme inhibitory activity, antioxidants, blood metabolites, cytokines, enzymatic hydrolysis, power drying, heat stress, immunity, laying hens, leukocytes, stress indices, and animal welfare, blood has often been studied in relation to animal stress.

Among the studies related to alternative livestock foods that have received significant attention in recent years, those focusing on cell culture have investigated blood (serum), satellite cells, fetal bovine serum, scaffolds, taste characteristics, adipogenesis, amino acids, hyperthermia, milk protein synthesis, antimicrobial peptides, myoblast cells, C2C12 cells, culture temperature, cell differentiation, growth factors, myosatellite cells, myofibers, cell proliferation, skeletal muscles, and myofiber types. However, despite the increasing number of studies on cultured meat, many of them have not provided specific techniques for manufacturing cultured meat. This suggests that,

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in addition to satisfying the increasing demand for further research into the industrialization of cultured meat, time is also required for this industrialization. Research related to edible insects included the following topics: "mealworm", "black soldier fly larva", "insect protein", "protein properties", "soluble protein", "toxicity", "food safety", and functionality", and it was mainly inclined to safety and protein properties.

To further investigate global research trends with respect to the growing interest in cultured meat, we used Google Scholar to search for 100 research and review articles on cultured meat published in 2023 (Fig. 3). Over 200 keywords were identified in these articles, with the most common being "cultured meat", "cultivated meat", "cellular agriculture", "consumer acceptance", "sustainability", "alternative protein", and "*in vitro* meat." However, owing to the wide variety of research topics, identifying specific areas that have undergone comprehensive research is extremely challenging. As mentioned earlier, several detailed studies have focused on a single method of producing cultured meat rather than direct research methods related to cultured meat production; hence, further studies on technologies that develop direct cultured meat are required for the industrialization of cultured meat.

FUTURE RESEARCH AGENDA FOR ANIMAL FOOD PRODUCTION

After analyzing the latest research topics, we hereby propose the following agenda for future animal food research and industrialization. The main areas of focus will be as follows: alternative proteins, nutrition, reducing environmental impact, animal welfare, food safety, and quality, smart packaging and distribution, consumer preferences and behavior, value addition to livestock products (including by-products), the social impact of livestock and livestock products, multidisciplinary collaboration to promote synergies in related industries, regulatory and policy-related research, global food security, and sustainable livestock production.

Research on alternative protein sources

The advancement of alternative protein sources will involve research on:

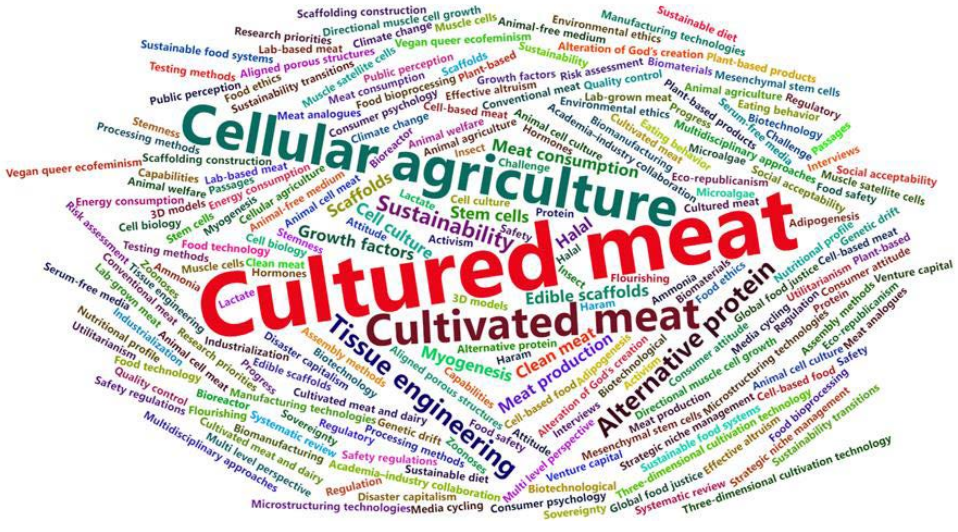

Fig. 3. **Bigdata analysis for research keywords in cultured meat related studies in the world.**

- the development of novel protein sources, such as plant-derived, insect-derived, and single-cell proteins as well as cultured meats;
- the quality, flavor, nutritional value, and safety of these alternative proteins; and
- the reduction of production costs and increase in production efficiency.

Research into promoting nutritional value

The enhancement of nutritional value will entail research on strategies for reducing the production of potentially harmful substances in livestock foods and improving the healthfulness of livestock foods through fortification with beneficial nutrients.

Research into reducing the environmental impact of animal agriculture

Mitigating the environmental impact of livestock production requires research on technologies that (1) reduce the use of land, water, or pasture for livestock production; (2) minimize waste generation; and (3) decrease greenhouse gas emissions. The impact of these technologies on the quality of livestock food also warrants exploration.

Research on animal welfare and ethical livestock production techniques

Ensuring animal welfare and ethical livestock production calls for research into improving the welfare of livestock while minimizing the stress and disease associated with raising animals, enhancing consumer preference for ethically produced animal products, and labeling strategies.

Research into improving the safety and quality of animal food

Developing technologies for the rapid detection of microbiological contamination and pathogenic bacteria in food to reduce consumer anxiety and distrust of livestock foods as well as improving the quality and safety of livestock foods requires relevant research.

Research on smart packaging and storage technologies

Research on packaging materials, packaging technologies, and storage technologies that potentially improve livestock food economics and reduce food wastage via methods that extend the shelf life of livestock food while minimizing changes in quality is warranted.

Research on consumer preferences and consumption behavior

Satisfying consumer needs and optimizing livestock food production will involve research into the production of high-quality livestock products by analyzing consumer preferences, perceptions, and purchasing-behavior patterns.

Development of processed and value-added products

Improving the stability, flavor, and health benefits of livestock food products will entail research into the development of new food products that minimize waste generation and add value to animal products, including the exploration of novel processing and manufacturing methods.

Research on the social and economic impact of livestock

Research on general consumer perceptions regarding traditional livestock farming and means of improving the competitiveness of smart farms and livestock farming is warranted.

Collaborative, multidisciplinary, and synergistic research

Addressing challenges bedeviling the livestock industry will entail research involving the sharing of

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knowledge and collaboration across multidisciplinary fields, such as food, environment, and health.

Assessment of regulatory and policy frameworks

Research on effective regulatory and related legal policies is required to improve consumer confidence in sustainable and ethical livestock production.

Global food security studies

The achievement of global food security demands research on food scarcity and wealth distribution according to population growth as well as that on the role of animal agriculture in global food security.

Sustainable livestock research

Research into minimizing the impact of livestock production on the global environment and developing ethical livestock production technologies that are economically and socially responsible is warranted.

Research on Internet of Things (IoT), blockchain, and artificial intelligence (AI) technologies

Research into enhancing transparency in food production, distribution, and supply by integrating IoT, blockchain, and AI technologies as well as upgrading production efficiency by predicting food consumption trends, ensuring effective inventory management, and preventing product loss is required.

Research into the development of feed resources to improve animal welfare and produce high-quality livestock products

The development of animal feed that improves animal welfare while ensuring high-quality food products merits research into formulating feed resources that optimize the nutritional status of livestock, diversifying feed resources, minimizing competition with human foods, and identifying new feed ingredients and formulations.

FUTURE RESEARCH AGENDA FOR MEAT ANALOGS

Meat analogs (meat substitutes) or alternative protein foods tend to constitute the most actively researched topic in animal agriculture. As the taste and quality of meat analogs have not yet reached the level of traditional livestock products, research into these aspects by various research institutions and food companies is expected to continue. The research agenda can be summarized as follows: improving the ingredient content of alternative animal products, improving texture and flavor, alleviating environmental impact, raw material composition, processing and manufacturing methods, health and safety, consumer purchasing patterns, reducing the cost of cultured meat production, economic and market analysis, social and ethical considerations regarding alternative foods, and laws and regulations related to novel foods.

Research into improving the ingredient content of alternative livestock products

Improving the ingredient content of alternative livestock products will entail a comparative analysis of nutrient and ingredient contents between meat analogs and traditional meat products as well as research into developing products with the same, or higher, nutrient and ingredient contents as traditional meat products using various raw materials.

Research into enhancing the texture and flavor of meat analogs

Research into the formulation or molding of new materials (e.g., extrusion, support, 3D printing, high-pressure processing, etc.) is required to ensure that the physical properties and flavor of meat analogs, such as texture, age, and chewability, are similar to those of traditional meat products.

Flavor improvement research

Research into developing preservatives, spices, seasonings, and flavor enhancers as well as that on fermenting, curing, and cooking techniques is requisite to achieving the same taste and flavor as that in traditional meats.

Research on sustainable livestock production and its environmental impact

Protecting the global environment calls for research on the environmental impact of the production methods of various meat analogs and on alternative methods of producing animal products.

Exploring new ingredients for the development of meat analogs

The production of novel meat analogs will be underpinned by research aimed at discovering or acquiring new raw materials (e.g., algae, fungal proteins, legumes, edible insects, animal-derived cells, synthetic materials, etc.) from which they can be manufactured.

Research on the safety of meat analogs

To ensure meat analog safety, exploring methods that effectively investigate and evaluate the potential risks (allergenicity, reproductive toxicity, genotoxicity, etc.) associated with long-term meat analog consumption is imperative.

Consumer behavior research

Examining consumer attitudes toward, preferences for, and acceptability of various meat analog types as well as means of increasing meat analog diversity and consumption is warranted.

Analysis of the economics and market of meat analogs

Research on the demand, pricing, market potential, and consumer needs for the industrialization and growth of meat analogs as well as comparative economic and competitive analyses between traditional meat and meat analogs are necessary.

Research on the social and ethical impacts of meat analog industrialization

Research on meat analog industrialization's social and cultural impacts, including those on animal welfare, land use, and the environment, among others, is imperative.

Research on the regulations and standards for novel food development

Research on the formulation of standards for the authorization of novel food production and distribution as well as that on the legal system related to novel food regulations is required.

Research into developing personalized nutrition and functional foods

The effects of food on individual health and disease as well as strategies for improving health through personalized food intake are also key future research topics.

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FUTURE RESEARCH AGENDA FOR DAIRY PRODUCTS

The future research agenda for the dairy sector will need to be aligned with the increasing demand for sustainable, nutritious, and innovative dairy products driven by longer, healthier lifespans and a growing population. This agenda can be summarized as follows: sustainable dairy production, high-quality and functional dairy products, alternative dairy products, lactose-free products, dairy processing, and packaging, quality and flavor enhancement, use of information and communication technologies, animal welfare in dairy production, personalized dairy product development, consumer preferences, and the authorization and reference standards for novel foods.

Sustainable dairy production

Improving the sustainability of the dairy industry will entail research into reducing the environmental impact of dairy farming, including methane emissions from fermentation in the gut of cows, water use, and waste management.

Nutritional quality and functional dairy products

Future research will include assessing the nutritional content of dairy products; identifying new ingredients, such as probiotics, prebiotics, bioactive compounds, and omega-3 fatty acids, that enhance the added value and functionality of dairy products; and developing functional dairy products that target specific health needs, including immune enhancement, digestive health, and cognitive function.

Alternative dairy sources

Satisfying the varying demands of the diverse consumer base calls for research into alternative dairy products, such as plant-based (e.g., almond, oat, rice, soy, and pea milk) and microbially cultured milk.

Lactose- and pesticide-free products

Research on dairy products with reduced or eliminated lactose for consumers with lactose intolerance will be paramount.

High-quality dairy processing and packaging

Upgrading the quality, safety, and shelf-life of dairy products while minimizing nutrient loss will entail exploring novel processing, packaging, and storage technologies.

Quality and sensory evaluation

Enhancing the value of dairy products will involve examining the sensory attributes, flavor profiles, and consumer acceptance of various dairy products.

Research into increasing trust through the integration of information technology (IT)

Research on how IT, such as AI, blockchain, and IoT, can enhance traceability and transparency across the dairy supply chain is warranted.

Animal welfare in dairy production

The production of dairy products that upholds animal welfare requires research on animal welfare standards and ethics and on the relevant management strategies.

Personalized nutrition and dairy consumption

Research into developing personalized dairy products based on individual nutritional requirements and health goals, among others, in an aging society is imperative.

Research on consumer needs and consumption patterns

Research into identifying the changing needs of consumers and their consumption patterns is necessary for developing new products and advancing the dairy industry.

Novel-food licensing and laws related to dairy products

Research on the formulation of standards and regulations governing the consumption of novel dairy food products is warranted.

Animal agriculture has been suggested to be a potentially predominant and increasing contributor to climate change, land system change, biodiversity loss, water consumption and pollution, and environmental degradation [4]. These effects contribute to a decreased reliance on animal-derived products and an increased use of alternative plant-derived products [4]. Therefore, McDermid et al. argued that food system transformation is required through collecting and analyzing data on the impacts of animal production and consumption on human and natural systems as well as determining whether they interact [4]. In addition, because livestock farming used to be a source of income for a wide range of people in rural areas but now benefits only a few, such as large farms and corporations [5], we believe that multidisciplinary research is warranted to ensure that livestock farming becomes a sustainable industry that benefits the general populace and reduces environmental impacts. However, based on our research, we believe that studies published in Asia on animal agriculture and food that focus on reducing the negative impacts of livestock farming or alternatives for sustainable livestock development are currently limited. We believe that such research can be maximized via collaborative efforts; however, the present study suggests that gaps remain in multidisciplinary research. Although data were not presented in this study, we believe that the main researchers were limited to livestock- or food-related majors, and relatively minimal interaction existed among researchers in animal welfare, global environment, and consumer research. As detailed in the present study, research on the utilization of animal products is dominant, whereas that related to sustainable future livestock production is considerably scarce.

CONCLUSION

This study aimed to investigate current research trends related to animal food products in Asia and predict the research agenda for the future development of the industry. The results demonstrate that the topics of the studies published in major Asian countries, such as Korea, China, and Japan, were significantly diverse, rendering it difficult to systematically identify and categorize them; nonetheless, they included both the latest research trends, such as alternative livestock products, and traditionally researched topics, such as meat quality measurement and antioxidant research. Nevertheless, numerous research topics that have not been included in the future research agenda proposed by our research team remain; therefore, we believe that further research topics can be identified. Although research on sustainable livestock farming, alternative livestock ingredients, cultured meat, plant-based alternatives, and insect- and microbial-derived protein foods, which have recently received substantial attention, has increased, we believe that it is still insufficient. In addition, determining the extent to which previous studies' findings have been applied to industrialization was challenging. Moreover, almost no research on laws and policies related to animal food has been conducted. Therefore, identifying research topics on the latest research trends,

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industrialization, and related policies and laws is imperative. However, as this study was a review of previous research within a relatively limited field, concluding that its results represent global research trends in the field of animal agriculture and food may be difficult; hence, continuous monitoring through additional follow-up studies is warranted.

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