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Food Industry Wastes for the Development of Innovative Functional Pet Food

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ABSTRACT

The review was aimed to discuss the beneficial effect various bioactive compounds harnessed from by-products of both plant and animal origin in the development of functional pet food for dogs . Functional foods occupied a special place in the science of food technology and nutrition. Bioactive compounds became one of the most trending research areas in the field of functional food. This review aimed to highlight the role of various bioactive compounds harnessed particularly from by-products of agro-food-processing and meat processing industries in the development of innovative functional foods for pet nutrition. Additionally this article featured various studies to support the positive impact on the health of pet animals. Functional foods provided proven health benefits to both humans and animals, when consumed on a regular basis. Studies have demonstrated the effect of bioactive compounds in functional pet food formulation such as modified gastrointestinal physiology, promoted beneficial biochemical changes, minimized the risk of developing specific diseases, and improved nutritional stability. These effects were achieved through varied properties such as antioxidant, anti-inflammatory, antimicrobial, antiatherogenic, antithrombotic, cardioprotective, and vasodilatory properties present in various bioactive components obtained from both plant and animal sources. However, further research was required to up-scale production process of bioactive compounds for industrial application and regulatory compliance. This review article threw lights to pet food manufacturers in the development of functional pet foods. It also addressed the need of utilization and up-cycling of food waste for value addition for sustainability of food processors.

KEYWORDS: Functional food, bioactive, health benefits, food industry by-products

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1. INTRODUCTION

Today the influence of food on health and well-being on either human or animals is getting prime importance mainly due to awareness and health consciousness with the rapid expansion of knowledge and better understanding of various bioactive components and their role in the physiological system in both men and animals. Globally pet population is on the rise. The 2024 Global Pet Parent Study estimates about one billion pet population globally. Dogs being the most common pet with 34% and cat (20%) followed by fish (Anonymous, 2021a). Adoption of dogs is on increasing trends, due to steady rise in conjugal family, increasing insecurity, need for companionship, influence from media, and changing perceptions toward pet animals. Today pet dogs and cats are treated no less than a family member and due care is given regarding their diet, health, and overall well-being. However, it has been seen that due to overfeeding, lack of exercise, poor diet, pampering, and humanization; various lifestyle diseases like obesity, diabetes, cardiovascular diseases, kidney problems and arthritis condition are on increasing side. Due to these increasing problems the demands for functional, neutraceuticals, or more healthy pet food products are increasing at a robust pace. Several studies have shown that supplementation of various bioactive compounds as functional ingredients showed positive effect on, which consequently incur beneficial effect on the growth and regulation of the host organ system (Evenepoel et al., 2017; Makki et al., 2018; Tizard and Jones, 2018). The beneficial gut microbiota play a crucial role in the regulation of immune system, which is important for the growth of the intestinal physiology in dogs (Mondo et al., 2019).

The term 'functional foods' refers to processed foods containing ingredients that aid specific body functions besides to its nutritive value. Functional food can be defined as "food products that offer physiological benefits beyond basic nutrition, represent a proactive approach to wellness, harnessing the potential of bioactive compounds to promote health and prevent diseases" (Dixit et al., 2023).

A large quantity of by-products are generated from agro and meat processing industries, and if these by-products not properly utilized, it goes as waste resulting in various environmental pollution and decrease the return from unit animal. However, with the development of technology most of the by-products are further processed to produce various bioactive compounds, which are being utilized in various feed formulations and functional foods. The inedible portion for human consumption consists approximately 40% of the total animal live weight produced globally. The inedible element such as skin, blood, horns, hooves, viscera, bones, hair, and feathers are usually rendered to produce animal by-product meal (such as meat-cum-bone meal, poultry by-product meal, blood meal, animal plasma, and feather meal). These by-products are being used for feeding pet, livestock feeding or as fertilizers. Annually about 9 MT of animal by-product meal and fats are used to produce dry food for dogs and cats (Alexander et al., 2020).

Viewing the practical importance of functional foods in pet nutrition, this article aimed to explore and reviewed the potential of bioactive compounds, emphasizing their nutritive value, functional properties, and their sustainable uses. Thus, the objective of this review paper is to discuss the beneficial effect various bioactive compounds harnessed from by-products of both plant and animal origin in the development of functional pet food for dogs and cats.

2. BIOACTIVE COMPOUND: A ROAD AHEAD FOR FUNCTIONAL FOODS FOR PETS

The term 'bioactive' is synonym for 'biologically active'. Bioactive compounds are a diverse group of molecules with potential health benefits (Kamiloglu et al., 2022; Kumar et al., 2023). They possess certain properties like antioxidant, anti-inflammatory, antimicrobial, antiatherogenic, antithrombotic, cardioprotective, and vasodilatory effects (Kamiloglu et al., 2022; Mohamed, 2015). Bioactive phytochemicals like sterols, tocopherols, carotenes, terpenes and polyphenols can be extracted from tomato or by-products from tomato processing. These phytochemicals possess significant amounts of antioxidant properties, which can be used as natural antioxidants for functional food formulation or as additives in to extend shelf-life of food products (Kalogeropoulos et al., 2012). Bioactive compounds derived from plants are biologically active proteins, polyphenols, phytosterols, biogenic amines, and carotenoids, which are known to have beneficial effect on certain condition like cancer, cardio-vascular diseases, and diabetes (Samtiya et al., 2021). Many co-products obtained from fruit and vegetable processing contains considerable bioactive components like polyphenols, flavonoids, and tannins. And their inclusion could improve overall animal health (Correddu et al., 2020). Curcumin is a natural polyphenol compound obtained from rhizomes of turmeric (*Curcuma* spp.) and it has been used for thousands of years in Ayurvedic medicine. Many studies suggest that curcumin might protect against colitis, stomach ulcers, high cholesterol, and many bacterial and viral infection. It is also credited for its nutritional and pesticide properties improving livestock and poultry production performances and it does not cause any side effects for animals. Today the livestock and poultry feed industries are shifting towards plant-based natural feed additives to improve livestock and poultry production performance. The introduction

of curcumin in the animal diet enhances the growth and increase disease resistance, over-all health and conditions of livestock. Researchers suggest that plant-based natural products like curcumin are promising replacement additives to antibiotics (Sureshbabu et al., 2023). A dietary curcumin supplement in Hu sheep (rare localized Chinese sheep breed) for antimicrobial, antioxidant and anti-inflammatory effect was investigated. And it was found to promote lipid metabolism, antioxidant status, reproductive performance and improve immune ability by increasing the concentrations of IgA, IgM, and IgG in plasma (Jiang et al., 2019). Therefore it may be concluded that curcumin may be used in development of functional pet food to meet the above health benefits.

3. INNOVATIVE GREEN FORMULATION AND THEIR HEALTH CLAIM

One of the most commonly used functional food ingredients found in pet food is dietary fibres. Food ingredients such as wheat, corn, oats, barley and rye which are rich in dietary fibers, trace minerals, vitamin B and E., as well as bioactive compounds like tocotrienols, lignans and polyphenols, lipotropes and methyl donors, such as choline, methionine, betaine, inositol and folate. Dietary fibers can modify gut microflora by promoting the growth of commensal bacteria (Kahlon, 2009). Rice bran is an excellent source of sulphur containing amino acids, micronutrients such as magnesium, manganese and vitamin-B along with tocopherols, tocotrienols, polyphenols such as ferulic acid and α-lipoic acid, phytosterols, γ-oryzanol, and carotenoids such as carotene, lycopene, lutein and zeaxanthin. Functional properties, such as antioxidant, anti-inflammatory and chemopreventive properties of these bioactive compounds have been well documented. And inclusion of the ingredient can contribute to the prevention and control of chronic diseases such as cardiovascular disease, type-2 diabetes and obesity in companion animals (Ryan, 2011). Contrary to this, (Stratton-Phelps et al., 2002) reported that inclusion of 26% full-fat rice bran in a purified cat diet significantly decreased whole blood taurine concentration compared to control group fed on a purified diet containing 26% corn starch. The lower taurine concentration was due to increased fecal excretion of conjugated bile acids in addition to changes in hindgut microbiota due to the indigestible protein fraction of rice bran able to degrade taurine (this amino acid is not degraded under physiological conditions). This study concluded that a higher concentration of dietary taurine as functional ingredients (>0.05%) should be included in feline diets that contain rice bran. Spears et al. (2004) reported that functional food-containing diets with poultry fat combined with 12% stabilized rice bran increased food intake and decreased plasma phospholipid total monounsaturated fatty acids in dogs. Phytosterols are considered as a dietary functional food component due to their ability in reduction of excess cholesterol levels associated with cardiovascular diseases in dogs. Unrefined plant oils, nuts, seeds, legumes, vegetables, and fruits are good source of phytosterols. Baritugo et al. (2023) used phytosterols present in navy bean or dry black bean powder in diet to feed obese dogs, and observed a significant reduction in serum total cholesterol. Significant reduction in serum triglyceride level was also observed when fed with 45% of navy bean powder. However no significant weight loss was observed. The study concluded that phytosterols can be effectively used as functional food ingredients to reduce the excess cholesterol levels thus maintaining better health status for obese dogs. Boileau et al. (2009) investigated the effect of avocado and soya bean unsaponifiables (ASU) on canine osteoarthritis and observed significant increase in the level of cytokine (TGF-β1, TGF-β2) in the synovial fluid of healthy canines on feeding ASU at 10 mg kg^{-1} for 8 weeks. Both TGF-β isoforms are expressed by chondrocytes and osteoblasts for stimulation of synthesis of cartilage matrix, which explains the reduction in cartilage breakdown. Additionally, ASU was shown to be capable of inhibiting inflammatory cytokines (eicosanoid prostaglandin E2, IL-1β, L-6, and IL-8) in articular chondrocytes and stimulating collagen synthesis. Green tea is rich in flavanols, particularly catechin derivatives which have been associated with anti-inflammatory and anti- obesity properties (Hininger-Favier et al., 2009; Li et al., 2020; Rahman et al., 2020; Yang et al., 2009). When dogs fed on a high fat diet for 18 weeks supplemented with green tea polyphenols (low (0.48%); medium (0.96%); and high (1.92%)) exhibited lowered weight gain, mitigated intestinal inflammation seen with the high-fat diet, with reduction of pro-inflammatory cytokines, and also served to counteract some of the resultant gut dysbiosis (Li et al., 2020). The result demonstrated the anti-obesity properties of tea polyphenols exhibiting clear impacts on weight management and obesity-related inflammation in dogs. Non-enzymatic antioxidants, including carotenoids, flavonoids and polyphenols, may reduce renal oxidative stress (Brown, 2008). Supplementation of vitamin-E and carotenoids to 6 to 8 years Beagles breed of dogs for 16 months reduced proteinuria, glomerulosclerosis, and interstitial fibrosis independent of the omega-3: omega-6 fatty acid ratio in the diet (Brown, 2008). Abdelrahman et al. (2020) studied the effect of polyphenol in insulin sensitivity and glycaemic control in Rottweiler dogs. Dietary fortification with rosemary leaves or basil leaves separately at 0.05%, or in combination at 0.025% each, significantly reduced fasting glucose level as compared to the control group after two months on each diet. The hypoglycaemic effect was correlated with the increased insulin secretion in

those receiving basil leaves alone and those receiving the combined fortification. The positive impact on pancreatic β-cell function might be attributed to the polyphenol content of rosemary and basil. Apple pomace, the leftovers from cider industry, may be used as functional food ingredients for weight-loss diets. Nine adult, neutered, obese cats were fed a meat-based diet incorporated with different levels of apple pomace. The result showed than 10 and 20% level significantly reduce the energy density, decreased the digestibility of crude protein and it did not affect the palatability of the food (Fekete et al., 2001). Spice and herbs like basil, cinnamon, clove, ginger, thyme etc. contains active bioactive components such as vitamins, carotenoids, flavonoids, terpenoids, and phytoestrogens, which have an excellent antioxidant property (Carlsen et al., 2010, Panda et al., 2022). Inclusion of one or mixture of these might be useful in development of functional foods, however the strong flavour might also be assessed during the process Canine nutrition is moving towards functional foods fortified with prebiotics and probiotics. Prebiotics are non-digestible carbohydrates that promotes beneficial gut microorganism, imparts resilience and enhanced immunity in dogs. Prebiotics act as fuel for the beneficial bacteria, which might act as probiotics in their gut. Though optimization of doses and individual variability are challenges and required further investigation, however concluded that, interdisciplinary efforts could harness the transformative power of advanced nutrition required by dogs (Kumar and Sharma, 2024).

4. COMPONENT FROM MEAT INDUSTRY BY-PRODUCTS FOR FUNCTIONAL PET FOOD INNOVATION

Utilization of by-products originating from meat industry provides a sustainable and efficient way to enhance pet food nutrition. By-products like poultry by-product powder, meat-cum-bone meal, blood meal etc. are listed in AAFCO and NRC ingredients list for pet food. However ingredients to be used in pet diet must be within the limits of its established safety and utility (Anonymous, 2007). Functional food for dogs containing fructooligosaccharides alone or in combination with, mannanoligosaccharides incorporated with poultry by-product meal, brewers rice, poultry fat, beet pulp, dehydrated egg, sodium chloride, potassium chloride, choline chloride, vitamin premix and mineral premix increased ileal immunoglobulin-A and decreased fecal total indole and phenol concentrations (Swanson et al., 2002). Pet food for dog supplemented with PUFAs such as omega-3 fatty acid aid to decrease the production of inflammatory mediators which ultimately decreases inflammation. PUFAs also act as precursor in development of vital organ systems. Linoleic acid has an important role in maintaining coat health due to its function in maintenance of cutaneous water barrier. Eicosapentaenoic (EPA) acid and Docosahexaenoic acid (DHA) are an important precursor in development of brain, retinal and immune system of puppies and adult dogs (Bauer, 2011; Filburn and Griffin, 2005; Kirby et al., 2007; Lenox, 2015). Varieties of fish such as mackerel, herring, bluefish, salmon, sardines, trout, tuna, and anchovy oil are good source of EPA and DHA. Thus fish oil can be successfully used in canine diets to supplement essential fatty acids. One of the most abundant proteins in vertebrates is collagen, which can be easily and cheaply harnessed from meat industry. It is produced by denaturation and subsequent hydrolysis of skins, bones or fish scales (Hong et al., 2019). It is a key component of connective tissues, including bones, joints, ligaments, and skin in pet animals. About 90% of the protein content of bone is made up of type I collagen. It provides framework for bone materialisation and important for strong-healthy bones. Types I and III collagen are important for strong, healthy skin and coat; helps to maintain elasticity of skin and hydration in dry and itchy skin. Cases of osteoarthritis are increasing in both humans and dogs as well. Dogs are mainly affected by joint dysfunctions. Many of the pet food products include hydrolyzed collagen peptides, which are claimed to benefit joint health. Use of hydrolysed collagen in dog's diet improved chondrocyte function and improvement in the biosynthesis of type II collagen and elastin compared to the control group (Schunck et al., 2017). In another study hydrolysates from the eggshell and membrane improved the mobility of dogs with arthritis (Ruff et al., 2016). Since hydrolyzed collagen feature proven health benefits such as increasing bone strength and density, decreasing the extracellular matrix and the markers of joint degeneration, inhibiting inflammatory cytokines, and improving joint stability. Gelatin hydrolysate is a purified, enzymatically treated protein derived from collagen in bone and skin of swine and cattle. The protein has a typical and unique amino acid composition, rich in glycine, proline and hydroxyproline. Beynen et al. (2010), carried out a double-blind, placebo-controlled trial with privately owned dogs to assess the efficacy of a gelatin hydrolysate preparation in the treatment of osteoarthritis. The result showed that, administration of gelatin hydrolysate significantly improved activity (vitality) and significantly reduced stiffness and lameness. From the study it was suggested that a dose of about 2.5% in a dry food would be beneficial for dogs with osteoarthritis. Therefore these compounds could be successfully used as a nutritional supplement and as an active functional component in pet foods to exert anabolic effects on osteoarthritic joint cartilage as well as disease-modifying effects.

Plasma is a co-product from pork and beef obtained during

the processing of animals for human consumption. Further separation of plasma and cellular fraction (red blood cells and platelets) is done through centrifugation then spray dried to obtain spray-dried animal plasma (SDAP). SDAP can be used to produce wet foods (pates and chunks in gravy). Due to its excellent emulsifying and binding properties, it can be used to replace hydrocolloids partially or totally, which have a negative implication for digestibility, fecal quality, and intestinal inflammation. High digestibility and an amino acid profile of SDAP compatible with high-quality ingredients, such as egg powder makes it an excellent functional ingredients source. SDAP enhanced palatability, act as immunomodulatory, anti-inflammatory, prebiotic, and neuroprotective when used in pet foods (Vasconcellos et al., 2023). Diet enriched with antioxidants can be used to achieve a better reproductive performance. Fourteen dogs were fed on diet incorporated with hydrolyzed fish and potato proteins, Mojave yucca (*Yucca schidigera*), Peruvian maca (*Lepidium meyenii*), and goatshead weed (*Tribulus terrestris*) as functional ingredients. The experiment resulted a constant improvement in testosterone metabolic activity and semen motility and vitality significantly increased in dogs aged between 2 and 7 on 45 days of feeding the enrich diet compared to dogs fed a control diet (Cerboa et al., 2017). Hypersensitivity symptoms could be significantly reduced in dogs and cats by use of protein hydrolysates (derived from industrial by-products of meat production for humans) in hypoallergenic diets, since they do not stimulate immune reactions due to their low molecular weight (Olivry et al., 2017). Use of hydrolysed meat protein in diet have shown positive effect in the long-term treatment of chronic enteropathies in dogs and could help regulation of gut microbiota (Hollmann et al., 2018). A modified thermal extraction protocol was used for the preparation of gelatin from skipjack tuna (*Katsuwonus pelamis*), with an aim to increase the yield, the study followed warm water-coupled NaCl pre-treatment for reduction of lipid content of the extracted gelatin. The modified protocol could able to extract gelatin of 9.30±0.22% from fish skin. Hence it was concluded that the modified protocol could be effectively used for extraction of commercial gelatine (Joy et al., 2023). And this large scale production would contribute to overall nutritional, technological, and functional benefits in the area of food technology more-particularly in the area of neutraceuticals and functional foods for both humans and animals.

5. MARKET TRENDS OF FUNCTION PET FOODS

The actual market size of functional pet foods market is hard to estimate, both locally and globally, due to differences in definitions and interpretations of what is to be included (Siro et al., 2008). Larger enthusiasm for functional foods is observed around the globe; which is evident from the growing demands for functional foods. Studies on functional foods intended for pets indicated that pet owners are willing to pay more due to the added functional ingredients. Thus most suitable pricing strategy for a functional pet food is 'value-based pricing' based on the functional component instead of its production. The global market size of pet food in 2023 was around 117.34 billion USD and is expected to grow at a Compound Annual Growth Rate (CAGR) of 4.4% from 2024 to 2030 (Anonymous). More than 50% of the total market share is occupied by the dog segment. The pet food market in India is estimated at 1.01 billion USD in 2025, and is expected to reach 2.2 billion USD by 2030, growing at a CAGR of 16.74% during the forecast period of 2025–2030 (Anonymous, 2023). As per pet food market (2020), the dog segment accounted for about 50 per cent of the global functional pet foods and is expected to maintain the trend. The functional pet food market size was valued at $ 1,954.8 million in 2020, and is estimated to reach $ 4,676.1 million by 2030, registering a CAGR of 8.8% from 2021 to 2030, and is expected to maintain the trend. As per 'Future Market Insights report, 2022' on the "Collagen supplement market", global demand for collagen supplements is forecast to grow at 6.4% CAGR and will reach US$2.8 billion in 2032. Functional foods with bone health segment are estimated to reach $284.6 million by 2030 at a CAGR of 9.6% (Anonymous, 2023). The market analysis report on functional pet foods in Asia-Pacific showed that, it is expected to grow at a CAGR of 10.90%, generating USD 1,788.85 million during the forecast period from 2022-2030. The market for functional pet foods in China, Japan, Australia, India, and the rest of Asia-Pacific is anticipated to be a very lucrative, due to rising disposable income, rising standards of living, and spending on pet health.

6. WAY FORWARD

The pet food industry has increased the production of functional bioactive ingredients, targeting specific health improvements. Various bioactive compounds derived from both plant and animal sources have been well recognized and considered safe for use as functional ingredients in pet foods (Anonymous). The dietary constituents for claimed health benefits beyond meeting nutritional requirements should be further tested with different breed of dogs or other companion animals in order to increase the validity. Incorporation of bioactive functional ingredients such as antioxidants, immunomodulatory, anti-inflammatory, prebiotic, and neuroprotective agents for functional pet food innovation hold immense potential for improving overall health and approach to combat specific health issues. However identification and understanding

of the appropriate bioactive compounds and their specific function can be a challenging task. Currently most of the pet foods are prepared through extrusion process, therefore the heat stability of the bioactive component need to be studied. Further research should be emphasized on understanding the bioavailability, and to establish the health-diet relationships and benefits. The need of the hour with respect to functional foods intended for pets now is to study the potential toxicity if any due to addition of these bioactive compounds, establishment of uniform regulation, and up-scaling the production to meet the growing demands.

Furthermore, studies on bioactive compounds should focus on assessing functionality, immunomodulatory, antioxidant effect, control of blood pressure, and prebiotic effects. However, scientifically proven data on the beneficial effect of bioactive compounds derived from both plants and animals is still insufficient. However, research in this area is increasing over the last few years and these studies and findings will provide positive contribution in the development of innovative functional food products for pet nutrition.

7. CONCLUSION

The incorporation of bioactive compounds derived from food industry waste presented a promising strategy to develop functional food for pet nutrition. They possessed properties like antioxidant, anti-inflammatory, antimicrobial, antiatherogenic, antithrombotic, cardioprotective, and vasodilatory effects for overall health and prevented certain diseases. Advanced technology helped to transform the by-products from agro and meat industries into valuable resource used in functional pet food could enhance economic return meeting the demand of pet.

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