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The Formulation of Poultry Feed Using Different Categories of Food and Crop Waste for Economic and Environmental Sustainability

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ABSTRACT

In Bangladesh, we are living in an era of unprecedented population growth. To feed the overpopulation on earth, particularly in Bangladesh, the immediate response often is to ramp up the production throughout the country. The cultivable land is decreasing drastically for abrupt industrialization, urbanization, road transportation etc. Moreover, the increased production and industrialization of agricultural sector generate lot of waste products which is the cause of environmental challenges. Therefore, this article aims to arrange the current knowledge on utilization of these nutrition rich waste products to formulate poultry feed as poultry is the mostly consumed affordable protein nutrition in the world. But the rising costs of poultry feed creates a significant challenge for farmers worldwide, impacting the profitability and sustainability of poultry production. Hence, this article describes the conversion of different categories of food and crop waste into poultry feed, their effect on health and performance of birds, safety and challenges of the formulated feed product and different country's initiative to use food and agricultural wastes as feed to maintain the economic and environmental sustainability.

Key words: Poultry feed; Food and crop waste; Bioeconomy

INTRODUCTION

Today's world takes us to face both increasing food demands, rising costs of food and environmental challenges. As the population of the world is increasing the demand for food and agro-industrial goods together with their prices are also rising. Therefore, continuous production of agricultural and agro-industrial products generates enormous quantities of agricultural, agro-industrial residues and food, fish, slaughter house wastes with diverse characteristics. It is estimated that about one-third of all food produced globally is lost as waste, causing a loss of US$ 1 trillion annually [1].

As food is wasted, the costs associated with the production, processing, delivery, and selling of that food are also lost. Food waste refers to food and the associated inedible parts not ultimately consumed by humans rather it is discarded, and refers not only to food that consumers don’t finish at restaurants and are thrown out at home, but also raw materials and produce that are lost in the farming stage, harvesting process, during transportation, and storage [2]. Inedible parts of food include peels, bones, fins, skin, rinds, pits, stones etc. Food waste can occur anywhere throughout the entire supply chain.

At present achieving food security, ensuring sufficient, nutritious and safe food for all and maintaining agricultural sustainability is a global challenge and these are presented in the United Nations' Sustainable Development Goals (SDGs), particularly Goal 2, which refers to Zero Hunger [3]. This goal emphasizes the necessity to end hunger while achieving food security through improved nutrition and promote sustainable agricultural practices and zero loss or waste of food. Food waste can be minimized or making zero taking different initiatives using food waste for producing different valuable products. This can contribute to economic growth and environmental cleanliness.

In addition, improper waste management and disposal of the generated crop, fruit, food, fish waste here and there can lead to a variety of environmental problems including development of breeding grounds for disease-causing microbes, reduced water holding capacity, altered soil biological metabolisms, unbalanced nutrient cycles, uneven organic matter distribution, and the generation of greenhouse gases such as CO_2, N_2O, SO_2, CH_4, and smoke [4]. Greenhouse gases trap heat and make the planet warmer and lead to global warming and climate change, with wide-ranging negative impacts on human health, the environment, and the economy. In developing countries, including Bangladesh, burning agricultural waste is a common practice that causes considerable air pollution. Crop residue burning has a wide range of consequences on and off farm, including losses in soil nutrients, soil organic matter, production and productivity, air quality, biodiversity, water and energy efficiency, and human and animal health [5]. Instead of random disposal here and there, different categories of agricultural crop and kitchen food waste, fishery, meat waste that are rich in nutritional properties can be used as precious raw materials for the production of value-added products such as Single-Cell Protein (SCP), enzymes, feed additives, animal feeds as well as other useful products or as a source of renewable energy. This article will emphasize on the formulation of poultry feed using agricultural, agro-industrial and market, kitchen and restaurant food waste, fishery, slaughterhouse waste that can be used as cheap source of poultry nutrition for enhancing the poultry farming in the rural level; thus, maintaining the circular bio economy and minimizing environmental pollution.

Poultry are domesticated avian species that are raised commercially or domestically for eggs, meat and/or feathers. In Bangladesh, most common poultry are chickens, turkeys, ducks, geese, pigeons, quail etc. Poultry represent the largest domestic animal stock, and poultry meat and eggs are the mostly consumed, affordable high-quality protein throughout the country as well as throughout the world. But commercially available poultry feed is becoming expensive day by day [6]. For sustainable poultry production availability of low-priced, high-quality feed is a vital requirement. The good side to work on poultry feed is that poultry eat anything and everything [7]. They are omnivores, which means they eat both plants/vegetables and meat.

Worldwide practical poultry diets are formulated using a mixture of ingredients, i.e. cereal grains, cereal by-products, fats, plant protein sources, vitamin and mineral supplements, crystalline amino acids and feed additives [8]. Increasing costs and decreasing supplies of traditional feedstuffs (due in part to food-feed competition and population growth) can affect the future expansion of poultry production. Recently some deceitful people are using Tannery Solid Waste (TSW) for producing livestock feed especially for poultry as TSW are protein rich and cost-effective [9]. The feeds using TSW may contain toxic chromium, which accumulates in the poultry and cause chrome contamination in human food chain. Therefore, it is an urgent need to make greater use of a wide range of alternative feeds (e.g. crop-food-fish waste, insect meals) in poultry diets. We should focus on three areas for improving the poultry nutrition i.e. understanding and development of nutrient metabolism and requirements, determination of the availability of nutrients in feed ingredients and formulation of cost-effective poultry diets for supplying sufficient nutrients.

LITERATURE REVIEW

Benefits of transforming food and crop waste into poultry feed

Transforming food scraps and other edible leftovers to poultry operations and converting agricultural, agro-industrial, fishery, slaughterhouse waste to make bird feed can directly benefit the planet and make the farming industry more sustainable.

Environmental benefits

Conversion of food waste to animal feed offers numerous environmental benefits. It reduces the amount of food waste sent to landfills; thereby minimizes greenhouse gas emissions associated with decomposition. Additionally, the reliance on conventional feed ingredients, which often require intensive agricultural practices and resource consumption, can be diminished. Replacing conventional feed with food waste can conserve land, water, and energy resources, contributing to a more sustainable food system. Repurposing food waste for livestock, poultry meals keep the value of food material within the food system maintaining huge environmental savings.

Economic impact

- Lowers costs for farmers by offering a cheaper alternative to traditional feed.
- Creates opportunities for businesses by processing and distributing food waste as feed.

Steps for producing poultry/ livestock feed from different types of food/ crop waste

Collection

Collection of food, crop, fishery, meat and bone waste from various sources, including restaurants, supermarkets, house, slaughterhouse, fish market, food processing facilities etc. The waste is then separated into organic and non-organic categories, with non-organic waste disposed of appropriately.

Pre-processing

In this stage, the food waste is thoroughly checked for remaining non-organic materials and sorted based on its suitability for different types of animal feed. This step ensures that only high-quality organic waste moves forward in the process.

Heat Treatment

The waste then undergoes heat treatment or sterilization. The goal is to reduce moisture, eliminate harmful substances, kill any disease-causing agents and pathogens, and break down complex nutrients into a form more easily digestible by birds, animals preventing any health risks to the respective birds, animals and, subsequently humans.

Conversion

The conversion process may involve several methods, including fermentation, dehydration, and grinding, which help in elevating the nutritional value of the feed and make it easy for feed handling, transportation, and longer shelf-life. Due to the abundance and availability of fiber-rich ingredients in food related waste, recycling and bio-valorization through microbial fermentation is an excellent strategy for waste management among different conversion processes. Microbial fermentation is the biological process that can convert food, agricultural and agro-industrial wastes into useful, value-added products. It can improve the nutritional quality of feedstuffs by reducing dietary fiber and anti-nutritional factors and enhancing lipids and protein levels. Moreover, amino acid composition, protein digestibility, vitamin availability, calcium, and organic matter digestibility can be improved by fermentation [10]. It has been reported that bacterial fermentation results in the production of a considerable amount of lactic acids, which would retard harmful bacterial multiplication in the gut, minimize nutrient and dry matter loss during storage, and boost the palatability of the diet to the animal [11].

Quality control and distribution

Quality control is critical throughout the processing phase to ensure that the final product meets safety and nutritional standards. Palatability is another important factor of processed feed, as poultry may reject feed if it has an unpleasant taste, smell, or texture. Therefore, formulation of software and nutritional modeling are necessary to adjust and balance the inclusion rates of novel ingredients tested based on their nutritional content. Once the feed passes the nutritional content and safety checks, then it’s packaged and ready for distribution.

Effects of feeding recycled food waste and fermented agricultural and agro-industrial products to chickens

Feeding birds and animals with food scraps is a common practice in many countries, particularly in the developing world. This practice has several disadvantages, including nutrient variability, inconsistent waste supply, and risks associated with sanitary conditions and biological contaminants, such as live bacteria and viruses. However, with the application of modern processing technologies, it has been demonstrated that poultry feed may be formulated from food waste materials that meet the birds’ nutritional requirements and hygiene and safety standards [12].

There are many studies where effects of different food-waste based diets were observed in laying hens and broiler chickens. The paper of the journal scientific reports demonstrated that higher feed efficiency was observed in laying hens treated with food waste based-diets compared to when they are offered a standard diet based on wheat, sorghum, and soybean meal. If food waste-based diets have higher energy, fat, fiber, and protein levels hens consume less feed and are more efficient in converting feed to egg mass than the control treatment. It is widely accepted that feed intake is inversely related to the dietary energy and/ or fat level [13]. Furthermore, the high fat and protein content of food waste may result in a more efficient metabolism, possibly due to the higher net energy to Apparent Metabolizable Energy ratio [14]. According to a study, energy digestibility is higher in hens offered the food waste-based diets compared to those offered the control diets. These are likely the reasons for the higher feed efficiency in hens offered food waste-based diets [15].

In addition, current diet-formulation practice feeds birds as if they are strictly granivores, neglecting the fact that they are actually omnivores [7]. Hence, modern poultry nutrition typically relies on grain-based diets. Food waste-based diets may allow optimization of the genetic potential of birds as omnivores. Therefore, the digestibility and availability of nutrients within key waste streams should be evaluated to ensure accurate diet formulation. Dao et al demonstrated that food waste is a suitable feedstuff and its nutrient content can be rapidly determined by Near Infrared Spectroscopy (NIR) to combat any variability issues [15]. In the study of Dao et al., hens offered food waste-based diets were in general lighter than those offered the control diets based on wheat, sorghum, and soybean meal [13]. In the study, hens on the control treatment consumed more feed than the food waste treatment, but instead of using it for production, the excess nutrients were likely deposited as fat and/or excess heat increment, explaining the extra weight and higher Feed Conversion Ratio (FCR) of the control hens.

According to a study, replacement of the commercial feed with 30% of kitchen waste-based feed for laying hens has no negative effect on production performance and egg characteristics. This study summarizes that partial substitution of food waste as feed stuff may be an efficient way of using waste food. This practice can help to meet the growing demands of the poultry production in decreasing cost of commercial feed and provide cheap, tasty and nutritionally enriched organically raised eggs of best quality to the customers [16]. In the study of Hossein and Dahlan, 20% inclusion of dehydrated processed food waste in formulated feed showed no adverse effects on growth performance (feed intake, body weight gain, body weight change and feed conversion ratio) of free-range village chickens [17].

Many countries use unsold bread from bakeries in poultry feed formulations and this can effectively replace grains, such as maize in poultry feed with 100% incorporation. Other types of recovered food (e.g. leftovers and kitchen scraps from households, restaurants, cafeteria/other food service institutions, restaurants, household composts, markets or supermarkets) are also included with the range of 5 to 30% to formulate poultry feeding in different studies [18]. After evaluation of feeding recovered food at various growth stages, one study concluded that recovered food inclusion was not appropriate for birds at the 0-4 week period due to negative impacts on growth performance that was not seen in 4-8 week old birds [19].

Regarding bone quality in laying hens, studies reported that bone strength in birds is not only influenced by bone mineral density but also by organic factors, such as collagen crosslinkage in bone [20]. Mineral sources in food waste-based diets are organic sources i.e. fish offal, spent brewers' grain, pub and restaurant meal, recycled meat and bone meal, hospital and nursing home meal, vegetable and fruit meal, oyster, shrimp shell meal etc. whereas the minerals present in the control diets are inorganic sources, such as limestone and di-calcium phosphate. It is widely accepted that organic minerals are more bioavailable and digestible compared to inorganic mineral sources [21]. Organic minerals diminish the complexation of trace minerals with phytate, fiber, and macro minerals, such as Ca and/or P, leading to fewer antagonistic reactions with these dietary components during feed digestion. Kibala et al, found that utilization of 15%, 30% and 45% kitchen food waste in laying hen diet did not exert any negative effect on egg shell strength [22].

According to Nonga et al., many factors such as age, feed, chicken ecotype, live body weight, and genetic makeup of the birds affect egg weights [23]. In the study of Sarwar et al. egg weight was highest in the 30% kitchen food waste treated laying hen groups. The 15% and 45% kitchen waste treated groups also showed greater values of egg weight than control group treated with commercial feed. Egg yolk height, weight, diameter, index and ratio were highest in the 30% kitchen food waste treated chicken group as compared to other treatment groups [16]. In a study, Kojima reported higher production rate of eggs when 25 % food waste was substituted in the diet [24]. Desired production performances could be achieved by adding amino acid concentration to low energy diets [25].

Previously it is mentioned that biological process like fermentation is used to enhance the nutritional quality of food waste and decrease the quantities of anti-nutritional factors such as hydrocyanic acid, oxalates, phytates, tannins, polyphenols, saponins etc. that impair nutrient availability and digestibility of feed and agro-industrial byproducts [11]. Biotransformation using microorganisms have been shown to enhance chicken feed's chemical composition and nutritional value [26]. Lu et al. reported that microbial fermentation increased levels of organic acids (citric, succinic, and butyric), amino acids (Ser, Gly, Cys, Leu, Lys, His, and Arg), crude protein, and levels of neutral and acidic detergent fibers in soybeans and other flour types. The findings demonstrated that fermentation by microorganisms altered the feed's chemical makeup and boosted certain nutrients [27]. Guo et al. showed that microbial fermentation increased the crude protein content of the substrate substantially [26]. The breakdown of macromolecular proteins, primarily antigenic proteins, may have contributed to the rise in crude protein. Use of endophytic fungi doubled the crude protein level in biotransformed crop residues. The rise in crude protein could be due to the fungi's production of mycelial proteins or the fermenting fungus's growth, breaking down complex polysaccharides into single-cell proteins. The extracellular enzymes-amylases, cellulases, xylanases, and pectinases-secreted by fungi to use complex polysaccharides may be the reason of the processed material's higher protein concentration [28,29].

Fermentation has been demonstrated to improve the feed's palatability and digestibility of numerous nutrients, including calcium, nitrogen, amino acids, fiber, and organic matter [30].

Feeding fermented feed has been shown to positively affect the quality of the eggs in laying hens. Studies have demonstrated that fermented feed prepared from *Lactobacillus salivarius, Bacillus subtilis*, *Lactobacillus butyricum*, and yeast can reduce feed conversion and improve performance and protein quality in laying hens [26]. Fermented feed supplementation has also been shown to significantly improve the hen laying rate and the quality of the eggs, significantly increase both albumin levels and Haugh unit value and reduce the percentage of broken eggs and feed conversion rates.

There is a study where effect of fermented feed on broiler growth performance, the metabolism of nutrients, and gastrointestinal health was observed. The fermented feed was made by mixing the bran of wheat, corn, soybean meal, and water and fermenting with lactic acid bacteria for 48 h. The outcomes demonstrated that the broilers' growth performance and nutrient metabolism were enhanced by the addition of the fermented feed to their diet. The 10%- and 15%-fermented-feed groups had the highest body weight gain and feed conversion ratio. The broilers' fecal microbiota was also changed by the addition of a fermented feed, with more significant abundances of good bacteria like Lactobacillus and Bifidobacterium in the 10%- and 15%-fermented-feed groups. The inclusion of fermented feed, on the other hand, did not affect carcass yield or meat quality. It is important to note that adopting alternative feed ingredients for poultry poses significant issues and constraints. For instance, additional processing and handling may be required to assure safety and quality when employing bioconverted byproducts as feed ingredients. Also, fermented feed may require careful monitoring to ensure proper fermentation and prevent contamination. Despite these challenges, using alternative feed ingredients for poultry can contribute to sustainable agricultural practices and reduce waste. The studies suggest that bioconverted residues and fermented feed can be used as broilers' feed without affecting growth performance or meat quality [31].

Safety of recycled food waste and fermented animal feed

Transforming food waste into livestock and bird feed can play an important role in a sustainable economy; but it has some complexities. If food waste is not managed properly, it can pass on bacterial, parasitic, viral diseases to animals that can cause health problems to humans [32]. In the past, food waste fed to animals has been associated with serious outbreaks in people. For example, a neurological condition called bovine spongiform encephalopathy (commonly known as mad cow disease) was spread when calves ate meat and bone meal made from cattle. This epidemic peaked in 1992 and killed more than 200 people [33]. These risks can be avoided by treating the feed before it is given to animals. In the U.S., for example, food scraps derived from animals must be heated to boiling temperature (212 degrees Fahrenheit) for 30 minutes to kill off any disease-causing bacteria before the scraps get fed to pigs [34]. Therefore, for promoting the production of feed using recycled food and agricultural waste, assurance of safety is one of the main priorities. Besides it is important to guarantee regularity of supply, nutrient values, quality and preservation and low production costs of produced feed from recycled food waste. In this regard, in Japan the Ministry of Agriculture, Forestry and Fisheries (MAFF) issued a guideline for the safety assurance of recycled food waste products in August 2006 [12]. The guideline was made to control health problems of general animal and people of their country to prevent Bovine Spongiform Encephalopathy (BSE) [35]. Generally, manufacturers using recycled food waste to make feed are subjected to obligations under the Feed Safety Law.

Despite policy challenges, researchers around the world are looking into better ways to transform food waste into animal feed. At present conversion of commercial food waste into animal feed is a major challenge because of varying nutrient levels in the final product and the high cost due to additional steps like manual waste sorting. Another problem is food scraps break down during transportation and storage owing to high concentration of water. To solve these issues, scientists are looking into new techniques such as utilization of solar energy to dry out food waste to increase its shelf life and make it easier to transport to farms-while also reducing greenhouse gas emissions in the treatment process [36].

Some researchers think insects can help transform food waste into better animal feed. Black soldier fly larvae, for instance, can munch on food waste (up to around four times their body weight per day) and help create feed that's higher in protein than scraps alone [37]. It also saves a lot of energy and space compared to other methods of animal feed production.

DISCUSSION

Regarding fermented feed products, these are beneficial but they also have some health risks. The particular concern is the safety of Solid State Fermented (SSF) feed product developed from food and agro-industrial waste. During the fermentation process the growth of microorganisms are influenced by the conditions of fermentation, such as pH, temperature, moisture content, and inoculum size. If the fermentation conditions are not controlled properly then quality, safety and acceptability of fermented feed product can be affected. Changes in any of the physiological and chemical factors necessary for microbial growth and nutrient assimilation can result in the production of mostly mycotoxins-aflatoxin, fumonisin, ochratoxin, patulin, trichothecenes and zearalenone – and other deleterious substances in an SSF product [38]. Consumption of this toxic feed may cause different diseases; such as weight loss, loss of appetite, reduction in feed intake, feed rejection, a poor conversion rate of feed after consumption, and a low reproduction rate [39]. Therefore, toxicological assessments are carried out routinely on the final products of SSF to ensure the safety for consumption. Furthermore, microbial toxins are evaluated for their toxicity on the essential organs of animals using animal models. For doing so, essential organs of animals such as liver and kidney are excised and tested for biochemical changes in alkaline phosphatase, aspartate aminotransferase, alanine aminotransferase, creatinine, and urea concentrations. Moreover, fermented products of agro-industrial wastes also contain higher concentrations of nucleic acid together with microbial toxins compared to conventional animal feed. High contents of nucleic acid-containing proteins in fermented feed can cause an increase level of uric acid in the blood, resulting in gout and kidney stones [38]. Therefore, Zhang et al, thoroughly reviewed some technologies such as the use of microorganisms, enzymes, appropriate fermentation temperature, and chemical degradation technologies etc. for the remediation of these biomolecules in fermented products [40]. Nasseri et al. suggested that a toxicological assessment of fermented food and feed products is a prerequisite to ensure the safety of final products of fermentation for consumption, both for humans and animals [41].

Status and utilization of recycled food waste and fermented agro-industrial wastes as animal feed in Bangladesh

Since Bangladesh is an agricultural country, the economy of Bangladesh depends largely on agriculture. The agriculture sector in Bangladesh comprises crops, livestock, poultry, fisheries, and forestry. For managing the demand of rapidly growing population in Bangladesh significant investments are done in the food and agriculture industry. Increasing population together with industrialization of agricultural sector generates huge amounts of food and crop wastes that create a significant environmental challenge. According to a statistics, in Bangladesh annual food loss and waste is over 2.11 crore tonnes while it is around 62.78 lakh tonnes at production stage, 68.81 lakh tonnes at postharvest stage, 32.30 lakh tonnes at processing stage, 31.62 lakh tonnes at distribution and 16.35 lakh tonnes at consumption stages [42]. In Bangladesh, food loss and waste generation is primarily linked to agricultural operations, restaurants, kitchen trash, and related residential activities and social parties. Thousands to millions of tons of food are wasted every year as a result of these anthropogenic activities that are not addressed by any comprehensive regulation. In general, no specific food loss and waste management policy is followed in Bangladesh. Food waste is usually managed as a component of Municipal Solid Waste (MSW) in Bangladesh. Usually, the food waste is disposed of or minimized through the three most common procedures, which include land filling, open burning, and sometimes open dumping. Recycling of food waste is very limited. It can be done through three traditional methods i.e. aerobic digestion, animal feeding and composting which can be applied to any sort of food waste that occurs in our environment. But the appropriate knowledge of the types of food waste and their innovative and sustainable management policy in Bangladesh is not well established whereas global research has already taken several cutting-edge policies and valorization approaches for managing and recycling global food waste [43,44]. In this context, Bangladesh needs policy formulations and research to utilize the vast amount of food waste as a bio resource for the production of economically useful products.

Global research on the application of recycled food waste and fermented agro-industrial waste in the production of animal feed

A European Union project on sustainability in agriculture has revealed that incorporation of plant and dairy wastes into feeds for broilers could significantly reduce the carbon footprint of poultry meat production [45]. The produced food waste not only pushes up greenhouse gas emissions for overall food production, but it also represents huge wastage of precious natural resources, including water, land, energy, labor and capital. Therefore, NOSHAN project in Spain started to work on the process and technologies for using food waste to produce feed at low cost, low energy consumption in 2012. The project identified functional feeding ingredients from food waste to meet the demand of animals [46].

Many countries, including Japan, South Korea, Taiwan, and the US, have already implemented recycled food waste for making animal feed [38]. In South Korea approximately 46% and in Japan 40% of mixed food waste is recycled as poultry and livestock feed, thereby reducing the cost of animal feed 40 to 60% in these countries [47]. In the US, 84- 86% of food waste is diverted to land applications or animal feed from the processing sector [48]. For managing food waste Australia has started food recycle by converting food waste into poultry feed [49].

In case of fermentation technology, microbial fermentation is applied to produce popular indigenous fermented foods worldwide, such as koji, miso, shoyu, tofu, idli, ontjom, tempeh, sauerkraut, chichi, champu, dawadawa, gari etc. Fermentation biotechnology is very popular in south-east Asia where corn, wheat, rice, barley and soybean are usually used as raw materials for Solid State Fermentation (SSF) [38]. Fermented foods are usually consumed by humans. Asian countries (India, China, Japan, Malaysia, Singapore, and Indonesia) have contributed immensely to animal-feed production through SSF technology, where nutrient-rich feed and single-cell proteins have been developed from agro-industrial wastes. It is well known that anaerobic SSF technology can reduce anti-nutritional factors and improve nutrient contents in feedstuffs.

In the Philippines, agro-industrial wastes like banana stalks, cabbage waste, corn stalks, and peanut tops are used in hog feed production [50]. In Ghana, feeding laying hens with processed *Mucuna* beans also reduced feed cost, improved egg production, and increased profit. Adzitey et al. reported that processed *Mucuna* bean meal used as substitute for fish and soybean meal had no adverse effects on the carcass characteristics, primal cutting, or meat quality of broiler breast and thigh [51].

In Europe, several initiatives have been taken toward biotransformation and valorization of agro-industrial wastes into value-added feed products under controlled fermentation procedures. These initiatives have contributed to sustainable waste management and the creation of eco-friendly environments. For example, few companies in Europe commercialize fermented animal feed products and their additives. European protein, with branches in Denmark, Ukraine, and the United States of America, is a company that applies SSF to produce fermented feeds for the Asian and Eastern European markets, where they supply protein-rich soybean and rapeseed meals for poultry and pigs [38].

Developmental Strategies for Processing Poultry Feed from food and crop waste

Some strategies should be adopted for using food and crop waste to make poultry feed. i) Food and crop waste can be dried or silage to enhance preservation before being used as feed. In case of fermentation, knowledge on different microorganisms (bacteria, fungi and yeast) should be gathered and taught to farmers. It is particularly important in those areas where food and crop processing is done. Identification of right and acceptable food and crop wastes in amounts is important for commercial production of feed. ii) Research partnership between the research organization and private sector is necessary for commercialization of mass production of feeds. Regarding fermentation, growth kinetics of different micro-organisms under different food and crop wastes should be facilitated to find out the optimum conditions for commercialization of the technology. iii) There should be a systematic plan to implement research findings on use of food and crop waste as feed to the end user level for benefitting the stakeholders in poultry industry. iv) People engaged in poultry farming should be encouraged to rear insects and use SSF technology on a small and medium scale alongside industrial mass processing. This will promote sustainable production of feeds from food and crop waste and also create employment opportunities. v) Upon successful research on economic and technical feasibility, a supportive legal environment is required to facilitate the processing, trade and utilization of food and crop waste in the poultry feed industry. This will create collaboration between regulators, researchers and private sector. vi) Prior to feeding, the nutritional composition of most food and crop waste should be done as different food and crop waste have different nutritional composition. This practice will be helpful to develop a proper feeding system for chicken. vii) In addition, the poultry farmers need to be well-informed through short extension classes or on-farm visits about the nutritional demands of poultry products and the development of best suitable feed alternatives for poultry.

CONCLUSION

The increasing demand for chicken and other poultry products has accelerated the requirement of more nutritionally enrich feed stuffs globally but feed resources are becoming expensive day by day. So, it is important to embrace alternative sustainable feeding strategies in poultry production to achieve Sustainable Development Goals (SDG) 2, Zero Hunger. Through adoption of innovative alternative feeding practices, the poultry industry can greatly contribute towards global food security as well as environmental sustainability. Academia, industry, government collaborations can enable the development of affordable, sustainable feeding solution using food and crop waste. Moreover, clear guidelines must be followed to ensure the safety, quality, and environmental benefits of alternative feed ingredients.

DECLARATIONS

Conflict of interest

The authors declare no conflict of interest.

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Author contributions

The authors contributed to the conception, design, analysis, interpretation, and writing of this manuscript.

Consent for publication

Not applicable.

Declaration of interest

The authors declare no conflicts of interest related to this work.

Availability of data and materials

All data generated or analysed during this study are included in this published article.

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