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Potentials of Solid State Fermented Non-Conventional Feedstuffs: A Review

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Abstract
There has been an increasing development in the utilization of biotechnology especially solid - state fermentation. Solid-state fermented feed has been a possible strategy to close the gap between supply and demand of feed resources, promote feed hygiene safety, enhancing energy conservation and emission reduction. It has also been associated with methods of improving the nutritional value of non-conventional feed stuff. The process of fermentation has been employed to produce functional feed that has potentials to improve birds' gastro intestinal tract micro ecology, health and production performance. This study reviews the potential of solid state fermented non - conventional feed stuff on the growth performance, gastro intestinal health, meat yield and quality. This is essential as it will further reduce the cost of feedstuffs needed for production because solid state fermentation will enhance the utilization of non-conventional feedstuffs by monogastric animals. The study also reveals the need for more research in the application of fermented feed especially in monogastric animal production, it likewise shows the need for the most cost effective process of solid state fermentation.

Keywords: Biotechnology, Feedstuff, Growth performance, Non-conventional, Solid State Fermentation

Introduction

In recent times, there has been a hike in the global feed prices leading to an increase of over 70% in the cost of feed in poultry production (Zhang et al., 2022). In addition to the high cost of feed ingredient, is the massive increase in the world population thereby multiplying the need for increase in Livestock production (Sujani and Seresinhe, 2015). The Food and Agriculture Organization (FAO, 2021) projected that due to population growth and rising incomes, between 60 and 70 percent more food will need to be produced in the next 35 years. By 2050, there is expected to be a 3 billion ton demand for cereals for both human and animal feed, meaning that the 2.1 billion tons of cereals produced annually will need to be increased by nearly a billion tons. In contrast, the production of meat must increase to more than 200 mil Zhang lion tons in order to reach 470 million tons overall in 2050. Developing nations will consume 72% of this total, as opposed to the current consumption rate of 58%. Additionally, it was stated that by 2030, there would be a shortage of animal protein due to Nigeria's expanding population of over 200 million people (FAO, 2021).

The Nigerian livestock feed market faces competition from other industries for the use of traditional ingredients. The cost of completed feed is increased even more by this competition.

One suggestion for resolving this issue is to shift focus to the utilization of agricultural byproducts. Livestock productivity was somewhat increased by the traditional methods of livestock improvement employed in the past. These alternatives, however, are no longer able to support production; new, labor-intensive methods, such as biotechnology, are now necessary to argue productivity (Tesso and Liu, 2017).

According to Asmare (2014), contemporary biotechnology holds promise for creating new avenues for achieving increased livestock productivity in a way that reduces poverty, enhances food security and nutrition, and encourages environmentally safe and sustainable resource use. Nigeria is a country rich in agro-industrial by-products; some examples are soybean meal, brewer's dried grains (BDG), rice bran (RB), palm kernel meal (PKM), corn bran (CB), and cassava peels (CP). The possibility of using these by-products for livestock feeding has been investigated, but with limited success due to processing costs. The disposal of agro-industrial by-products has been a significant environmental challenge and very expensive for most industries (Iyayi and Aderolu, 2014).

Because these non-conventional feed resources (NCFR) contain anti-nutritional factors, their use in feed formulations is limited. Prior to including NCFR in feed formulations, these anti-nutritional factors need to be eliminated (Pathak et al., 2022). By lowering the cellulose content and raising the acid-soluble protein content, solid state fermentation, one of the methods of contemporary biotechnology, has been shown to be a successful strategy for increasing the nutritional value of unconventional feed sources or agro-industrial byproducts (Teng et al., 2017).

Microorganisms and enzymes are used in the field of fermentation technology to create various compounds (Pathak et al., 2022). According to Zhang et al. (2022), fermentation has several advantages, including raising the concentration of organic acid, lowering pH, and increasing the number of lactic acid bacteria (LAB). Reviewing the possibilities of solid state fermented non-conventional feedstuff in chicken production is the goal of this work.

Solid State Fermentation

Microorganisms grow on solid materials during solid state fermentation when there is no free water present. The necessary moisture is present in the solid matric in an absorbed state, but the substrate still needs to be sufficiently moist to support the growth and metabolic processes of microorganisms (Akintunde et al., 2011; Olukomaiya et al., 2019).

Most notably, filamentous fungi belonging to the genera Aspergillus, Fusarium, Penicillium, Rhizopus, *Bacillium spp*. and Trichoderma are employed in solid-state fermentation (Zhang et al., 2022). Conditions including initial moisture, particle size, pH, temperature, media composition, operating system, mixing, sterilization, water activity, inoculum density, agitation, aeration, product extraction, and downstream process all affect the quality of solid state fermentation (Santos et al., 2021).

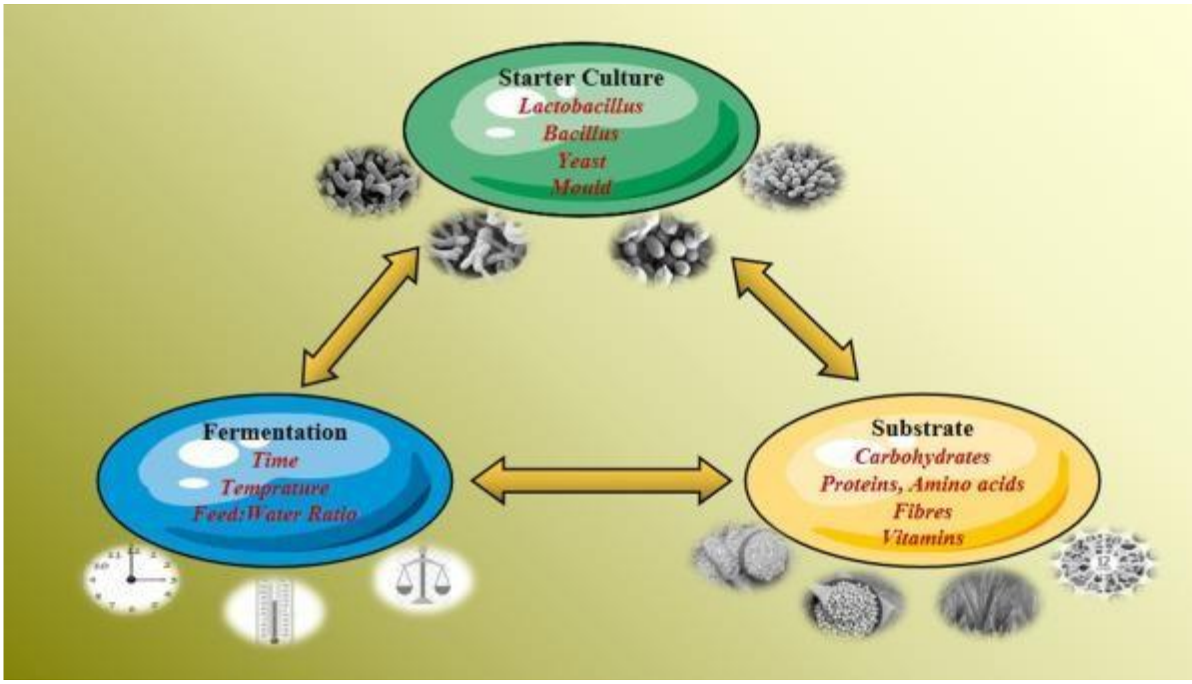

Fig. 1. Interactions in fermented feed among micro-organisms present, fermentation parameters, and substrate quantity and quality that influence final end products.

Source: Yang et al. (2021)

According to Olukomaiya et al. (2019), it is favored to utilize agro-industrial byproducts or residues as feedstock for solid state fermentation. They are widely available, they compete less with humans and livestock, their nutrient composition is appropriate, and they can promote microbial development during solid state fermentation, all of which make them crucial to the production of high-value feed.

Solid State fermented Non- Conventional feed Stuff and its Nutrient Composition

Zhang et al. (2022) conducted a research on wheat bran's solid state fermentation. To create fermented wheat bran, *Lactobacillus acidophilus* (NHB-La13), *Bacillus subtilis* (NHB-Bs32), and *Saccharonyces cerevisiae* (NHF-Sc9) were inoculated into wheat bran in a vacuum tank. The strains' primary characteristic is that they secrete protease and cellulose. Anaerobic conduction solid state fermentation was carried out for 12 hours at 300^{o}C. Fermented wheat bran (FWB) showed slightly higher value of crude protein and crude ash compared to raw wheat bran (RWB), crude protein 18.5% - 16.62%, crude ash 6.2% - 5.3%. Compared to the RWB, the following recorded lower percentages starch 6.2% - 7.3%, crude fiber 7.2% - 8.8%, neutral detergent fibre (NDF) 28.9% - 36.3%, acid detergent fibre 9.8% - 10.2%. The NDF showed the biggest shift, falling from 36.3% to 28.9% on a DM basis. Comparing fermented WB to RWB, the amount of acid soluble protein increased by about seven times, from 1.21% to 8.34%. During fermentation, the pH of RWB dropped from 6.7 to 4.7 and the number of *Bacillus subtilis* and lactic acid bacteria (LAB) quickly increased. There was a 3% rise in the amount of organic acid. During fermentation, the cellulose or NSP enzyme activities caused a decrease in the NDF content of FWB.

Similar drops in crude fiber content were noted by Supriyati et al. (2015) after fermenting rice bran with *B. amyloliquefaciens*. Numerous types of enzymes, including α-amylase, protease, and βendoglucanase, are produced by *Bacillus subtilis* (Zhang et al., 2022). These enzymes have the ability to break down complex molecules into smaller molecular components, especially lignocellolase, which is a limiting factor in non-conventional feed. Zhang et al. (2022) found that the FWB increased by 1.88% in comparison to the RWB. It was found that, rather than an actual increase in protein content, the increase in crude protein is most likely the result of a decrease in the levels of other nutrients, especially in relation to the fermentable carbohydrate content, which caused the protein content to increase proportionately. The rise in protein content is comparable to what Suprigati et al. (2015) found after fermented rice bran.

Solid state fermentation was performed on canola meal and rapeseed meal by Olukomaiye et al. (2019). Depending on the amount of hull and processing technique, the leftover rapeseed meal, after the oil was extracted, contained 34% to 36% crude protein. However, the amount of glucosinolate present restricts its use in chicken feed. After the oil was extracted, canola meal contained 40% crude protein. Their nutritional quality was reduced by the existence of anti-nutritional factors (ANF). It has been demonstrated that solid state fermentation lowers the amount of ANF and increases the bioavailability of nutrients. For nutritional enhancement, a wide range of microorganisms have been employed in the solid state fermentation of rapeseed and canola, primarily strains of Lactobacillus, Bacillus, and Aspergillus. Enzymes like hemicellulose, pectinase, protease, amylase, lipase, tannase, and phytase can all be produced by Aspergillus (Chiang et al., 2010).

Crude protein increased by solid state fermentation (SSF) using *Lactobacillus plantanum* and *Bacillus subtilis* from 31.7% to 58.4%. According to Xu et al. (2012), there was a 42.11%–44.63% increase in crude protein following inoculation with *Bacillus subtilis*, *Candidas utilis* and *Enterocucus faecalis*. A drop in dry matter content and the additional microbial protein produced during SSF could be the cause of the crude protein increase. Hu et al. (2016) observed a decrease in the dry matter content of rapeseed meal, which could be related to the microorganisms' consumption of carbohydrates.

Crude fat is another crucial ingredient in the creation of poultry feed; a lipid content of 5% or less is advised in feed formulation; a higher amount could harm the birds (Sugiharto and Ranjitkar, 2019). Rape seed meal's crude fat content is increased by soil state fermentation employing *Lactobacillus plantarum* and *Bacillus subtilis* (Xu et al., 2012).

When laying hens were fed brewer's dried grains (BDG), rice bran (RB), palm kernel meal (PKM), corn bran (CB), and cassava peels (CP) following solid state fermentation with *Trichoderma viride*, the protein levels of BDG, RB, PKM, and CB increased by 68.00, 87.00, 32.00, and 61.00%, respectively, while there was a moderate increase in energy levels by 5.00, 6.30, 9.00, and 18.50%, respectively (Iyayi and Aderolu, 2004). For BDG, RB, PKM, and CB, the soluble sugars increased by 37.00, 49.00, 9.00, and 5.50%, respectively. In contrast, the levels of crude fiber decreased by 40.00, 35.00, 36.50, and 37.50%, respectively. The levels of protein in the agricultural by-products were significantly altered by *Trichoderma viride*, with the effect being most noticeable in BDG. Nonetheless, there was only a slight increase in the wastes' energy value. *T viride* was successful in lowering the wastes' fiber content by 35.00–40.00%. The study's results, which showed higher levels of protein, sugar, and fiber and lower levels of fiber, showed that *T. viride* has the capacity to secrete the cellulase enzyme, which converts starch and non-starch polysaccharides into monomer sugars that are quickly metabolized. This also explains why the energy value of the byproducts of biodegradation increased. Protein enrichment of the by-products results from the bioconversion of starch or sugars to proteins. After adding defatted baobab seed powder (DBSP), Ezekiel et al. (2022) found that the chemical composition, physicochemical characteristics, and sensory qualities of fermented maize improved.

Effects of feeding solid state fermented non-conventional feed stuff on poultry birds

Effect on Growth Performance

Numerous researchers hypothesized that SSF fermented feed improved animal performance. According to Iyayi and Aderolu (2004) report, birds fed the fermented BDG and RB diets outperformed those on the other diets in terms of hen day production by a significant margin ($P<0.05$). The birds' performance was attributed to the increased protein and energy content of these diets. The highest feed utilization efficiency was achieved by BDG. Yasar and Yegen (2017) found that supplementing broilers with fermented wheat, barley, and oats significantly improved their body weight, feed intake, and feed conversion ratio (FCR) between days 21 and 42.

Similar findings were made by Yasar and Yegen (2017) in regards to broiler chickens fed diets supplemented with 5.0 and 10 g/kg of YFA (yeast fermented feed additive) and NYFA (non-yeast fermented feed additive) at 42 days of age. These birds showed significant increases in weight gain and improvements in feed conversion ratio.

In a feeding trial conducted by Chiang et al. (2010), broiler chicken weight gain and feed conversion ratio (FCR) were enhanced when fed rapeseed meal fermented with *Lactobacillus fermentus* and *Bacillus subtilis*. However, when soybean meal was substituted with up to 10% rapeseed meal fermented with *Lactobacillus fermentans* and *Bacillus sublitis*, Xu et al. (2012) observed that the fermentation did not have effect on the health status of broiler chickens but influenced performance.

When laying hens fed fermented feed material were compared to those fed dry mash, Engberg et al. (2009) found that the former group consumed less feed. However, the hens fed fermented feed weighed more overall, and there was no difference in the total number of eggs produced between the hens fed fermented feed and those fed dry mash. Even so, it was found that feeding chickens fermented feed during the laying or late broiler phases of their lives seems to improve their performance more than other feeding times. This supports the finding that, when compared to control, fermentation reduces broiler feed intake during the starter and grower phases. This led to a slower growth rate during these stages, but remarkably, the finisher phase shows a change in this. This observation could be explained by several factors:

1) The small birds might have found the moist diet to be too heavy.

2) After fermentation (a 24-hour soaking period), the diets might no longer be as appealing.

3) Vital nutrients such as lysine may be lost during fermentation (Supriyati et al., 2015)

Crimpes kernel maize silage (CKMS) did not significantly alter the body weight gain of broiler chickens between the control maize group and the 15% CKMS group, according to studies by Ranjitkar and Engberg (2016). Although the results are inconsistent, Sugiharto and Ranjitkar (2019) reported that solid state fermentation had a positive impact on the growth performance of broiler chickens. Furthermore, it was observed that although the fermentation process increases digestibility and enhances nutritional metrics. Also, fermented feeds improve intestinal morphology such as villus height and the ratio of villus height to crypt height in the duodenum and jejunum, as well as intestinal length indices, in order to preserve the health of the gut microbial ecosystem. It's possible that feeding with fermentation improves digestion and absorption, which helps birds grow more.

Effect on Nutrient Digestibility

The computation of the appropriate nutrient balance in chicken diets requires knowledge of the digestibility of crude protein and amino acids. According to Shi et al. (2015), rapeseed meal inoculated with *Aspergillus niger* had an improvement in *in vitro* total amino acid and essential amino acid digestibility of 5.87% and 6.69%, respectively, when compared to unfermented rapeseed. It was determined that this might be related to *Aspergillus niger*'s expansion, since the fungus can secrete a variety of extracellular breakdown enzymes, most notably protease.

In comparison to birds fed unfermented rapeseed meal, broilers fed solid state fermented rapeseed meal on day 42 showed lower total tract apparent digestibility coefficients for dry matter, energy, and calcium (Chiang et al., 2010). Although there was an increase in rapeseed's nutritional digestibility, the exact mechanism is still unknown.

The apparent nitrogen digestibility and energy digestibility of a corn-soybean diet did not differ between birds on diets containing 25g/kg (T1) or 50g/kg (T2) of wet fermented wheat bran, according to Zhang et al. (2022) report on the experiment on the nutrient digestibility of broiler birds fed solid state fermented wheat bran. Furthermore, it was noted that, in comparison to the control, these birds fed wet wheat bran (40 percent moisture content) showed no discernible effects on the average daily feed intake (ADFI), average daily gain (ADG), feed conversion ratio (FCR), livability, or European performance efficiency (EPEF). It was observed that conventional commercial fermented feedstuff is typically dried to a moisture content of less than 10%. However, volatile substances and probiotics in the fermented feedstock, such as organic acid, Latobacillus species, and yeast, are adversely affected by the drying process. The cost of fermented feedstock is additionally increased by the drying process. Nevertheless, because the broilers were fed 40% moisture content wet fermented wheat bran, the experiment did not have an impact on the performance metrics, which can be linked to the increased nutritive rate of the wheat ran during fermentation. Additionally, it increased the digestibility of nutrients (energy, nitrogen, and dry matter) in diets containing FWB, which led to broiler performance that was comparable to diets containing corn-soybean meal.

The effects of adding fermented soybean hull (FSBH) and fermented soybean hull *Pluerotus eryngii* (FSHP) to broiler diets were studied by Lee et al. (2017) in relation to the apparent digestibility of the entire tract after 35 days. The total digestibility of dry matter and protein for the control group and the supplemented fermented products did not differ significantly. The digestibility of acid detergent fiber in broilers fed fermented products was lower than that of the corresponding control group, and the lowest digestibility of neutral detergent fiber was observed in the birds that received 1.0% FSHP. It is noteworthy, though, that adding fermented products to the broiler diet increased the digestibility of hemicellulose when compared to the control.

Table 1. Effect of solid-state fermented feed (SFF) on Poultry production performance

Period	**Substrates**	**Starter Culture**	**Supplementation, %**	**Effects**	**References**
From 24 weeks old	Brewer's dried grains (BDG), rice bran (RB), palm kernel meal (PKM) and corn bran (CB)	*Trichoderma viride*	50% as energy source (for each of the substrates)	Enhanced their nutritional status. Spared the use of up to half the quantity of maize in conventional layers' diets. Reduced the cost of egg production	Iyayi and Aderolu, 2004
21 – 42 days	Wheat, Barley, and Oat grains	From Citrus pomace using the entire lemon	Up to 50%	Feeding broiler chicks diets of fermented grains, particularly wheat and barley, yielded certain performance and carcass benefits, promising a growth-stimulating effect.	Yaşar et al., 2016
1-40 days	Soybean Meal (SBM)	*Asperigillus oryzae* and *Bacillus subtilis*	Up to 100% replacement of normal SBM	Triggered better feed efficiency, nutrient digestibility, and amino acid transporters	Abdel-Raheem et al., 2023

				that improved the birds' weight gain and muscle nutritional value.	
1 to 42 da	Sour cherry kernel	*Aspergillus niger*	1	Structure of intestinal flora	Gungor and Erener (2020)

Effect on Gastro-Intestinal Health

An essential component of the digestive system, the intestinal microbiota affects nutrition, physiology, and gut morphology. According to Zhu et al. (2020), the microbiota plays a role in the host immune defense mechanism against pathogens. Good intestinal health is critical to the broiler's overall health and growth performance. It is necessary for nutrient absorption and digestion from food.

Lv et al. (2022) stated that the lactobacillus bacteria found in fermented feed lower the pH of the gut by producing organic acid. They also stop enteropathogen colonization by producing bacteriocin, engaging in antagonistic activities, and competitively excluding pathogens. According to Sugiharto and Ranjitkar (2019), fermented feed with a low pH acidifies the upper digestive tract, strengthening the gizzard's ability to act as a barrier against pathogens.

In broiler chickens, fermented feeds provide an environment that is not conducive to the growth of certain pathogens, such as Salmonella, *E. Coli* and Campylobacta. According to Sugiharto and Ranjitkar (2019), laying bird faecal counts of Enterobactericeae were demonstrated to decrease when fermented feeds containing *Lactobacillus plantanum* as starter culture were used.

In the cecum of birds fed wheat bran solid fermented by *Trichoderma longibrachiatum* (SF1), the study conducted by Belal (2017) reported decreased coliform count, while increased counts of Lactobacilli (8.71 log CFU/g cecum content) and Cellulolytic bacterial (6.64 log CFU/g cecum content). The birds' cecum recorded 8.55 log CFU/g cecum content, compared to diets with no wheat bran (9.51) and diets with 10% unfermented WB (9.55) log CFU/g of ceacal content.

According to Adesina et al. (2022), oven-dried melon seed peel meal can take the place of yellow maize meal in the diet of *Clarias gariepinus* because the blood parameters obtained were within acceptable ranges for fish kept in culture and there were no signs of infection, such as anemia, in the fish.

Effect on Meat Yield and Quality

When broilers are fed a conventional diet, factors such as meat yield and abdominal deposition are equally important as growth performance. These are essential metrics for gauging the production of meat (Sugiharto and Ranjitkar, 2019). According to a study by Kayode et al. (2012), adding up to 60% of *Aspergillus niger* and *Penicillium chrysogenum*-fermented mango kernel cake to the diet had no discernible effect on the amount of breast meat produced or the amount of abdominal fat deposited when compared to the control group.

From the study by Bhavna et al. (2024), it was concluded that fermented cassava leaf meal (FCLM) could be used as an ingredient in the diets of broiler chickens. They observed that FCLM did not affect the eating quality of breast meat. Nevertheless, birds fed fermented moist feed had a lower body yield and percentage of live body weight (Missotten et al., 2013).

One of the main problems facing the modern poultry industry is the buildup of excess abdominal fat in broiler chickens, as this not only lowers the carcass yield but is also considered a waste of dietary energy and a residue with little economic value (Fouad and El-Senousey, 2014). In the Lee et al. (2017) study, adding 0.5% or 1% of fermented soybean hull/*Pleurotus eryngii* to the diet considerably decreased the relative fat content of the breast meat. Aiming for positive development in the main characteristics of meat quality, targeted feeding strategies are valued because high-quality meat is required to meet industry and consumer demands.

From the perspective of both the consumer and the processor, one of the most crucial quality attributes in raw materials is the fresh meat's capacity to hold onto moisture (Bowker et al., 2014). A decrease in water-holding capacity (WHC) can result in liquid outflow, which can lead to a loss of flavor and soluble nutrients (Suo et al., 2015). It can also cause an unsightly buildup of moisture in packaging, a cooked product that is less tender, and a reduction in functionality when it comes to producing further processed poultry products (Bowker et al., 2014).

The findings of Lee et al. (2017) demonstrated that a higher WHC is associated with a higher protein percentage in the leg meat of all three treatment groups and the breast meat of chickens fed 0.5% FSBH. Muscle proteins have the ability to bind a large number of water molecules to their surface. The protection against oxidation may be connected to the improvement in the WHC (Filipović et al., 2014). Because the meat has less fat and a higher protein and better WHC content, supplementing with co-fermented by-product materials may provide the best outcomes for processors and consumers alike.

Effect on Fatty Acid Profile

According to certain earlier studies, feeding fermented feed in a solid state seems to enhance the fatty acid composition of chicken meat. According to MarcinIák et al. (2018), feeding 10% cornmeal fermented with *Umbelopss isabellina* LCF2412 led to improved ratio of n-6 to n-3 polyunsaturated fatty acid in raw meat as well as increased amounts of gamma-, alpha-, and oleic acids in breast meat fat. These fatty acids accelerated the birds' growth and fattening rates, but they also raised blood cholesterol levels, which had an adverse effect on the birds' metabolism (Alagawany et al., 2019). Additionally, these authors reported that broiler meat's quality, oxidative status, and sensory attributes were all enhanced by fermented feed.

Conclusion

This review shows that solid state fermentation enhances the fatty acid profile, meat yield and quality, growth performance, nutrient digestibility, intestinal health, and nutritional quality in birds fed the novel non-conventional feed material. Some of the results remain inconsistent, which could be attributed to different environmental factors, different rearing times, the solid state fermentation process, or the microorganisms employed in the fermentation process. Solid state fermentation, on the other hand, seems to be a useful method for raising the nutritional content of non-traditional feedstuffs and lowering the expense of feeding livestock. Further investigation is required regarding the utilization of fermented feed in the production of broilers and layers, as well as the most economical method of solid state fermentation.

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