

Hydroponic Fodder in Broiler Nutrition: Effects on Economics of Production, Environmental Impacts, Productive Indices, and Health Status

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Abstract: The projected global population of 9.7 billion by 2050 will escalate the demand for animal protein, intensifying food insecurity. Broilers, being highly efficient in converting grains into protein-rich food, are crucial in meeting the ever-increasing demand for animal proteins. However, broiler production, especially in developing countries, is constrained by low quality and unavailability of conventional feed grains utilized in poultry production, resulting in high cost of poultry feed. As a result, several approaches have been explored to reduce feed cost and increase broiler productivity. One such innovative approach that has attracted global attention is Hydroponic Fodder (HDF) technology. This is a soil-less method of growing fodder in a water-based nutrient solution. Hydroponic systems produce about 8 kg of green fodder from one kilogram of grain within one week, compared with traditional soil-based farming. HDF production is highly efficient in terms of water saving and takes about 3-5% of the water used under field conditions to generate the same quantity of fodder. Hydroponics also increased the nutritional qualities of HDF when compared to the original seeds. Historical perspectives of the HDF production system, procedures for producing HDF, the effect of HDF on broiler productivity and economics of production, and its implications for the environment were also discussed. In conclusion, this review demonstrated the potential of HDF to improve growth performance, product quality, and physiological well-being of broilers at a reduced feed cost.

Keywords: Hydroponic Fodder, Growth Dynamics, Blood Characteristics, Meat Quality, Broiler Production

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Introduction

Feed grains, particularly those obtained from cereals and legumes, are the main components of broiler feed and contribute largely to carbohydrates and proteins. Soybean, groundnut, millet, oats, barley, rye, sorghum, wheat, maize, and rye are the preferred grains for broiler feeding [1]. The high cost of these grains caused by feed-food competition has hampered poultry

production in developing countries. In addition, the use of grains in poultry feed is constrained by the presence of Antinutritional Factors (ANFs) such as β -glucans, pentosans, trypsin inhibitors, phytates and several others which may result in poor digestibility and utilization [2, 3]. The use of autoclaving, enzyme supplementation, fermentation, alkaline, and urea treatment to improve utilization of feed grains in poultry nutrition have been investigated with limited success [4-8]. Thus, this has compelled researchers to search for sustainable alternatives [9]. The use of HDF technology (a technique for cultivating crops in water or nutrient-rich solutions without soil), one such innovative and sustainable method of improving the nutritional quality of feed grains has been advocated [3, 10].

HDF production systems require small land space and need a smaller quantity of water compared to traditional (conventional) fodder production system. In comparison with conventional fodder production, 6-8 kilograms of green fodder can be produced from one kilogram of grain within one week, regardless of season [3]. Studies have shown that fodder produced via the HDF technique has a higher nutrient content than the original dry grains [10, 11]. The process of soaking and germination (sprouting) often results in reduced Dry Matter (DM) content of the seed and increased crude protein, minerals (phosphorus, calcium, and iron), and vitamins (vitamin E and β -carotene) content of the fodder by activating the activities of digestive enzymes such as protease, lipase, amylases, and β -glucanases [11].

The positive effects of HDF on broiler performance have been reported [10, 12, 13]. However, some researchers indicated that HDF did not affect broiler productivity and health [14, 15], or decreased broiler productivity [16-19]. Therefore, the varied responses of broilers to HDF need to be understood as to use these findings in decision-support systems in the poultry industry. Therefore, the objectives of this paper were (1) to review historical perspectives of HDF production, procedures for producing HDF, and its impact on the environment, (2) to assess the nutrient content of HDF compared with the original dry seeds, and (3) to ascertain the effects of HDF-based diets on broiler performance and economics of production.

Hydroponics: Definition and Brief Historical Perspectives

The term hydroponics stems from two Greek roots: hydro (water) and ponos (to labor or water-working). Hydroponics is based on the idea that plants need nutrients rather than soil to grow and thrive. It is the process of growing plants in water or nutrient-rich solutions for a short time. A variety of terms are used interchangeably with HDF, including grain sprouts, artificially grown forage, hydroponic seedlings, hydroponic sprouts, alfaculture, seed-type feed, hydroponic greens, sprouted fodder, and several others in various geographical locations [20, 21]. Forage cultivation under a hydroponic system is not a new activity [22]; in fact, it dates back over 4000 years ago [23] as shown in Table 1.

Table 1: History of HPF

Year	Activity
1800	European farmers included sprouted feed grains in winter diets to boost milk production in ruminants [24] (Bakshi <i>et al.</i> 2017). The German botanist Julius von Sachs discovered that plants could utilize nutrients from water, providing the ground for modern hydroponics [26] (Dowrah and Reena 2018).
1920	Dr Williams F. Gericke of the University of California created the word 'hydroponics' and set up a commercial HDF unit in the United States.
1699	John Woodward published an article on the growth of plants in water, marking the beginning of modern hydroponics research.
2000	The development of Light-Emitting Diode (LED) lights and other advanced technologies further increase the efficiency and productivity of hydroponic systems.
2010	The rise of urban agriculture and vertical farming led to increased interest in hydroponics as a sustainable and space-efficient way to grow food. With the advances in automation, Artificial Intelligence (AI), and data analytics, hydroponics continues to evolve, enabling more precise and efficient control over growing conditions.

Methods for Hydroponic Fodder Production

In general, there are two methods of producing HDF. This includes the low-cost hydroponic system and the hi-tech commercial system. The latter is automatic and capital-and energy-intensive [3, 26], while the former is economical and has gained acceptance in developing nations. Apart from seed and water, trays (which can be plastic or metallic), racks, and a shed are needed for producing HDF [27]. The shed creates a microenvironment to ensure optimum temperature (19-22°C),

sunlight (2000 lux for 12-16 h), and humidity (60%) for seed growth [24]. There exists a difficulty in regulating the internal environment (humidity and air circulation) in locally designed low-cost HDF units, especially on dry hot summer days, which may affect the yield of forage biomass [24]. Good quality and intact seeds without physical or fungal damage can be grown with fresh water or in nutrient-enriched solutions. According to Gunasekaran *et al.*, maize seeds grown in water yield more biomass than those grown in other nutrient-enriched solutions [28]. Chethan *et al.* observed that levels of minerals and crude protein were raised in HDF produced with nutrient solutions [20]. The production of HDF involves physiological transformation from seeds rich in starch into leaves, which is an energy-consuming process. Soaking softens the hard seed coat, facilitating germination through the rapid uptake of water, initiating metabolism and utilization of reserve materials of seeds.

The seeds are usually soaked in 4% vinegar, or 0.1-1.5% sodium hypochlorite or 1-2% hydrogen peroxide for 30 minutes to prevent mold growth. There is scanty information on safety or residue effects of vinegar, sodium hypochlorite and hydrogen peroxide on poultry. Thus, more study is needed in this direction. The various steps involved in HDF production have been reviewed [3]. Maize, barley, oat, rye, wheat, sorghum, triticale, and millet are the most common cereal used in HDF production, as cowpea, alfalfa, horse gram, sun hemp, moth bean, and rice bean are the most common legumes [3]. The fresh fodder yield of the common grains is ranged between 3.0-8.6 kg fodder/kg seed for the cereals and 6.6-13.5 kg fodder /kg seed for the legumes. The optimal seed density loaded into a tray for each crop is critical because it affects the quality of HDF. Mahesh *et al.* recommend a seed rate of 4-6 kg/m² for barley, wheat, or sorghum, 6.4-7.6 kg/m² for maize, and 2.54 kg/m² for cowpea [3]. Ningoji *et al.* discovered that a lower seed rate of 2.50 kg/m² was optimal for hydroponic maize production in terms of yield and cost [29]. In addition, a high seed rate can lead to fungal contamination in the root mat, whereas a low seed rate produces less forage biomass [30]. HDF production is highly efficient in terms of water saving and consumes about 3-5% of the water used under field conditions to generate the same quantity of fodder [20, 23]. This indicates that HPF technology has the potential to reduce water footprint by increasing the water-use economy. The HDF system is a potential solution in locations where there is scarcity of water.

Environmental Impact of Hydroponics Fodder Systems

In the agricultural sector, feed production and enteric fermentation are the two largest sources of greenhouse gas (GHG) emissions [31]. For example, hydroponics has been demonstrated to release fewer GHG emissions than traditional (conventional) farming methods, reducing global warming and carbon footprint [32]. According to VijayKumar *et al.*, hydroponic systems require less land and water than traditional soil-based farming methods, making them suitable for use in urban agriculture and in water/land-and-scarce regions [33]. It also allows for vertical farming (stacking crops in layers in an indoor or controlled environment) to maximize space, increase yield (Fig. 1), and preserve natural habitats [34, 35]. Naik and Singh found that up to one ton of maize fodder can be produced daily from a 45–50 m² space under hydroponic systems, which is equivalent to 25 acres of arable land utilized to produce the same quantity of feed under the traditional farming system. A previous study shows that under a hydroponic system, 1.5-2.0 liters of water are required to grow 1 kg of fodder, as opposed to 73-160 liters of water required to produce 1 kg of green fodder under traditional field conditions [36]. Hydroponics often utilizes fewer chemicals compared to traditional soil-based farming methods, thus minimizing the adverse effect of these chemicals on soil and water bodies [9]. With hydroponics, fodder can be grown all year round, regardless of season [3, 36].

Despite the positive impact of hydroponics on the environment, it has been observed to have the following negative impacts on the environment [36]:

- 1). It requires large amounts of energy to power lighting, heating, and cooling systems;
- 2). It also needs a steady supply of nutrients, which can result in resource depletion and environmental degradation;
- 3). Hydroponics can generate a substantial quantity of waste, including nutrient-rich effluent and discarded plant material;
- 4). If not well handled, hydroponics can cause water pollution through the release of nutrients.

However, the observed adverse consequences of hydroponics can be mitigated by

- (1). The use of renewable energy sources (solar or wind power), which can lower the carbon footprint of hydroponics;
- (2). Implementing recycling and reuse systems can minimize waste generation and lessen the demand for non-renewable resources;

(3) Adopting sustainable nutrient management methods, such as organic nutrient sources, can lessen the environmental impact of hydroponics; and (iv). Implementing water conservation and management measures, such as rainwater harvesting and efficient irrigation systems, can minimize water waste and pollution.

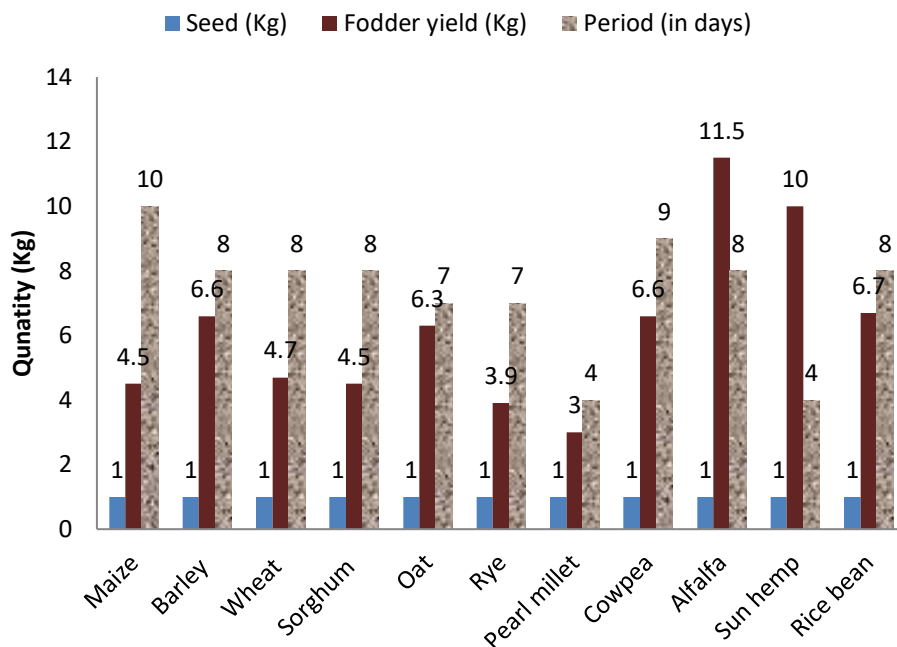


Fig. 1: Food yield biomass under hydroponic fodder production system. Adapted from [3]

Nutritional Value of Hydroponic Fodder

The nutrient quality of HDF is comparable to that of conventional leguminous fodder but superior to that of conventional cereal fodders [37]. The sprouting process has been demonstrated to trigger enzymes that convert protein, starch, and fats in the original grain to amino acids, soluble sugars, and essential fatty acids, respectively, resulting in energy loss in the original grain. As a result, HDF has lower DM content than the original seeds [3]. Nonetheless, the reduced DM in seed sprouts during hydroponics, relative to the original seeds, may be traced to increased water intake during sprouting which elevates the moisture content. Naik *et al.* showed that during sprouting, the DM content of cowpea, maize, and barley seeds was reduced by 6%, 11–14%, and 19%, respectively, due to the conversion of starch to simple sugar [12,21,38,39]. In a similar study, Baye *et al.* demonstrated that apart from DM, Hydroponic Barley Fodder (HBF) had higher proximate values than original barley grain [10]. Gunasekaran *et al.* also noticed that except for DM value, Hydroponic Maize Fodder (HMF) had improved proximate values compared to original maize grain [28]. The reduced DM in HDF compared to original grains implies that feeding birds with HDF can result in poor feed intake, nutrient utilization, body weight gain (BWG) and litter quality [28]. Gunasekaran *et al.* found that HMF grown in nutrient solutions had a higher DM value (20.6%) than HMF grown in water only (17.7%). However, these values were lower than the DM value of 88–94.4 reported for maize grain [40–41]. Al-Kanaan showed that sprouting increased crude protein (CP), crude fiber (CF), and extract (EE) content in barley grain by 93%, 40%, and 53%, respectively, and reduced the nitrogen-free extract (NFE) content by 18% [42]. Likewise, Alshamiry reported a 25%, 105%, and 46% increase in CP, EE, and ash content of barley grain, respectively after 8 days, with decreasing NFE and metabolizable energy (ME) levels [43]. The reduction in NFE and ME in HDF reflects the loss of DM mainly in the form of carbohydrates as reported by other investigators [17,3]. These findings agree with the results of other studies, which demonstrated that grain sprouts are higher in nutrients than the original grain [40–41] as shown in Table 2. Similar studies found lower cell wall components and ME in feed grain sprouts than in the original grain [38,11,3]. The DM, CP, CF, EE, and ash values reported for barley sprouts by Abouelezz *et al.* were similar to the values earlier reported by other researchers [11,38,44]. Sprouting of feed grains increased their EE, CP, digestible energy, fats, vitamin, and mineral levels. It also serves to remove phytic acids from cereal seeds [30], resulting in improved HDF digestibility and utilization by chickens [20]. Studies have shown that HDF contains important vitamins, minerals, and bioactive compounds with the potential to improve broiler

productivity [24,3]. The β -carotene content of HMF increased by 90% after 8 days of sprouting compared to the original seeds [28]. In general, the CP value of HMF can be compared to a blend of legume and non-legume fodder and is high in micronutrients [21].

Table 2: Comparison of nutrient content of feed grains and their sprouts

Nutrients (%)	Maize		Barley		Sorghum	
	Maize grain	HMF	Barley grain	HBF	Sorghum grain	HSF
Dry matter	88-94.4	12.5-25.0	89.1-93.1	12.6-14.0	90.4	84.2-93.2
CP	6.8-10.1	10.6-23.0	9.2-12.7	12.8-20.3	9.3	10.8 -18.9
CF	0.8-7.1	3.4-14.8	4.5-6.3	6.3	1.0	4.7 -12.0
EE	1.8-2.6	2.3-4.7	1.8 -2.2	3.4 - 4.2	4.9	2.4-1.1
Ash	0.8-1.4	1.8-4.0	2.8-4.0	4.0	1.7	1.8-6.3
NFE	50.6-76.3	56.6-77.5	26.7-80.7	66.1	73.5	64.2-66.5
ME (Kcal/kg)	3923.0	2905.2	-	3441.1- 3550.8	3270-3653	3274-3115

HMF- hydroponic maize fodder; HBF- hydroponic barley fodder; HSF- hydroponic sorghum fodder

Effect of HDF on Growth Dynamics of Broilers

Growth performance indicators of broilers are often expressed as feed intake, feed conversion ratio (FCR), and body weight gain (BWG). Baye *et al.* [10] and Zohrabi *et al.* [13] reported that HDF improved growth performance metrics, as shown in Tables 3–5. This improvement in growth performance could be linked to the enhanced nutritional quality of HDF, as sprouting increases the nutritional value of feed grains [30,38]. Baye *et al.* [10] showed that broilers receiving dietary HDF supplementation had higher feed intake than those fed diets without HDF. This observation may reflect a compensatory response by birds to meet their energy and nutrient requirements, as HDF is often low in dry matter (DM) content [3,21]. Zohrabi *et al.* [13] found that broilers fed sprouted barley had higher feed intake and BWG than those fed diets without HDF, which is consistent with the findings of Baye *et al.* [10]. However, this contrasts with the findings of Atturi *et al.* [45], who reported reduced BWG in broilers fed HMF-based diets for 21 days. This discrepancy may be attributed to differences in the inclusion level of HMF in the diet.

HDF may also improve BWG in broilers through several mechanisms, including: (1) modulation of gut microecology in favor of beneficial intestinal microbes [42]; (2) increased feed intake and nutrient digestibility [3,10]; (3) improved immunity and gut health [46]; and (4) provision of essential nutrients such as proteins, fats, minerals, lysine, β -carotene, ascorbic acid, tocopherol, and retinol [10,11,42].

It has been reported that sprouting activates several physiological processes in grains, including the synthesis and release of gibberellins, which regulate plant growth and development. These hormones act on deoxyribonucleic acid (DNA) in the aleurone layer, promoting the expression of genes encoding enzymes responsible for the degradation of carbohydrates and other storage compounds [47]. Amylase, for instance, converts starch into simple sugars that can be utilized by the embryo [48]. The conversion of starch into simple sugars, along with the breakdown of non-starch polysaccharides and other anti-nutritional factors (ANFs), contributes to increased feed intake and BWG in broilers [49]. Sprouting may also hydrolyze water-soluble non-starch polysaccharides in feed grains.

Mahesh *et al.* [3] reported that sprouting reduced the crude fiber (CF) content of grains, which has been associated with improved feed intake, FCR, and BWG in broilers [10]. Similar findings were reported by Svihus *et al.* [50]. However, these results differ from those of Younis *et al.* [51], who observed no significant differences in feed intake, FCR, and BWG in chickens fed HSF-based diets for 38 days. Similarly, Maidala *et al.* [52] reported comparable BWG in broilers fed HSF-based diets.

The improved FCR observed by Baye *et al.* [10] in broilers fed HDF-based diets, compared to those fed control diets, may be attributed to enhanced villus function, leading to improved nutrient absorption and utilization. In contrast, Lasisi [17] and Atturi *et al.* [45] reported poorer FCR in broilers supplemented with HDF maize. These inconsistencies in growth performance may be attributed to variations in factors such as broiler age, strain, inclusion level of HDF, and environmental conditions. Therefore, further studies are required to determine the extent to which these variables influence growth performance outcomes.

Several studies have demonstrated that hydroponic processing reduces major ANFs, such as phytic acid and non-starch polysaccharides, while enhancing nutrient availability in feed grains [3,42,53]. The reduction of ANFs is likely a key factor contributing to improved FCR in broilers fed HDF-based diets.

Table 3: Effect of HDF on average daily feed intake (ADFI) of broilers

Ref.	HDF type	Dosage (%)	Feed intake (g/birds)		Main findings
			CTL group	Exptal group	
[17]	HSF	0, 5, 10, 15, 20	61.08	49.6-62.8	The inclusion of high levels (15% and 20%) of HSF in starter broilers reduced their ADFI. However, starter broilers fed 5% HSF had similar ADFI to the control.
[17]	HSF	0, 5, 10, 15, 20	140.8	105.8-124.4	The addition of 10, 15, and 20% HSF to the diets of finisher broilers significantly reduced ADFI, while broilers fed 5% HSF had similar ADFI.
[12]	HWF	0, 2.5, 5, 7.5	70.4	69.6-72.4	Broilers fed 2.5% HWF had numerically lower ADFI than the control, but those fed 5 and 7.5% had their ADFI increased by 3 and 5%, respectively.
[10]	HBF	0, 3.5, 7, 10.5	105.5	107.3-112.7	Incorporation of HBF to broiler diets increased ADFI in Cobb 500 broilers by 2 to 7%.
[13]	HBF	0, 54.5	136	173	Dietary HBF improved ADFI in starter broilers.
[13]	HBF	0, 63.1	113.2	120.5	HBF-based diets increased ADFI by 6% in finisher broilers

HSF – hydroponic sorghum fodder; HWF – hydroponic wheat fodder; HBF – hydroponic barley fodder; CTL - control

Table 4: Effect of HDF on BWG of broilers

Ref.	HDF type	Dosage (%)	BWG (g/birds)		Main findings
			CTL group	Exptal group	
[17]	HSF	0, 5, 10, 15, 20	35.8	18.4-36.8	Dietary HSF (10, 15, and 20%) reduced BWG in starter broilers.
[17]	HSF	0, 5, 10, 15, 20	38.1	22.3-33.5	HSF (5, 10, 15 and 20%) reduced BWG in finisher broilers.
[12]	HWF	0, 2.5, 5, 7.5	42.1	41.3-51.4	Broilers offered HWF at 5.0% superior BWG than broilers fed HWF at 0, 2.5 and 7.5%.
[10]	HBF	0, 3.5, 7.0, 10.5	47.0	50.7-56.4	HBF supplementation increased BWG in Cobb 500 broilers
[13]	HBF	0, 54.5	84.0	109.0	HBF increased BWG in broilers by 10% during the starter phase.
[13]	HBF	0, 63.1	60.7	67.2	HBF improved BWG in broilers by 2% during the finisher phase

Table 5: FCR of broilers fed HDF-based diets

Ref.	HDF type	Dosage (%)	FCR		Major findings
			CTL group	Exptal group	
[17]	HSF	0, 5, 10, 15, 20	1.71	1.71-2.76	Inclusion of HSF in starter broilers at 10, 15 and 20% had adverse effect on FCR. However, broilers fed 5% HSF compared favourably with the control in term of FCR. This implies that 5% could be the best inclusion level of HSF that optimized FCR in broilers during the starter phase.
[17]	HSF	0, 5, 10, 15, 20	3.74	4.28-4.86	Dietary HSF (5-20%) resulted in poor FCR during the finisher phase, suggesting poor quality of the treatment diets
[12]	HWF	0, 2.5, 5, 7.5	1.64	1.47-1.72	Broilers on dietary HWF supplementation at 5% had significantly better FCR than those on the other three diets. This indicates that HWF can be added up to 7.5% in the broiler diet
[10]	HBF	0, 3.5, 7.0, 10.5	2.24	2.0-2.11	Cobb 500 broilers on dietary HBF had superior FCR to those on the control diet.
[13]	HBF	0, 54.5	1.61	1.58	Dietary HBF enhanced FCR in starter broilers.
[13]	HBF	0, 63.1	1.86	1.79	Dietary HBF improved FCR in finisher broilers

Influence of HDF on Carcass Characteristics, Organ Weights, and Meat Quality

Baye et al. [10] noticed improved carcass yield, dressing percentage, and cut-part weights (drumstick, thigh, and breast) of broilers fed HBF-supplemented diets, which agreed with the findings of Dastar et al. [54]. In a similar study, Ali et al. [55] found increased carcass yield in broilers offered diets supplemented with HWF. The beneficial effect of HDF on carcass characteristics of broilers might be explained by enhanced quality of the HDF-based diets [3,24] as sprouting increases the

lysine content in seed sprouts [42], which plays a vital role in the formation of muscle protein in chickens [56]. In contrast, others [13,57] reported that inclusion of HBF in broiler diets did not increase carcass yield, dressing percentage, or weights of breast, spleen, and liver. These findings support Sultana *et al.* [12], who demonstrated that HWF supplementation at 2.5, 5.0 and 7.5% for 32 days did not affect dressing percentage, cut-part weights, internal organ weights (liver, heart, gizzard), and abdominal fat content in broilers. Also, Younis *et al.* [51] recorded similar dressing percentages and relative organ weights (liver, gizzard, heart, testes) in birds fed sorghum sprouts. However, these findings disagree with Kidulani *et al.* [58] and Zohrabi *et al.* [13], who found decreased carcass yield, Bursa of Fabricius, and abdominal fat in chickens fed HDF-based diets. The inability of HDF to improve carcass yield in broilers may be attributed to the presence of ANFs, which may exceed the tolerance level of the birds [58]. The deposition of high levels of fat in the abdomen of broilers fed HDF suggests poor utilization of dietary energy. Similar abdominal fat content in broilers fed HBF, as reported by Zohrabi *et al.* [13], suggests better dietary energy use efficiency. Baye *et al.* [10] showed that HBF had no significant effect on pH, water holding capacity (WHC), and cooking losses in broiler meat. Similarly, the inclusion of bean sprouts in the diets of broilers did not affect WHC of broiler meat [59].

Effect of HDF on Blood Chemistry and Hematology

Blood is used as an index of health and nutritional quality of feedstuffs [10,60]. The blood components mostly affected by nutrition include red blood cells (RBC), hematocrit, hemoglobin (Hb), white blood cells (WBC), protein (albumin and globulin), glucose, total cholesterol, triglycerides, among others. A higher WBC level suggests a better ability to combat diseases. The 5% increase in WBC count in finisher broilers fed sprouted seeds may be attributed to the quality of the protein contained in the diet [46,61]. This increase in WBC count of broilers fed sprouted seeds may be the likely explanation for the reduced mortality rate in broilers as reported by Alewi *et al.* [57] and Baye *et al.* [10]. The high levels of bioactive compounds (flavonoids and polyphenols) in HDF [62] may facilitate their use in broiler nutrition as a feedstuff. Clinical data strongly support the relationship between diets and blood cholesterol levels in broilers [63–64]. Feeding sprouted barley to broilers increased the concentrations of blood total cholesterol, low-density lipoprotein cholesterol (LDL-c), total protein, and uric acid by 9, 20, 7, and 6, respectively, compared to broilers fed a diet without sprouted barley [13]. The authors also found that sprouted barley had no effect on high-density lipoprotein cholesterol (HDL-c), lymphocytes, heterophils, and H/L ratio in broilers. This observation may be due to the ability of the HDF technique to reduce the amount of fiber contained in the diet, as low-fiber diets negatively impact blood lipid levels, potentially leading to higher levels of total cholesterol and LDL-c. The significantly higher level of uric acid observed in broilers fed sprouted barley could be connected to increased blood uric acid formation as a result of large amounts of amino acids being catabolized. The inclusion of HWF in broiler rations decreased the concentrations of triglyceride and cholesterol and increased the concentration of HDL-c [12]. This finding is consistent with Younis *et al.* [51], who reported that replacement of yellow maize (25, 50, and 100%) with HSF reduced blood cholesterol and triglyceride levels in poultry by 10.82%. This implies that the effect of HDF on blood lipid profiles is dependent on the HDF type and quantity included in the diets. The same authors also revealed that total protein, globulin, albumin, and glucose were not significantly affected in broilers by dietary HSF. These results agree with Fafiolu *et al.* [16], who reported significantly reduced plasma triglyceride and cholesterol in chickens fed sorghum sprouts.

Effect of Dietary HDF on Mortality Rate and Gut Health

Mortality rate was not significantly affected by dietary HBF supplementation levels (0, 3.5, 7, and 10.5%) in broilers [10], which agrees with Alewi *et al.* [57], who demonstrated that mortality rate was not affected by HDF. The high survivability rate among birds fed HDF could be attributed to the ability of HDF to improve WBC in broilers [46]. Similarly, Zohrabi *et al.* [13] observed that birds fed HBF had lower ascites mortality than birds fed the control diet. The authors attributed the lower ascites mortality in birds fed HBF to a higher level of blood uric acid (a potent antioxidant), as reduced levels are linked to ascites syndrome [66]. Therefore, a higher level of serum uric acid in the germinated barley group could explain the lower rate of ascites mortality [46]. In addition, a lower depth of jejunal crypts in the germinated barley group compared to the unprocessed barley group could imply reduced turnover of enterocytes, which is associated with decreased oxygen consumption by the gut and explains the lower rate of ascites mortality.

The duodenum, jejunum, and ileum are the primary sites of nutrient absorption in poultry [67]. Villus height (VH), crypt depth (CD), and the VH/CD ratio are used as biomarkers to assess intestinal health [7,68]. In broilers, higher VH and lower CD indicate improved absorptive surface area for nutrient uptake [7]. Zohrabi *et al.* [13] found that broilers fed HDF-based diets had higher VH and lower CD than those fed diets without HDF, indicating better intestinal absorptive capacity. This observation agrees with earlier findings in the jejunum of broilers fed HDF-barley [50], suggesting improved productivity.

Similarly, Afsharmanesh *et al.* [69] reported improved ileal VH and CD in broilers fed sprouted feed grains. Afsharmanesh *et al.* [70] also demonstrated that pearl millet sprouts enhanced intestinal absorptive capacity. Feeding seed sprouts improved intestinal microbiota and gut function in broilers [69].

In a similar feeding trial, Al-Kanaan [42] evaluated broilers fed varying levels of HBF. Broilers fed 10% HBF had significantly reduced total fungal and bacterial counts, including *Escherichia coli*, and increased proliferation of beneficial bacteria (lactic acid bacteria). This suggests that HDF inclusion at 10% can enhance gut microbiota balance in broilers. Although VH/CD ratios were similar across groups, broilers receiving 10% HBF showed significantly improved VH and CD. These findings are consistent with other reports [13,70] on the beneficial effects of HDF on intestinal morphology. Overall, these results indicate that HBF (10%) enhances broiler performance by promoting beneficial gut microbiota and improving intestinal structure. This observation is also consistent with Shaheed [71], who reported increased lactic acid bacteria and reduced *E. coli* counts in the jejunum of broilers fed date kernel sprouts.

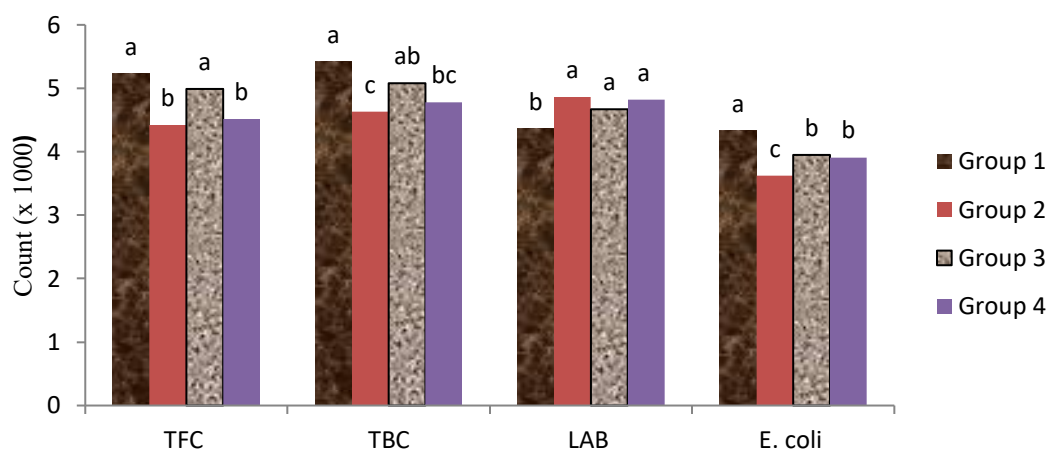


Fig. 2: Jejunum microbial counts of broilers on dietary HBF. TFC- total fungi count, TBC - total bacterial count; LAB - lactic acid bacteria. Group 1 - fed a diet without HBF; Groups 2 and 3 - fed a diet with HBF at 10 and 20%, respectively; Group 4 - fed a diet supplemented with fresh chopped HBF twice daily. ^{a,b,c}Bars with different superscripts differ significantly at $P < 0.05$. Adapted from [42]

Economics of HDF Production in Broiler Production

Only a few studies have been done on the economics of production of broilers fed HDF-based diets [45,72,42]. The use of HDF sorghum in broiler diets at 5 and 10% reduced feed costs but increased costs at 15 and 20% [17]. In addition, the supplementation of HMF in broiler diet at 50 g/kg feed reduces the feed cost [45]. In a similar experiment, Baye *et al.* [10] found the highest net return from broilers fed 10.5% HBF, which agrees with the findings of Miah *et al.* [72], who obtained the highest net income in animals other than broilers fed HMF at 7.5%. This concurs with Al-Kanaan [42], who demonstrated that addition of up to 15% HBF to the poultry diet reduces feed cost and total production cost in chickens other than broilers. This finding also supports the earlier reports of Alinaitwe *et al.* [40] that 23% is the best inclusion level of HBF that enhanced broiler performance, which decreased 63% of the cost of broiler production. Likewise, Atturi *et al.* [45] observed that inclusion of 25% HMF in broiler diet reduced feed costs.

Conclusion and Future Research Direction

This review demonstrated that except for DM, HDF is higher in nutrients than the original dry seeds. Barley, wheat, and sorghum are the most common HDF used in broiler production. This review suggests that HDF had beneficial effects on growth dynamics and carcass characteristics in broilers. It also enhanced meat quality, intestinal microbiota composition, and villi parameters of broilers, implying that HDF can be included in broiler diets to improve broiler productivity and reduce feed cost. Despite the potential of HDF to improve broiler performance, and reduce feed cost, there is still scanty information on mineral, fatty acid, vitamin, and amino acid profiles of HDF used in broiler nutrition as well as the shelf-life of dietary HDF. Also, there are limited published studies on hematology and meat quality attributes of broilers fed HDF-based diets as well as the inclusion levels of HDF that optimize broiler productivity. Taking these observed research gaps into consideration, it is

recommended that further research be directed in these areas. Further experiments should be channeled towards determining the economics of using HDP in broiler production compared to the feed grains as to enhance the uptake of these findings in the poultry industry.

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Authors Contributions

All authors equally contributed to this study.

Conflict of Interest

Authors have no competing interest to declare.

Data Availability

Data will be made available on reasonable request.

References

1. Sugiharto S (2021) The use of sprouted grains as dietary feed ingredients for broilers - a brief overview. *Livestock Res for Rural Dev* 33 (3):1-5.
2. Samtiya M, Aluko RE, Dhewa T (2020) Plant food anti-nutritional factors and their reduction strategies: an overview. *Food Prod Process and Nutr* 2:6. <https://doi.org/10.1186/s43014-020-0020-5>
3. Mahesh MS, Chaudhary SK, Tewari D, Dutta N (2024) hydroponic forage for ruminant feeding: A comprehensive review. *Anim Nut and Feed Tech* 24: 441-459. doi: 10.5958/0974-181X.2024.00034.9
4. Nkhata SG, Ayua E, Kamau EH, Shingiro JB (2018) Fermentation and germination improve nutritional value of cereals and legumes through activation of endogenous enzymes. *Food Sci and Nut* 6: 2446-2458. <https://doi.org/10.1002/fsn3.846>
5. González-Ortiz G, Aurélio Callegari M, Wilcock P, Melo-Durán D, Bedford MR, Hilário RVOliveira M, Pierozan CR, Silva C (2020) Dietary xylanase and live yeast supplementation influence intestinal bacterial populations and growth performance of piglets fed a sorghum-based diet. *Anim Nutr* 6:457–466. doi: 10.1016/j.aninu.2020.05.005
6. Poernama F, Wibowo TA, Liu YG (2021) The effect of feeding phytase alone or in combination with nonstarch polysaccharides-degrading enzymes on broiler performance, bone mineralization, and carcass traits. *J Appl Poult Res* 30:100134. doi: 10.1016/j.japr.2020.100134.
7. Ogbuewu IP, Aladi NO, Mabelebele M, Mbajjorgu CA (2024) Meta-analysis of performance and intestinal histomorphology of broilers fed diets containing fermented tropical seed meals. *Amer J Anim and Vet Sci* 19 (4): 377.392. doi: 10.3844/ajavsp.2024.377.392
8. Walker H, Vartiainen S, Apajalahti J, Taylor-Pickard J, Nikodinoska I, Moran CA (2024) The Effect of including a mixed-enzyme product in broiler diets on performance, metabolizable energy, phosphorus and calcium retention. *Animals* 14(2):328. doi: 10.3390/ani14020328
9. Okoli IC, Etuk UNE, Martins U, Giwa AL, Azodo NL, Achonwa CC, Etuk EB (2023) Potentials of hydroponic fodder system as a sustainable animal feed production alternative in Nigeria: A review. *Nig J Anim Prod* 50(4):45 - 69 <https://doi.org/10.51791/njap.v50i4.3866>.
10. Baye W, Moges F, Andualem D (2024) Effect of hydroponic barley fodder on growth performance, carcass yield and carcass quality of Cobb 500 broilers. *Heliyon* 10:e33909.
11. Abouelezz KFM, Sayeda MAM, Abdelnabi MA (2019) Evaluation of hydroponic barley sprouts as a feed supplement for laying Japanese quail: Effects on egg production, egg quality, fertility, blood constituents, and internal organs. *Anim Feed Sci and Tech* 252: 126–135.
12. Sultana M, Das SC, Dey B, Salam A, Afrin A, Ahmed T (2022) Effect of hydroponic wheat sprout on the growth performance, carcass characteristics, and lipid profiles of broilers. *Brazil J Poult Sci* 24(3): 001-008.
13. Zohrabi M, Khajali F, Dastary B (2024) Effect of barley processing and enzyme supplementation on broiler performance, gut morphometry, and the occurrence of ascites syndrome in broiler chickens. *Poult Sci* 103:104410. <https://doi.org/10.1016/j.psj.2024.104410>
14. Abbas TEE, Musharaf NA (2008) The effects of germination of low - tannin sorghum grains on its nutrient contents and broiler chicks performance. *Pak J Nutr* 7: 470–474.
15. Min L, Tuo Y, Li D, Zang C, Amat, G, Zhang Z, Guo T (2024) Impact of 5–20% hydroponic wheat sprouts inclusion on growth and metabolic parameters of growing ewes. *Animals* 14: 1630.
16. Alewi AO, Oduguwa OO, Ikeobi CO, Onwuka CF (2006) Utilization of malted sorghum sprout in the diet of rearing pullets and laying hens. *Archivos de Zootecnia* 55: 361–371.

17. Lasisi OT (2018) Nutritive value of malted sorghum sprout in broiler chicken diets. M.Sc Thesis, Ahmadu Bello University, Zaria, Nigeria, pp 1-104.
18. Al-Baadani HH, Alowaimer AN, Al-Badwi MA, Abdelrahman MM, Soufan WH, Alhidary I.A (2022) Evaluation of the nutritive value and digestibility of sprouted barley as feed for growing lambs: In vivo and in vitro studies. *Animals* 12, 1206. <https://doi.org/10.3390/ani12091206>
19. Li Y, Peng R, Kunz C, Wang K, Terranova M, Zhang Y, Macsai M, Frossard E, Niu M (2024) Hydroponic fodders as alternative feeds for ruminants to reduce ruminal methane emissions: An in vitro study. *J Dairy Sci* 107:10932–10944. <https://doi.org/10.3168/jds.2024-25274>
20. Chethan KP, Gowda NKS, Girish CH, Prabhu TM, Giridhar K, Anandan S (2021) Grain sprouts as green feed with hydroponic technique: Review of merits and limitations. *Indian J Anim Nut* 38: 109-122.
21. Naik PK, Swain BK, Beura CK (2023) Role of hydroponic forage production for livestock in the current scenario of climate change. In: *Proceedings of XII Biennial Animal Nutrition Association Conference Mathura, India, February 16-18*, pp. 81-88.
22. Akkenapally JS, Lekkala S (2021). Hydroponic fodder production: A review. *Pharma Innov J* 2435-2439.
23. Velazquez-Gonzalez RS, Garcia-Garcia AL, Ventura-Zapata E, Barceinas-Sanchez JDO, Sosa-Savedra JC (2022) A review on hydroponics and the technologies associated for medium and small-scale operations. *Agric* 12: 646. doi:10.3390/agriculture12050646
24. Bakshi MPS, Wadhwa, M, Makkar HPS (2017) Hydroponic forage production: a critical assessment. *Broadening Horizons* 48:1-10; Feedipedia, a programme by INRAE, CIRAD, AFZ and FAO. <https://www.feedipedia.org/node/556> (last accessed on 15 December 2024).
25. Dowrah R, Reena Y (2018) Hydroponics forage production and importance of feeding: A mini review. *North-East Vet* 17: 12-16.
26. Naik PK, Gaikwad SP, Gupta MJ, Dhuri RB, Dhumal GM, Singh NP (2013). Low-cost devices for hydroponics forage production. *Indian Dairymen* 65: 68-72.
27. Mohapatra KK, Mohapatra S, Ekka R, Behera RC, Mohanta RK (2019) Variations in round the-year forage production in a low-cost hydroponic shed. *Nat Acad Sci Letters*, 42: 383-385.
28. Gunasekaran S, Valli C, Bandeswaran C (2017) Effect of different nutrient solution on the biomass yield and nutritive value of low cost hydroponic forage maize. *Indian J Anim Sci* 87: 1418-1419.
29. Ningoji SN, Thimmegowda MN, Boraiah B, Anand MR, Murthy RK, Asha NN (2020) Influence of seed rate on growth, yield and economics of hydroponic forage maize production. *Range Management and Agroforest* 41: 108-115.
30. Naik PK, Swain BK, Singh NP (2015) Production and utilization of hydroponics forage. *Indian J Anim Nut* 32: 1-9.
31. Opio C, Gerber P, Mottet A, Falcucci A, Tempio G, MacLeod M, et al. (2013) Greenhouse gas emissions from ruminant supply chains: a global life cycle assessment. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.
32. Tuomisto HL, de Mattos MJT (2011) Environmental impacts of cultured meat production. *Environmental Sci & Tech* 45(14): 6117–6123.
33. VijayKumar R, Jeevan Sangram SR, Shukla P, Gadi Y, Beese S, Khurshid N (2023) Hydroponics: Innovative farming without soil. *Global Agri Vision* 2(1): 11-14.
34. Naik PK (2014) Hydroponics green fodder for dairy animals. *Recent Adv Anim Nutr* (Eds. Bakshi MPS and wadhwa M).191-210.
35. Naik PK, Singh NP (2013) Hydroponics fodder production: an alternative technology for sustainable livestock production against impeding climate change. *Compendium of model training course. Management strategies for sustainable livestock production against impending climate changes*. Adugodi, Bengaluru, India, pp: 70–75.
36. Shit N (2019) Hydroponic fodder production: an alternative technology for sustainable livestock production in India. *Exploratory Anim Med Res* 9(2):108-119.
37. Pastorelli G, Serra V, Turin L, Attard E (2023) Hydroponic fodders for livestock production – a review, *Annals of Anim Sci*. doi: 10.2478/aoas-2023-0075
38. Fazaeli H, Golmohammadi HA, Tabatabayee SN, Asghari-Tabrizi (2012) Productivity and nutritive value of barley green forage yield in hydroponic system. *World Applied Science Journal*, 16: 531-539.
39. Suma TC, Kamat VR, Sangeetha TR, Reddy M (2020) Review on hydroponics green fodder production: Enhancement of nutrient and water use efficiency. *Int J Chem Stud* 8: 2096-2102
40. Alinaitwe J, Nalule A, Okello S, Nalubwama S, Galukande E (2019) Nutritive and economic value of hydroponic barley fodder in kuroiler chicken diets. *J Agric Vet Sci* 12:76-83.
41. Hassan MM (2020) Improving utilization of barley grains as a source of energy in ducks diets under south sinai conditions, *Egypt Poult Sci J* 40: 133–151.
42. Al-Kanaan JJ (2022) Effects of adding different levels of hydroponic barley fodder on the productive performance and economic value of broiler chickens. *Archives of Razi Institute* 77 (5): 1853-1864.
43. Alshamiry FA (2020) A brief report on barley hydroponics; The importance, steps, advantages and disadvantages. *Int J Food Microbiol.*;19(5):212-24.
44. Gebremedhin WK (2015) Nutritional benefit and economic value of feeding hydroponically grown maize and barley fodder for Konkan Kanyal goats. *IOSR J Agric Vet Sci* 8: 24–30.
45. Atturi KM, Chakravarthy K, Guduru D (2020) Effect of hydroponic maize fodder supplementation on production performance in broilers, *Forage Res* 46 (1):98–100.
46. Ashom SA, Tuleun CD, Carew SN (2016) Serum biochemical indices of finisher broiler chickens fed diets containing unprocessed and variously processed roselle (*Hibiscus sabdariffa* L.) seeds. *Nig J Anim Sci* 2: 356-363.
47. Habschied K, Lalic A, Horvat D, Matijevic K, Lukinac J, Jukic M, Krstanovic V (2020) β -glucan degradation during malting of different purpose barley varieties. *Fermentation* 6:21.
48. Jamar C, du Jardin P, Fauconnier ML (2011) Cell wall polysaccharides hydrolysis of malting barley (*Hordeum vulgare* L.): a review. *Biotech Agronomy Soc Environ* 15:301–313.
49. MacGregor AW, Dushnicky LG, Schroeder SW, Balance GM (1994) Changes in barley endosperms during early stages of germination. *J Inst Brew* 100:85–90.

50. Svihus B, Newman RK, Newman CW (1997) Effect of soaking, germination, and enzyme treatment of whole barley on nutritional value and digestive tract parameters of broiler chickens. *Brit Poult Sci* 38:390–396. doi:10.1080/00071669708418008.
51. Younis M, Essa N, Abdo S (2019) Effect of dietary germinated sorghum on growth performance, carcass characteristics and some blood parameters of growing Japanese quails. *Archives Agric Sci J* 2 (2): 31–42.
52. Maidala A, Bakoshi AM, Gumai SA (2016) Growth performance and economics of production of broiler chickens fed three partially sprouted sorghum varieties as a replacement for maize. *J Biol and Gen Res* 2(3): 8–16.
53. Purohit P, Rawat H, Verma N, Mishra S, Nautiyal A, Bhatt S, Gupta AK (2023) Analytical approach to assess anti-nutritional factors of grains and oilseeds: a comprehensive review. *J Agric Food Res* 100877. doi: 10.1016/j.jafr.2023.100877
54. Dastar B, Moghaddam A, Shargh M, Hassani S (2014) Effect of different levels of germinated barley on live performance and carcass traits in broiler chickens. *Poult Sci J* 2 (1): 61–69.
55. Ali HS, Miah AG, Sabuz SH, Asaduzzaman M, Salma U (2019) Dietary effects of hydroponic wheat sprouted fodder on growth performance of turkey. *Res Agric Livestock and Fisheries* 6 (1): 101–110.
56. Brito CO, Dutra JLL, Dias TN, Barbosa LT, Nascimento CS, Pinto APG, Albino LFT, Fernandes RPM, Macário MS, Melo JS (2017) Effect of dietary lysine on performance and expression of electron transport chain genes in the pectoralis major muscle of broilers. *Animal*, 11:778-783.
57. Alewi M, Guteta A, Tesfaye E (2018) Effects of feeding malt barley sprout as a protein inclusion in broiler ration. *Results of Livestock Res* 249:512-520.
58. Kidulani V, Mbaga S, Aboud A (2019) Effect of sprouting on performances of improved sasso chickens fed with sorghum hydroponic fodder. In: *Effect of sprouting on chemical composition and performances of improved chickens fed with hydroponic sorghum fodder (Hsf)*, p. 20.
59. Rukmini NKS, Mardewi NK, Rejeki LGADS (2021) Characteristics of broiler chicken meat given with fermented bean sprouts ration. *Proceedings of the 3rd Warmadewa Research and Development Seminar, Denpasar-Bali, Indonesia.* <http://dx.doi.org/10.4108/eai21-12-2020.2305849>
60. Ogbuewu IP, Emenalom OO, Okoli IC (2015). Alternative feedstuffs and their effects on blood chemistry and haematology of rabbits & chickens: a review. *Comp Clin Pathol* 26 (2): 277 – 286. doi:10.1007/s00580-015-2210-0.
61. Robert K, Murray D, Daryl K, Grammer K, Rodwell W (2003) *Harper Biochemistry*, 29th edition
62. Kim MJ, Kwak HS, Kim SS (2018) Effects of germination on protein, -aminobutyric acid, phenolic acids, and antioxidant capacity in wheat. *Molecules* 23: 2244.
63. Obikaonu HO, Okoli IC, Opara MN, Okoro VMO, Ogbuewu IP, Etuk EB, Udedibie ABI (2011) Haematological and serum biochemical indices of starter broilers fed neem (*Azadirachta indica*) leaf meal. *Online J Anim Feed Res* 1:150–155.
64. Ogbuewu IP, Mbajjorgu CA (2024) Incorporation of yeast treated dialium bark meal on growth performance, blood indices and intestinal physiology of broilers. *Heliyon*, e3172555.
65. Regar MN, Tulung B, Londok JJMR, Moningkey SAE, Tulung YRL (2019). Blood lipid profile of broiler chicken as affected by a combination of Feed restriction and different crude fiber sources. *IOP Conf. Series: Earth and Environ Sci* 387: 012053.
66. Behrooj N, Khajali F, Hassanpour H (2012) Feeding reduced protein diets to broilers subjected to hypobaric hypoxia is associated with the development of pulmonary hypertension syndrome. *Brit Poult Sci.* 53:658–664, doi:10.1080/00071668.2012.727082.
67. Slawinska A, Dunislawska A, Plowiec A, Radomska M, Lachmanska J, Siwek M, Maiorano G (2019) Modulation of microbial communities and mucosal gene expression in chicken intestines after galactooligosaccharides delivery in ovo. *PLoS One* 14:1–23. doi:10.1371/journal.pone.0212318.
68. Ducatelle R, Goossens E, De Meyer F, Eeckhaut V, Antonissen G, Haesebrouck F, and Van Immerseel F (2018) Biomarkers for monitoring intestinal health in poultry: present status and future perspectives. *Vet Res* 49:1–9. doi:10.1186/s13567-018-0538-6.
69. Afsharmanesh M, Paghaleh AS, Kheirandish R (2013) Effects of sprouted and non-sprouted wheat and barley with and without enzyme on intestinal morphometry of broiler chickens. *Comp Clin Pathol* 22: 993–998. <https://doi.org/10.1007/s00580-012-1517-3>
70. Afsharmanesh M, Ghorbani N, Mehdipour Z (2016) Replacing corn with pearl millet (raw and sprouted) with and without enzyme in chickens' diet. *J Anim Physiol and Anim Nut (Berlin)* 100:224-228. <https://doi.org/10.1111/jp>
71. Shaheed MJ (2021) The effect of adding germinated date kernel powder to the diet on production performance and some broilers *E. coli* bacteria. *Ann Romanian Soc Cell Biol* 25(3):8135-142.
72. Miah AG, Osman AA, Mobarak MH, Parveen R, Salma U (2020) Evaluation of supplementation of hydroponic fodder on productive and reproductive performance of rabbit, *J Vet Res Adv* 2(2):41–50.