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Research Article
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EFFECT OF VARIETY ON THE POTENTIAL NUTRITIVE VALUE OF OAT HAYS

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Abstract: This study was conducted to determine the differences in the chemical composition, *in vitro* gas production (GP), methane production (CH_4), metabolizable energy (ME), and *in vitro* organic matter digestion (IVOMD) of oat hay varieties commonly used in ruminant feeding (Küçükyayla, Kahraman, Kırklar, ST-4, Yeniceri, Sebat, and Arslanbey). The oat hay varieties in the study were harvested during the flowering period in the 2019-2020 season in Kahramanmaras province. The *in vitro* findings of this study revealed significant differences among oat hay varieties in terms of their chemical composition, *in vitro* gas production, methane production, ME and IVOMD (P<0.001). The crude protein (CP) content of oat hays ranged from 7.61% to 9.57%, neutral detergent fiber (NDF) ranged from 64.46% to 72.96%, acid detergent fiber (ADF) ranged from 36.74% to 41.70%, crude ash (CA) ranged from 6.56% to 7.91%, metabolizable energy ranged from 6.96 to 7.98 MJ kg^{-1} DM, IVOMD ranged from 67.30% to 74.90%, and methane production rate ranged from 15.42% to 16.35%. The Yeniceri variety stood out with a NDF content of 64.46%, an ADF content of 36.74%, a ME of 7.98 MJ kg^{-1} DM, and an IVOMD of 74.90%. ST-4 had the highest *in vitro* gas production with 49.46 ml, while Sebat had the highest methane production rate with 15.42%. In conclusion, considering the chemical composition and fermentation parameters, the Yeniceri variety can be considered a potential source of forage, but further *in vivo* studies are needed to assess their effects on feed intake and animal production.

Keywords: Oat hay varieties, in vitro, Methane production, Metabolic energy

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1. Introduction

Oats are preferred as a feed ingredient in animal nutrition due to their high nutritional value, antioxidant content, and facilitative effect on digestion (Peterson et al., 2005; Naneli and Sakin, 2017). Oat grain is known as a functional food due to its distinct chemical composition, nutritional value, and beneficial effects on health compared to other cereals (Biel et al., 2014; Sterna et al., 2016). Consequently, significant efforts have been made in recent years in agronomic research, leading to the emergence of a substantial number of new oat varieties with different agronomic characteristics (Buerstmayr et al., 2007; Redaelli, 2008; Martínez et al., 2010).

The nutrient content of forages included in the rations of ruminant animals and their microbial digestion in the rumen, as well as the extent to which they are converted into metabolic energy, are of vital importance for ruminants (Ørskov and McDonald, 1979). Ruminants, due to their digestive systems, undergo ruminal fermentation of the consumed feed, resulting in the production of methane (CH_4), which is released into the environment. This emission leads to an energy loss of approximately 12-16% from the feed (Johnson and Johnson, 1995; IPCC, 2001). Therefore, low methane-producing feeds should be preferred in ruminant rations (López et al., 2010). Additionally, factors such as the timing of forage harvesting, maturity stage, and processing methods applied to these feeds, such as grinding, drying, wilting, etc., greatly affect their potential nutritional values and fermentation parameters (Doane et al., 1997; Sanderson et al., 1997; Filya et al., 2002).

The aim of the current experiment was to evaluate effect of variety on chemical composition; *in vitro* gas production, methane production, ME and IVOMD.

2. Materials and Methods

The trial was conducted at the experimental field of the Faculty of Agriculture, Kahramanmaras Sutcu Imam University, during the 2019–2020 season. Seven oat genotypes (Kucukyayla, Kahraman, Kırklar, ST-4, Yeniceri, Sebat and Arslanbey) were used in the study. The experiment was set up in a randomized complete block design with three replications. The plot size was 7 m long and 6 rows wide, with a spacing of 20 m between rows. The seeding rate was maintained at 500 seeds/m^2. Fertilization was applied at a rate of 12 kg/ha of pure nitrogen, half of which was applied as diammonium phosphate (DAP) fertilizer as top dressing, while the other half was applied as urea during the tillering stage. The oat varieties were harvested during the flowering period, and the remaining oat hay was brought to the laboratory for further analysis.

Dry matter, crude ash, crude protein and ether extract of oat hay samples were analyzed using the method of AOAC (1990). NDF and ADF contents of oat hay samples were analyzed with the method suggested by Van Soest (1991). All chemical analyses were carried out in triplicate.

The *in vitro* gas production technique was utilized to determine the gas production and methane production of oat hay. Rumen fluid was obtained from three sheep from a private abattoir in Kahramanmaras province and transferred to the laboratory in a thermos. The rumen fluid was then filtered through four layers of cheesecloth while being agitated with CO_2. Approximately 200 mg of oat hay samples were weighed into 100 ml glass syringes in triplicate. Subsequently, 30 ml of buffered rumen fluid (1:2 V/V) was added to the glass syringes containing oat hay samples and transferred to a water bath set at 39 °C for 24 hours of incubation. To obtain blanks, the same amount of buffered rumen fluid without substrate was added to four glass syringes (Menke et al., 1979). Gas and CH_4 production of the oat hay samples were measured after 24 hours of incubation. After the 24 hour incubation, the total gas production and the percentage of CH_4 in oat hay samples were determined using an infrared methane analyzer (Sensor Europe GmbH, Erkrath, Germany) (Goel et al., 2008).

The methane productions of oat hay samples as ml were calculated as follows in Equations 1-3:

$$CH4\ production\ (ml) = Total\ gas\ production\ (ml) * Percentage\ of\ CH4\ (\%) \quad (1)$$

The ME and IVOMD of oat hay samples were estimated with equations suggested by Menke and Steingass (1988).

$$ME\ \left(\frac{MJ}{kg}DM\right) = 1.06 + (0.1570 * GP) + (0.084 * CP) + (0.220 * EE) - (0.081 * CA) \quad (2)$$

$$IVOMD\ (\%) = 28.49 + (0.7967 * GP) + (0.325 * CP) \quad (3)$$

here, GP= gas production of 200 mg sample at 24 h incubation (ml), CP= crude protein (%), EE= ether extract (%), and CA= crude ash (%).

2.1. Statistical Analyses

One-way analysis of variance (ANOVA) was used to determine the effect of variety on chemical composition, *in vitro* gas production, methane production, ME and OMD of oat hay samples. Differences ($P<0.05$) among the mean of oat hay varieties were determined with Tukey's multiple range tests (Genç and Soysal, 2018).

3. Results

The effect of variety on the chemical composition of oat hay is presented in Table 1. Variety had a significant impact on the chemical composition of oat hay ($P<0.05$). The dry matter content of oat hay varieties ranged from 23.25% to 26.26%. The crude ash content of oat varieties ranged from 6.56% to 7.91%. The crude protein content of oat hay varieties ranged from 7.61% to 9.57%, with the highest values found in Kucukyayla, and Arslanbey variety, the lowest in Kırklar. Previous studies have reported crude protein contents of oat hay ranging from 4.2% to 9.2% (Sehu et al., 1998; Gursoy, 2023). The NDF (neutral detergent fiber) and ADF (acid detergent fiber) contents of oat varieties ranged from 64.46% to 72.96% and 36.74% to 41.70%, respectively.

The effect of variety on gas production, methane production, metabolizable energy (ME) and *in vitro* organic matter digestibility (IVOMD) of oat hay is shown in Table 2. Variety had a significant impact on methane production, ME, and IVOMD of oat hay. Gas production and methane production ranged from 50.17 to 58.73 ml and 7.98 to 9.37 ml, respectively. The percentage of CH_4 in oat hay ranged from 15.42% to 16.35%. ME and IVOMD of oat hay from different varieties ranged from 6.96 to 8.42 MJ (kg/DM) and 67.30% to 74.87%, respectively, with the highest values observed in Yeniceri and the lowest in ST-4.

4. Discussion

Gas production in feeds occurs as a result of the reaction between fermentable carbohydrates and buffer solutions, leading to the production of volatile fatty acids (Wolin, 1960). It has been reported that an increase in ruminal gas production may be associated with an increase in fermentable carbohydrate content (Sampath et al., 1995). The *in vitro* gas production values in the study indicate that the Yeniceri and Kucukyayla varieties fermented well compared to other varieties. In a study conducted by Lopez et al. (2010), feed ingredients were classified based on their anti-methanogenic properties. Feed ingredients with percentages ranging from 11% to 14% were classified as low, 6% to 11% as moderate, and 0% to 6% as high anti-methanogenic character. The findings of the current study revealed that oat hay varieties did not exhibit any anti-methanogenic effect according to the classification by Lopez et al. (2010).

It has been reported that if the crude protein (CP) content of feed ingredients is below 8%, the enzymatic activities of microorganisms in the rumen may be limited, resulting in an inadequate supply of ammonia in the rumen (Norton, 2012; Cappellozza et al., 2013).

Table 1. Effect of variety on gas, methane, metabolic energy and *in vitro* organic matter digestibility of oat hay

Variety	DM (%)	CA (%)	CP (%)	EE (%)	NDF (%)	ADF (%)
Küçükyayla	24.89^{ab}	6.56	9.57^{c}	3.06^{a}	66.76^{ab}	37.33^{ab}
Kahraman	25.87^{ab}	6.56	8.64^{abc}	3.14^{a}	69.37^{bc}	40.20^{bc}
Kırklar	24.97^{ab}	7.33	7.61^{a}	3.53^{ab}	72.96^{c}	41.70^{c}
ST-4	25.08^{ab}	7.91	8.02^{ab}	3.46^{ab}	68.70^{bc}	39.13^{abc}
Yeniçeri	23.25^{a}	6.86	8.82^{bc}	4.90^{bc}	64.46^{a}	36.74^{a}
Sebat	23.76^{ab}	7.72	8.73^{bc}	5.73^{c}	70.41^{cd}	38.06^{ab}
Arslanbey	26.46^{b}	7.56	9.52^{c}	3.08^{a}	66.85^{ab}	37.09^{a}
SEM	0.88	1.34	0.30	0.42	0.98	0.87
Sig.	0.036	0.901	<0.001	<0.001	<0.001	<0.001

ab: Column means with common superscripts do not differ (P<0.05), SEM= standard error mean, DM= dry matter (%), CA= crude ash (%), CP= crude protein (%), EE= ether extract (%), ADF= acid detergent fiber (%), NDF= neutral detergent fiber (%), P<0.05.

Table 2. Effect of variety on gas, methane, metabolisable energy and *in vitro* organic matter digestibility of oat hay

Variety	GP (ml)	CH_4 (ml)	CH_4 (%)	ME (MJ/kg)	IVOMD (%)
Küçükyayla	58.40^{c}	9.09^{bc}	15.55	7.97^{bc}	74.87^{c}
Kahraman	52.93^{ab}	8.65^{abc}	16.35	7.31^{ab}	69.66^{ab}
Kırklar	56.90^{bc}	9.10^{bc}	15.99	7.78^{bc}	72.96^{bc}
ST-4	49.46^{a}	7.99^{a}	16.15	6.96^{a}	67.30^{a}
Yeniçeri	58.73^{c}	9.37^{c}	15.95	8.42^{c}	74.90^{c}
Sebat	53.13^{ab}	8.20^{ab}	15.42	7.98^{c}	70.70^{abc}
Arslanbey	50.17^{a}	7.98^{a}	15.55	7.04^{a}	68.55^{ab}
SEM	0.88	1.34	0.30	0.42	0.98
Sig.	<0.001	0.002	0.304	<0.001	<0.001

ab: column means with common superscripts do not differ (P<0.05), SEM= standard error mean, GP= gas production (ml), CH_4= methane production (ml), CH_4= methane production (%), ME= metabolic energy (MJ/kg DM), IVOMD= *in vitro* organic matter digestibility (%), P<0.05.

With the exception of the Kırklar variety, the CP levels of oat hay varieties in the study can be considered sufficient for the proper functioning of microbial activity in the rumen. The difference in CP contents of oat varieties between the two experiments is possibly associated with differences in climatic conditions, fertilization, and soil type of the growing site (Sehu et al., 1998; Gursoy, 2023).

In rations, it is desired to have low acid detergent fiber (ADF) levels as it is difficult to digest in the rumen (Van Soest, 2018). An increase in ADF levels in the ration has been reported to result in a feeling of fullness in ruminants, leading to a decrease in feed intake and consequently a decrease in the utilization of energy and protein from the feed (Yavuz, 2005). Therefore, it is recommended to have ADF levels in ruminant rations between 21% and 30% (Balthrop et al., 2011). The ADF contents of oat hay varieties in the study were found to be higher than the desired optimal level.

The metabolizable energy (ME) values of oat hays obtained in the current experiment are consistent with the values indicated by NRC (2007). Furthermore, an increase in the cell wall content in feeds has been reported to result in a decrease in ME and organic matter digestibility (OMD) values (Sagocak, 2011).

5. Conclusion

Variety had a significant effect on chemical compositions, gas production, CH_4 production, ME and IVOMD of hay. There is considerable amount of variation among oat varieties in terms of chemical compositions, gas production, CH_4 production, ME and IVOMD of oat hay. The oat hays from different varieties had provided new raw materials with a range of nutritional characteristics and will provide not only energy and protein but also fiber for ruminant animals. Based on the chemical composition and fermentation parameters, variety Yeniceri can be recommended for hay production since it has a high CP, ME and IVOMD. However, *in vivo* studies are needed to determine the effects of oat hay varieties on feed intake and growth performance on ruminant animals.

Author Contributions

The percentage of the author(s) contributions is presented below. All authors reviewed and approved the final version of the manuscript.

	B.S.	A.K.	M.Y.
C	35	35	30
D	100		
S		100	
DCP			100
DAI	35	30	35
L	35	35	30
W	35	30	35
CR	35	35	30
SR	35	30	35
PM	35	35	30
FA	35	30	35

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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Research Article
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EFFECTS OF SPIRULINA (*S. PLATENSIS*) ADDITION TO DIETS OF BREEDER QUAILS

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Abstract: The experiment aimed to investigate how different levels of Spirulina (spirulina platensis) supplementation in the diet of breeder Japanese quail (Coturnix coturnix japonica) affect their laying performance, egg quality, and hatchability parameters. The study was carried out with 96 breeding quails (72 female, 24 male). Quails were randomly distributed to 4 treatment groups with 24 subgroups (1 male 3 female). The feeding trial lasted for 8 weeks, during which time four diets were prepared with powdered Spirulina supplementation at 0% (control), 0.75%, 1.5%, and 2.25% to the basal diet. At the end of the experiment, feed consumption was higher in the control group than in the other groups (P<0.05). The control group had the highest feed conversion ratio (FCR) while the group fed with 2.25% SP had the lowest FCR (P<0.05). No considerable differences were observed between the groups in terms of egg production, body weight, egg weight, and egg mass. Similarly, eggshell thickness, eggshell weight, eggshell ratio, egg shape, albumen, and yolk index parameters were not significantly affected by the treatment. L* value, which is one of the egg yolk color parameters, decreased linearly with increasing spirulina levels in the diet, while a* and b* values increased (P<0.01). Differences between treatment groups in terms of incubation parameters were not significant. In conclusion; the addition of 0.75%, 1.5%, and 2.25% SP to the diets of breeder Japanese quail had positive effects on feed intake and feed conversion ratio, and egg yolk color, but had no negative effects on egg quality and hatching parameters. It was concluded that spirulina can be used at a 2.25% level in breeder Japanese quail diets.

Keywords: Breeder Japanese quail, Spirulina (*spirulina platensis*), Incubation parameters, Performance, Egg yolk color, Egg quality

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1. Introduction

Spirulina, an edible cyanobacterium, has a spiral-shaped and filamentous structure. This bacterium is commonly found in alkaline lakes in nature. Previously, it was classified as a type of blue-green algae (Becker, 2007; Gupta et al., 2008). This is the reason why it attracts attention as animal feed, and human food due to its high crude protein, essential amino acid, fat, vitamin, and mineral content in its dry matter (Mišurcová et al., 2014; Salmeán et al., 2015). Spirulina platensis has antioxidant, anti-inflammatory, immune-modulating, and hepatoprotective functions (Jeyaprakash and Chinnaswamy, 2005; Abdel-Daim et al., 2015; Ibrahim and Abdel-Daim, 2015; Jamil et al., 2015). It can be grown in bioreactors or open ponds without using agricultural land (Chen et al., 2016). It is a sustainable resource that can be obtained without using agricultural land. Microorganisms, which can synthesize the nutrients (carbohydrates, protein, lipids, minerals, and vitamins) that form the basis of nutrition from simple organic and inorganic substances, gain great importance in solving the problem of food insufficiency in the world. Cellulose is not found in the cell wall of Spirulina Platensis. This can be absorbed by improving mucosal digestion and intestinal function. While the population of beneficial microorganisms (such as Bifidobacter, and Lactobacillus) increases, harmful microorganisms (such as Candida) are suppressed. The increase in the Lactobacillus-type microorganism population positively affects food digestion and absorption (Seyidoglu et al., 2017). There are some desirable properties in a source that can be used as an alternative in animal nutrition. Ideally, the features expected from this new source are high nutritional value and efficiency of conversion to animal products, optimizing quality of product, and using water and land efficiently (Poppi and McLennan, 2010). Spirulina is a strong candidate with the potential to meet all of these features. This trial was carried out to find out the effects of powdered spirulina added to breeder quail diets in the amounts of 0, 0.75, 1.5, and 2.25% on egg quality, performance, and hatching parameters. The efficacy of spirulina as a viable feed additive was evaluated in the investigation.

2. Materials and Methods

A total of 96 breeder quails (*Coturnix coturnix japonica*), 72 females and 24 males, aged 10 weeks, were used in the study. Four treatment groups were created to distribute quails, with each group having 24 subgroups. In each subgroup, there were 3 female quails and 1 male quail. For eight weeks, a specialized feed was prepared to meet the nutritional requirements of breeding quail. The feed was formulated to contain 2900 Kcal/kg metabolizable energy and 20% crude protein (Council, 1994). Spirulina (Spirulina platensis) powder form was used in the experiment. A set of rations for a trial was prepared, including a basal ration (0%) mainly made from corn and soybean meal. The preparation involved the use of Spirulina (*Spirulina platensis*) at different percentages of 0.75%, 1.5%, and 2.25% (Table 1).

Table 1. Nutrient content of experimental diets

Ingredients	Spirulina%			
	0	0.75	1.5	2.25
Corn	50.1	50.05	50.0	50.4
Spirulina	0	0.75	1.5	2.25
Soybean meal	36	35	34.0	33
Crude oil	6.2	6.5	6.5	6.5
Limestone	5.10	5.10	5.15	5.15
Dicalcium phosphate(DCP)	1.8	1.8	1.85	1.85
Salt	0.25	0.25	0.25	0.25
Premiks[1]	0.25	0.25	0.25	0.25
L-Lysine	0.10	0.10	0.15	0.15
DL-Methionine	0.20	0.20	0.20	0.20
Calculated nutrients				
Crude protein, %	20.0076	20.0038	20.0	20.0304
Energy, kcal/kg ME	2904.05	2928.99	2927.0	2938.91
Calcium, %	2.5049	2.5015	2.5294	2.5261
Available phosphorus, %	0.3508	0.3503	0.3589	0.3585
Lysine, %	1.0492	1.0251	1.0410	1.0178
Methionine, %	0.4768	0.4711	0.4654	0.4604
Methionine-cysteine, %	0.20	0.20	0.20	0.20

The experiment was carried out in multi-storey breeder cages with 3 cells (45x30x25 cm) on each floor in the quail unit located at the Faculty of Agriculture Department of Animal Science Farm of Selçuk University. In the experiment, quails were given trial rations for 8 weeks. During the trial, a 16-hour light/8-hour dark lighting program was applied. Feed and water were given ad libitum. At the beginning and end of the experiment, the animals in each cage were weighed as a group. In the experiment, two periods of measurement were made, each lasting 4 weeks. The given results are the average of the measurements taken in two periods. The amount of feed given was recorded daily. At the end of each period, feed intake (FI) was calculated from these records as the daily average FI per quail. For each period, the feed conversion ratio was calculated by dividing the daily average feed intake (in grams) per quail by the egg mass (in grams) during that period. Egg production (EP) was recorded daily and determined from these records at the end of each period. The weight of eggs (EW) was calculated by taking an average of the egg weights collected during the final two days of each period. To determine egg mass, the formula EM= (egg production x egg weight)/100 was used. Eggs were gathered during the final two days of each period for the experiment, where various factors were measured including shell thickness, weight, shape index, yolk and albumen index, and Haugh unit. The colorimeter (Konica Minolta CR410) was used to measure L*, a*, and b* values of egg yolk. End of the experiment, to determine the hatching properties, the eggs were collected for 7 days, and those with hatchability properties were numbered according to groups and placed in the incubator. The number of chicks hatched after the seventeenth day and the number of fertile and non-fertile eggs was determined by breaking the eggs that did not hatch after the twentieth day. The data obtained was used to calculate the hatching efficiency, fertility rate, and hatchability (Erensayın, 2000). One-way analysis of variance (ANOVA) was used for statistical analysis of the experiment's data (Minitab, 2000) and to determine the differences between the means, Duncan's multiple comparisons test was utilized.

3. Results

The effects of supplementing breeder Japanese quail diets with SP at varying levels (0%, 0.75%, 1.5%, and 2.25%) on parameters such as LWC, FI, FCR, EP, EW, and EM are presented in Table 2. The live weight change, egg weight, egg mass, and egg production of breeder quails were not affected by the addition of spirulina in their diets. However, the inclusion of spirulina resulted in a decrease in feed intake and feed conversion ratio. The lowest feed consumption was in the 2.25% SP group (P<0.05). The best feed conversion ratio was in the 2.25% SP group (P<0.05). Table 3 presents the effects of adding spirulina to the diets of breeder Japanese quails on egg quality parameters, including yolk L*, a*, and b* values. The effect of spirulina supplements on breeder Japanese quail diets on eggshell thickness, eggshell weight, eggshell ratio, yolk index, and Haugh Unit were not statistically significant. Table 4 presents the outcomes of incorporating spirulina into the diets of breeder quails, and its effect on the incubation parameters. There were no significant differences observed in the incubation parameters, including chick's weight, hatchability, and fertility, between the treatment groups (P>0.05), indicating that the treatment did not have a significant impact on these parameters.

Table 2. The effect of dietary different levels of SP on the performance parameters of breeder quails

Parameters	Control	0.75%SP	1.5%SP	2.25%SP	P-Value
Live weight change (g)	12.79±1.72	15.38±1.35	14.54±1.47	10.62±0.84	0.106
Feed intake (g)	29.00±0.59^{a}	27.68±0.42^{ab}	27.45±0.42^{ab}	27.05±0.84^{b}	0.019
Feed conversion ratio	2.79±0.11^{a}	2.59±0.14^{ab}	2.47±0.08^{ab}	2.34±0.07^{b}	0.011
Egg production (%)	87.14±1.38	90.63±1.42	89.76±1.21	90.46±0.66	0.180
Egg weight (g)	12.00±0.20	11.92±0.47	12.46±0.31	12.34±0.25	0.593
Egg mass (g/quail/day)	10.46±0.30	10.79±0.44	11.18±0.36	11.15±0.22	0.414

$^{a, b}$The differences indicated by different letters on the same row are statistically significant, P<0.05

Table 3. The effect of dietary different levels of SP on the egg quality, yolk L*, a* and b* values of breeder Japanese quails

Parameters	Control	0.75%SP	1.5%SP	2.25%SP	P-Value
Eggshell thickness(mm)	0.218±0.004	0.228±0.003	0.224±0.004	0.230±0.004	0.189
Eggshell weight (g)	0.97 ± 0.03	0.99 ± 0.04	1.00 ± 0.02	1.02 ± 0.02	0.703
Eggshell ratio (%)	8.07±0.14	8.32±0.17	8.06±0.16	8.26±0.15	0.542
Egg shape index(%)	77.08±0.86	75.44±0.64	76.89±0.49	75.16±1.14	0.263
Albumen index (%)	5.11±0.38	5.63±0.13	5.31±0.33	5.17±0.18	0.556
Yolk index (%)	47.06±1.27	47.34±0.48	46.29±1.08	47.90±1.18	0.750
Haugh Unit	90.39±1.11	91.20±0.45	90.63±1.19	90.36±0.45	0.896
L*	46.02±0.73^{A}	45.37±0.50^{AB}	43.13±0.24^{B}	40.70±0.80^{C}	0.000
a*	6.44±0.21^{A}	6.80±0.23^{A}	7.71±0.20^{B}	7.88±0.21^{B}	0.000
b*	25.57±0.50^{A}	26.81±0.49^{AB}	27.24±0.20^{B}	28.81±0.62^{B}	0.001

$^{A, B}$The differences indicated by different letters on the same row are statistically significant, P<0.01

Table 4. The effect of dietary different levels of spirulina on incubation parameters of breeder Japanese quails.

Parameters	Control	0.75%SP	1.5%SP	2.25%SP	P-Value
Chick's weight (g)	8.39±0.18	8.40±0.40	8.74±0.28	9.19±0.26	0.199
Hatchability of fertile eggs (%)	95.00±3.42	96.30±2.34	91.30±3.36	96.30±2.34	0.587
Fertility (%)	93.33±3.33	91.67±1.67	98.33±1.67	93.33±2.11	0.226
Hatchability of setting eggs (%)	88.33±3.07	88.33±3.07	90.00±4.47	90.00±3.65	0.975

4. Discussion

Numerous studies have shown that spirulina has an impact on poultry performance. It has been reported that diets containing Spirulina positively affect the production performance of laying poultry (Takashi, 2003; Nikodémusz et al., 2010). Similarly, adding spirulina has been reported to improve the FCR of laying hens (Kharde et al., 2012; Shanmugapriya et al., 2015). According to Mariey et al. (2012), adding 0.2 % spirulina to the laying hen feed improved FCR, EW, EM, EP, and FCR (P<0.05). It is similar to the results of the current study, but studies are reporting that adding spirulina to poultry diets does not affect performance data. Reportedly, the inclusion of spirulina in quail diets does not have any impact on their feed intake (Hajati and Zaghari, 2019; Omri et al., 2019). Zahroojian et al. (2013) stated that SP addition to laying hen diets had no statistically significant effect on EP, FI, FCR, and EW (P>0.05). Additionally, Hajati and Zaghari (2019) stated that SP did not affect FCR, EW, and EP. The reason for the differences in the results may be the amount of SP used the housing conditions of the animals, the animal species, the compositions of feed raw materials and production systems, etc.

Selim et al. (2018) conclusively demonstrated that the supplementation of spirulina (0, 0.1, 0.2, and 0.3%) to laying hen rations did not affect the shell percentage, albumen index, yolk index, shape index, and Haugh Unit. Similarly, studies are reporting that adding different amounts of spirulina to laying hen diets does not affect egg quality (Zahroojian et al., 2013; Curabay et al., 2021). The spirulina supplement to breeder quail diets decreased the L* value and increased the a* and b* values. A decrease in L* results in decreased brightness, while an increase in a* and b* leads to increased redness and yellowness. Egg yolks in laying hens supplemented with spirulina were reported to be redder and less yellow than the control group (P< 0.01) (Omri et al., 2019). The inclusion of 2.5% SP in the diet of quails resulted in an increase in the a* and b* values of the breast meat (Göçmen, 2022). Studies are reporting that adding SP to the diet increases the egg yolk score (Mariey et al., 2012; Selim et al., 2018). Spirulina's high carotenoids, including β-carotene, zeaxanthin, and xanthophylls, accumulate in the yolk, resulting in its characteristic color (Anderson et al., 1991; Takashi, 2003; Kotrbáček et al., 2013). Spirulina is a good source of xanthophyll for yolk (Ross and Dominy, 1990). According to Abouelezz (2017) report, adding 1% spirulina to the feed and 0.25% to the drinking water increased fertility in Japanese quails. The addition of up to 12% spirulina to Japanese quail diets positively affected fertility and hatchability (Ross and Dominy, 1990).

5. Conclusion

As a result, spirulina addition to breeder quail diets at 0 %, 0.75 %, 1.5 %, and 2.25 % levels did not affect EP, EW, and EM, but improved FI and FCR. There were no significant findings in regards to eggshell thickness, shell weight, shell ratio, yolk index, and Haugh Unit. None of these factors showed any significant variation or change. Egg yolk L* value decreased, and a* and b* values increased. Decreased feed intake as a result of the supplementation of spirulina to quail feeds in the experiment and improvement of FCR without affecting egg production are the desired changes in performance. The color of egg yolk is a parameter that affects consumer preference. The color of egg yolk can be altered by Spirulina, which is a natural feed additive. Further scientific research is required to establish the appropriate practices for incorporating spirulina into poultry nutrition.

Author Contributions

The percentage of the author(s) contributions is presented below. All authors reviewed and approved the final version of the manuscript.

	B.D.	R.G.
C	20	80
D	20	80
S	20	80
DCP	60	40
DAI	50	50
L	80	20
W	60	40
CR	40	60
SR	50	50
PM	40	60
FA	50	50

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

In the year 2023, a research study was carried out at the Livestock Facilities of Selçuk University's Faculty of Agriculture. The authors declare that the study was carried out by the animal welfare rules specified in Article 9 of the Republic of Turkey Law No. 5996.

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INVESTIGATING HEREDITARY DISORDERS OF SIMMENTAL FROZEN BULL SEMEN IMPORTED TO TÜRKİYE DURING 10-YEAR PERIOD

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Abstract: This study was aimed to determine hereditary defects of frozen Simmental bull semen imported to Turkiye between 2013 and 2022. As the source of this study, the websites of various companies that produce semen, bull catalogues, and databases of bull semen companies have been used. A total of 13 websites including Simmental semen databases and bull catalogues were investigated. The result of the study showed that 438 of 1301 Simmental bull's frozen semen carry at least one genetic defect during 10-year period of import. The most common hereditary defects are Bovine Male subfertility (BMS) for 164 frozen bull semen, Trombopathia (TP) for 155 bull semen and Fleckvieh Haplotype 4 (FH4) for 127 bull semen respectively. Significant effect was observed between different years and the rate of carriers was significantly decreased after 2019. As for origin of bull semen, the bull semen imported from Czech Republic showed significantly the least hereditary defect rate compared with those imported from Austria, Germany and Italy.

Keywords: Simmental bull sperm, Hereditary disorders, Genetic defects

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1. Introduction

The practice of artificial insemination (AI) is so prevalent in Türkiye. Nearly all the cows and heifers in the registered farms get pregnant by AI. A great portion of frozen semen used in Türkiye is imported. The procedures and principles regarding the import of semen, ovum and embryo were issued by General Directorate of Livestock of Ministry of Agriculture and Forestry. There are some important hereditary diseases which should be taken into consideration. However, there is no regulation or prohibition against importing Simmental bull frozen semen carried hereditary disorders. Hereditary defects are important for genetic pollution of livestock herds in the worldwide. Therefore, the raised bulls or the frozen semen should be tested for hereditary diseases and the results of analyses should be specified in pedigrees or information cards. İnal and Çam (2016) reported just the prevalence of hereditary disorders of imported semens in 2015. Since there is lacking of hereditary disorder information for frozen bull semen imported to Türkiye, a comprehensive study is needed to investigate occurrence of Simmental bull semen using the all revealed data via General Directorate of Livestock of Ministry of Agriculture and Forestry. So this study was aimed to determine hereditary defects of frozen Simmental bull semen imported to Türkiye between 2013 and 2022.

2. Materials and Methods

The name and ID of the bull, the importing company and the number of straws are the list of imported bulls issued by General Directorate of Livestock of Ministry of Agriculture and Forestry. In this study, hereditary status of imported Simmental bulls between 2013 and 2023 were examined and a category was created according to years and origins.

Table 1. Websites of various companies used in the study

Company	Websites
Center of Moruzzo	www.en.ctsmoruzzo.it
Libro Genealogico	www.online.anapri.it
Zuchtwert Austria	www.zuchtwert.at
ST Genetics	www.stgen.com
Accelerated Genetics	www.accelgen.com
Synetics	www.evolution-xy.fr
Swiss Genetics	www.swissgenetics.com
Superbrown	www.superbrown.it
Göpelgenetik	www.goepelgenetik.de
CBBA	www.db.cschms.cz
Munster Bovine	www.munsterbovine.ie
Melapolskie Centrum	www.mcb.com.pl
Aberekin	www.aberekin.com

Bulls were combined for general examination, reducing the number to 1302 bulls (13,113,327 straws) (Table 1). Some bulls with beef origin were excluded from the study due to the fact that their pedigrees don't include hereditary disorders.

Table 1 showed websites of various companies that produce semen, bull catalogues and database of bull semen in Simmentals.

Effect of number of carriers on different year and origin was analyzed using Chi-Square analysis in SPSS (ver. 25.0). %5 confidence interval was accepted for the significance level of the tests

3. Results and Discussion

Simmental breeding in Türkiye is getting popular day by day. The primary purpose of Simmental cattle breeding imported to Türkiye is for dairy production. So the majority of the Simmental bulls imported between 2013 and 2022 were for dairy production. Totally, 438 of 1301 bulls carried at least one genetic defect as a result of the research. The type of each hereditary defects of Holstein bulls were summarized in Table 2.

Table 2. Hereditary defects of the Simmental frozen semen imported between 2013 and 2022

HD[1]	Bulls n	Straw n
A[2]	0	0
DW[3]	4	25964
FH2[4]	55	360811
FH4[5]	127	906108
FH5[6]	51	468718
BH2[7]	42	403256
BMS[8]	164	1386618
ZL[9]	8	53121
TP[10]	155	1101387

[1]Hereditary Defect, [2]Arachnomelia, [3]Dwarfism, [4]Flekvieh Haplotype 2, [5]Flekvieh Haplotype 4, [6]Flekvieh Haplotype 5, [7]Braunvieh Haplotype 2, [8]Bovine Male Subfertility,[9]Zinc Deficiency, [10]Trombopathia.

Table 3. Effect of year on occurrence of hereditary defects of the Simmental bull frozen semen

Year	Bull (n)	CR[1] (n)	SNC[2]	TSN[3]
2013	92	39.1^{ab} (36)	176599	533881
2014	146	44.5^{a} (65)	414876	1008256
2015	168	45.8^{a} (77)	596778	1252819
2016	233	42.1a (98)	682012	1705780
2017	159	39.0^{ab} (62)	524924	1472013
2018	229	31.4^{abc} (72)	764619	2171580
2019	183	24.6^{cd} (45)	344425	1454485
2020	244	30.3^{bcd} (74)	467988	1343418
2021	214	26.2^{cd} (56)	333572	1258967
2022	174	21.8^{d} (38)	186432	912128

[a, b, c, d]; different superscripts in the same column show significant differences (P<0,001). [1]carriers rate, [2]straw number of carriers [3]total straw number.

The significant decrease in number of carriers imported in different years became prominent after 2018 (Table 3). Among 1301 Simmental bulls, It was determined that 4 bulls carried Dwarfism, 8 bulls carried Zinc Deficiency. Flekvieh Haplotype 2 (FH2) gene causing deficiency of growth in Simmentals can be another form of dwarfism (Burgstaller et al., 2016). It was determined that 55 Simmental bulls carried FH2. FH4 gene for Simmentals decreases the pregnancy rate like Holstein haplotype genes (Ling et al., 2018). Calves with FH4 genes can't survive because the homozygous FH4 gene causes zygote death. It was determined that 127 Simmental bulls of frozen semen carried FH4. FH5 is a new haplotype for Simmental causing death with symptoms of heart and liver failure in 48 hours after birth (Emmerling, 2015). 9 Simmental bulls carried FH5. 42 Simmental bulls carried Braunvieh Haplotype 2 (BH2) gene which is normally found in Brown Swiss Haplotype. Calves carrying BH2 genes as homozygous are either born dead or die after birth. 37 Simmental bulls were determined to be carrier of Trombopathia characterized by impaired blood coagulation (Ling et al., 2018). 32 bulls were found to have carrier of Bovine Male Subfertility gene causing sterility of bulls (Ling et al., 2018) and not problem for Türkiye (Table 4). It would be a problem in case Türkiye will start to have AI bulls for breeding. Given that 4705983 doses of frozen semen belonging to these bulls were imported and used in Türkiye, which can be concluded that Simmental breeding faces a grave serious genetic pollution.

Table 4. Effect of bull origin on occurrence of hereditary defects of the Simmental frozen semen

Origin	n	CR[1]	PNC[2]	TPN[3]
AT[4]	227	$30,8^{b}$ (70)	830146	2073004
CZ[5]	103	$17.,5^{c}$ (18)	237278	877278
DE[6]	861	38.2^{a} (329)	2391557	6558026
IT[7]	48	35.4^{ab} (17)	73601	441074

[a, b]; different superscripts in the same column show significant differences (P<0.001) [1]carriers rate, [2]straw number of carriers [3]total straw number [4]Austria [5]Czech Republic [6]Germany [7]Italy

5. Conclusion

This study highlights the importance of genetic pollution in imported bull semen. Even though there was a limited study investigating hereditary defects of imported semen to Türkiye; this research was the first to examine all hereditary disorders throughout ten-year period. The result of this study encourages authorities to make more precautions during importing frozen bull semen against genetic pollution.

Author Contributions

The percentage of the author(s) contributions is presented below. All authors reviewed and approved the final version of the manuscript.

	M.Ç.	Ş.İ.
C	80	20
D	80	20
S		100
DCP	100	
DAI	50	50
L	100	
W	70	30
CR	50	50
SR	70	30
PM	50	50
FA	50	50

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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Review
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USE OF SOME INDUSTRIAL PLANTS IN POULTRY

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Abstract: The rapid increase in the human population has also increased the demand for raw materials in many fields. The increasing population has brought along the problem of opening agricultural areas to settlement. For this reason, versatile plants that bring high efficiency from the unit area without harming the existing natural resources and can contribute in many fields such as food, textile, biofuel and animal nutrition arouse excitement among scientists. Industrial plants also provide the diversification of agriculture, enable the simultaneous development of plant and animal production, and make significant contributions to local economies, especially in developing countries. Industrial crops play a crucial role in various aspects of human society, economy, and sustainability. Their importance extends beyond food production and consumption, as they contribute to a wide range of industries and offer several benefits. One of these sectors which affected by industrial plants is poultry nutrition. Industrial crops are utilized to meet the energy, protein, vitamin, fibre, Omega-3, antioxidant, phytochemicals, phosphorous and mineral requirements of poultries. Such as soybeans, sunflower, maize, cottonseed and flax are widely used in the feeding of poultries. They serve as high-energy and protein sources, promoting healthy growth and productivity. These crops are specifically cultivated to provide essential nutrients and meet the dietary needs of poultries. As a conclusion, industrial crops serve as essential ingredients of poultry feeding methods, providing the crucial nutrients, energy, and protein required for the appropriate growth, development, and productivity of poultries. Their inclusion in diets ensures the optimal health and well-being of poultries in various agricultural settings. This review article has examined some important industrial plants as poultry feed.

Keywords: Industrial crops, Poultry nutrition, Poultry

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1. Introduction

Industrial crops play a significant role in the provision of nourishment for poultry, serving as both nutritious and cost-effective sources of feed for livestock. These plants are regularly assessed as potential feed content due to their nutritional importance and widespread availability. As a result of the studies, it was stated that white meat consumption will increase by 73% by 2050 (Percival, 2022). It is predicted that increasing world population and production costs will negatively affect the poultry industry (FAO, 2014; Cerisuelo and Calvet, 2020). Poultry production is sustainable with proper nutrition. The more efficiently feeding is done, the more resource demand will decrease and accordingly, costs will decrease (Greenhalgh et al., 2020). The suitability of a plant for poultry consumption is determined by a set of criteria that include the presence of various nutrient substances in different parts of the plant, as well as their digestibility, palatability, metabolizable, and the absence of harmful substances in different plant components (McDonald et al., 1998) and the agronomic properties, concerning cultivation, harvesting difficulties and financial issues. Regarding nutrient substances the essential nutrients in animal feeding items are (McDonald et al., 1998) proteinic nitrogenous compounds, with special reference to their major amino acid ingredients, nonproteinic nitrogenous compounds, carbohydrates, mainly starch, fats as oils, and cellulosic compounds as fibres, vitamins, and minerals.

Current developments show that the search for alternative feed sources is inevitable in the poultry industry. This paper offers an overview of several crucial industrial plants and their impact on poultry nutrition.

2. Poultry Industry

The World Food and Agriculture Organization, alongside various scholarly investigations, concurs that the human population is projected to reach approximately 9.2 billion individuals by the year 2050, thereby necessitating an augmented global food demand ranging from 35% to 56%. In light of these projections, the task of meeting this heightened demand while maintaining the nutritional adequacy of the food supply becomes increasingly complex and arduous (FAO, 2014; van Dijk et al., 2021). The shorter growth biology of poultry compared to other farm animals, the short period between two generations, and the fact that most of them have an omnivorous diet make them preferable to other animal species. In recent decades, the demand for poultry meat and, accordingly, per capita consumption rates have increased (OECD, 2022). Compared to other animal foods, the poultry industry has become preferable in terms of the high-quality animal protein, amino acids, energy and microelements it contains (Bohrer, 2017). As a consequence of the escalating need for sustenance brought about by the burgeoning human populace, the endeavour of supplying nutrient-dense food with constrained resources poses a formidable challenge for the field of animal husbandry. Developed countries such as the USA, China and Brazil rank first in world chicken meat production (FAO, 2021). Although the amount of chicken meat consumed per capita in the world is 14.7 kg, this rate reaches 64 kg in Israel and 50.1 kg in America (FAO, 2021).

In the past few decades, there have been notable advancements in the field of boiler production, which have undoubtedly revolutionized the industry. These remarkable developments have brought about significant improvements in various aspects of broiler manufacturing, resulting in enhanced efficiency and performance. For instance, between the years 1985 and 2010, there has been a substantial increase in the live weight and feed conversion rates of 35-day-old chickens. Specifically, the live weight has surged from 1.4 kg to an impressive 2.4 kg, while the feed conversion rates have also witnessed a commendable rise from 1.5 to 2.3. These findings highlight the tremendous progress made in optimizing the growth and productivity of poultry, thereby contributing to the overall advancement of the agricultural sector (Siegel, 2014). These increases have been associated with improvements in breeding, nutrition, vaccination, biosecurity guidance, disease prevention and control, and poultry environmental management. Considering these risks, it is important that protein production continues in a sustainable manner.

The objective of this overview is to describe the importance of nutrition in the poultry industry. The topics include the relationship between different industrial crops and poultry diets.

2.1. Sunflower

Sunflower seeds, which are characterized by their distinctively large and flat shape, belong taxonomically to the genus *Helianthus annuus*, which is a member of the family *Asteraceae*, commonly known as the aster, daisy, or sunflower family (Soliman et al., 1996; Canibe et al., 1999; San Juan and Villamide, 2001). The sunflower plant, which has been extensively recorded and studied, holds a prominent position in the hierarchy of essential resources in the realm of nutrition and agriculture. It stands as the second most significant reservoir of feed and protein, offering a valuable source of sustenance for both humans and animals alike. Sunflower seeds contain 20% of protein, whereas protein contents of the oil press cakes and extraction residues range from 30 to 50% (Dorrell and Vick, 1997). Sunflower seeds are considered rich with their energy content of 3,691 to 5,004 kcal (Daghir et al., 1980; Cheva-Isarakul and Tangtaweewipat, 1990). Furthermore, it also serves as the third most crucial source of oil, a highly sought-after commodity utilized extensively by both humans and animals for various purposes. In addition to its contributions in the realm of nutrition and oil production, the sunflower plant also holds the distinction of being the fourth largest supplier of oilseeds, further solidifying its position as a vital component of the global agricultural industry (Lusas, 1985; Aboul Ela et al., 2000; Garcés et al., 2009).

In a research endeavour that took place in 1997, an investigation was carried out, wherein it was ascertained and subsequently documented that the inclusion of sunflower meal within the poultry diets could serve as a feasible alternative to the utilization of soybean meal as a feed ingredient (Soliman, 1997). Research findings have indicated that the inclusion of sunflower in the diets of chickens at a level as high as 200g/kg does not appear to have any detrimental impacts on their growth performance and feed conversion (Valdivie et al., 1982; El-Sherif et al., 1995). In a separate and distinct academic inquiry, it has been conclusively ascertained that the existence and inclusion of substantial quantities of sunflower within the dietary compositions of poultry have been empirically proven to not yield any deleterious repercussions on key factors, such as the efficacy of productivity performance as well as the overall quality criteria pertaining to eggs (Tsuzuki et al., 2003; Casartelli, et al., 2006; Rezaei and Hafezian, 2007). On the other hand, in another study, the inclusion of sunflowers up to 20% (El-Sherif et al., 1997; Tavernari et al., 2008) or at even higher ratios (Rama Rao et al., 2006; Mushtaq et al., 2009) did not have any adverse effects on live body weight or body weight gain. In another study, sunflower was replaced with soybean meal up to 30% in chicken rations and the results were observed. According to the results of the study, it was ascertained that the consumption of feed by the animals and the subsequent increase in their live weight exhibited a significant enhancement of 13.17% and 12.04%, respectively, thereby indicating a marked improvement in their overall growth performance, all of which occurred in the absence of any adverse consequences (Furlan et al., 2001). According to the findings of scientific researchers, it has been determined that the inclusion of sunflower in chicken diet can reach a significant threshold of up to 15% without encountering any detrimental consequences. Additional investigations conducted by these very same scientists further elucidated that not only did the yolk index and Haugh unit score remain unaffected, but they also failed to exhibit any adverse effects. However, it is worth noting that the thickness of the shell exhibited an increase of 15% as a result of the incorporation of sunflower (Mirza and Sial 1992).

2.2. Soybean

Soybean (*Glycine max* L.), which is one of the basic nutrients with its high nutritional values, belongs to the *Leguminosae* family and has a high nutritional content.

Soybean, a grain rich in yellow vegetable protein, has its origins in China and has since become a widely distributed and cost-effective source of vegetable protein, comprising approximately 48 to 50% of its composition, while also boasting low-fat content (Garcia et al., 1997). Feed cost is seen as the main challenge in poultry production (Ravindran, 2013). Due to the prohibition of animal proteins from inclusion in feed in some regions (Van Harn and Veldkamp, 2011), vegetable protein is becoming an essential nutrition of feed for poultry (Ravindran, 2013), and SBM (soybean meal) remains the most crucial and preferred source of high-quality protein for animal feed manufacturing (FAO, 2014). Soy-based feeds, regarded as a means of obtaining animal protein, are experiencing a surge in popularity owing to their superior quality (Banaszkiewicz, 2011).

In their seminal work published in 1995, Fan et al. assert with utmost confidence that soybean meal is an unparalleled and supreme reservoir of protein, thereby solidifying its status as an unrivalled source of this essential macronutrient. Furthermore, they astutely emphasize that soybean meal bestows upon its consumers a staggering quantity of approximately 480 grams per kilogram of dry matter protein that is of unparalleled and exceptional caliber, thus solidifying its position as the epitome of protein quality (Yamka et al., 2003). Soybean has been reported to have the highest lysine digestibility and lowest crude fibre content among all other oilseed meals (Willis, 2003). Soybeans purportedly account for a significant proportion, specifically two-thirds, of the protein content found in animal feed on a global scale. Furthermore, soybeans contribute to over a quarter of the fats and oils utilized in the same context. Notably, three-quarters of the overall international trade in high-protein meals is attributed to soybeans (Peisker, 2001). It has been stated that the level of addition of SBM to diets varies from 25% in chick diets to 30-40% in the diets of old broiler chickens and laying hens (McDonald et al., 2002; Willis, 2003). One research study conducted an observation that soybeans possess a high level of digestibility suitable for avian species, regardless of their breed or age (Newkirk, 2010). Soybean meal has been reported to provide high energy density and feed conversion efficiency in broiler and turkey diets (Erdaw et al., 2016).

2.3. Maize

Alongside the tangible proof of sustenance discovered amidst selected archaeological excavations conducted within the geographical confines of Mexico, a scholarly consensus has emerged, positing that the crop of maize (scientifically classified as *Zea mays* L.) assumed a pivotal role in the early agrarian practices of ancient farmers, commencing some 7,000 to 10,000 years ago (Smith, 2001). Maize which is especially preferred for feeding poultry, is the most important feed grain grown worldwide. (Stamen, 2010). Since maize has consistently possessed the utmost level of dietary energy value when compared to other grains over an extensive span of time, it has undeniably emerged as the grain of choice in the realm of nutrition for domestic avian creatures in developing nations, including but not limited to Latin America, Africa, and Asia (Larbier and Leclercq, 1994). The primary consequence that arises from the process is commonly denoted as "draff" or "distillers dried grains" (DDG), and it possesses a significant protein content. In addition to DDG, it is also possible to incorporate another resulting substance known as "soluble," which encompasses the minutest remaining particles of both maize and yeast. Due to its elevated protein concentration, presence of trace elements and vitamins, and enhanced accessibility of phosphorus, DDGs have gained substantial popularity as feed ingredients for the purpose of poultry cultivation (Larbier and Leclercq, 1994). Corn grain contains nutrients in various amounts. They are approximately 4% fat, 9% protein, 73% starch, and 14% other components (mostly fibre). Oil is stored mainly in the seed, while starch and protein are mainly found in the endosperm, which makes up the majority of the seed (Tan and Morrison 1979). The digestible energy content of corn grain was indicated to be between 3.75–4.17 kcal/g in a particular study (Fetuga et al., 1979). The metabolized energy value of corn was stated as 3.6 kcal/g according to a study conducted on poultry (Nelson et al., 1974; Fetuga et al., 1979). Moreover, the recorded value for the digestibility of gross energy in chickens amounted to 86% (Fetuga et al., 1979).

2.4. Flaxseed

Flaxseed (*Linum usitatissimum* L.), a prominent oilseed plant, holds immense significance for its applications in industrial, food, and feed sectors. The appellation "flaxseed" derives from its Latin name, *Linum usitatissimum* L., which aptly translates to "very useful." With an extensive history spanning over five millennia, this plant has been widely consumed as a dietary staple since ancient times. Studies have reported that flaxseed contains approximately 40% lipid, 30% dietary fibre and 20% protein (Daun et al., 2003; Oohma, 2003). The primary objective of incorporating flax in poultry diets is to alter the composition of fatty acids in animal tissue, with the specific aim of generating eggs that are abundant in omega-3 fatty acids, thereby rendering them suitable for consumption by humans. A study on feeding 10%, 20% and 30% flaxseed for 28-day periods was reported for laying hens in 1990. According to this study, omega-3 fatty acids in eggs were reported to increase significantly at each level of flaxseed supplementation (Caston and Leeson, 1990). Feeding poultry with diets that are enriched with omega-3 has been observed to result in an augmentation of the omega-3 levels found in both eggs and meat. Enriched poultry products, as a result of their nutritional composition, possess the capability to function as a feasible and practical alternative for individuals who are seeking to augment their daily intake of omega-3 fatty acids, thereby presenting consumers with an advantageous opportunity to fortify their regular diet with this essential nutrient

(Leskanich and Noble, 1997). During the course of the study, the researchers introduced two different concentrations of linseed oil, namely 3% and 6%, into the diet of laying hens for a duration of 25 weeks. Throughout this period, the researchers meticulously observed and analysed the outcomes of this dietary manipulation. Notably, the findings from this investigation revealed that the addition of flaxseed oil had a remarkable and notable impact on the nutritional composition of the eggs, particularly with regards to the enrichment of α-linolenic acid and the overall content of omega-3-polyunsaturated fatty acids. Therefore, the results of this research strongly indicate the significant role of linseed oil in enhancing the nutritional quality of eggs, thereby highlighting its potential benefits in promoting human health. Furthermore, it was observed by the researchers that the level of cholesterol present in the yolk underwent a decline of approximately 5% in comparison to the control group. Additionally, when the hens were provided with the enriched diets, no significant alterations were identified in the quality parameters of the eggs, such as their texture, colour, or flavour. Moreover, the laying efficiency of the hens and the consumption of feed per egg remained consistent and unaffected by the dietary enrichment (Kozlowska et al., 2008).

2.5. Cottonseed

Cottonseed meal, used in certain amounts in poultry feeding, is a by-product obtained from the cotton plant. Cottonseed meal (CSM), which is derived from the process of extracting oil from cotton seeds, serves as a by-product of the oil industry. With protein levels ranging from 30% to 50%, CSM emerges as a notably abundant reservoir of this essential macronutrient. Furthermore, CSM is also found to be replete with a diverse array of amino acids, further enhancing its nutritional value and potential applications (He et al., 2015). One research investigation conducted an observation in which they found that chickens that are 7–21 days old have the capability to consume a diet that contains up to 20% cottonseed meal, provided that the formulation is supplemented with either 1.5% or 3% Lysine (Azman and Yılmaz, 2005). Mishra et al., 2015 have shown that low gossypol cottonseed meal (0.001% of free gossypol) can be safely incorporated at 5% (1-14 days of age) and 10% (15-35 days) as a partial replacement of soybean meal in diets containing the same level of crude protein and essential amino acids as control diet, without any adverse effect on performance (Mishra et al., 2015). The present study investigated the impact of different levels of cottonseed meal inclusion (0%, 4%, 8%, and 12%) in the diets of 1 and 42-day-old chickens, with regards to their digestibility, performance, and microflora composition. The results of this study demonstrated that the inclusion of 4% and 8% cottonseed meal in the feeds positively influenced the aforementioned parameters. The findings indicated that these particular levels of cottonseed meal inclusion were beneficial in terms of enhancing the digestibility and performance of the chickens, while also influencing the composition of the microflora in a favourable manner (Sun et al., 2013).

2.6. Hempseed

The Hemp plant, scientifically classified as *Cannabis sativa* L., which is a member of the *Cannabinaceae* family, has been widely recognized and acknowledged for its significant contributions throughout history in the realms of food production, medicinal applications, and the provision of various types of fibre (Russo and Reggiani, 2015). Hemp, a widely distributed and extensively cultivated plant, carries substantial industrial importance owing to its diverse applications as a source of whole seeds, dehulled seeds, seed flour, oil, and fibre (Callaway, 2004). In countries such as Iran, Pakistan and Türkiye, roasted salted hemp seeds are still sold as snacks in herbalists and are also used as bird feed (e.g., canary, pigeons) during mating period to increase stamina of male birds (Karimi and Hayatghaibi, 2006). Hemp seeds, which serve as an excellent protein source for poultry, have been documented to possess a noteworthy abundance of edestin and albumin, two types of storage proteins that exhibit exceptional quality and are characterized by their effortless digestibility and possession of indispensable amino acids (Callaway, 2004). Hemp seeds contain 20-25% high quality protein, 30-36% fat, 30-40% fiber and 6-7% moisture. In addition, while the energy content in the seed is 2200 kJ/100 g, the energy content in the seed meal is reported as 1700 kJ/100 g (Callaway, 2004). Khan et al. (2010) fed 160 day-olds broiler chicks with basal diet and basal diet+hemp seed (5, 10 and 20%). The findings of the study demonstrated that the inclusion of hemp seeds at a concentration of 20% in the diets of broiler chickens resulted in a significant improvement in body weight gain. In addition to this, the presence of hemp seeds in the diet led to a reduction in feed intake, indicating that the birds were able to achieve higher body weights with lower feed consumption. Moreover, the study also found a positive correlation between feed conversion and the inclusion of hemp seeds, suggesting that the birds were able to convert the feed more efficiently when hemp seeds were included in their diets. This is particularly noteworthy as hemp seeds are known to possess a rich nutritional profile, making them a potential alternative source of protein in organic poultry feeds. By incorporating hemp seeds into the diets of broiler chickens, it is possible to enhance their growth and performance while also reducing the reliance on traditional protein sources. Therefore, the inclusion of hemp seeds in organic poultry feeds holds promising potential in improving the overall sustainability and efficiency of broiler production systems. Thus, Eriksson and Wall (2012), added hemp seed cake in organic broiler diets (10% in starter and 20% in grower diets). It has been observed in many studies that it has a beneficial impact on egg weight (Gakhar et al., 2012; Halle and

Schöne, 2013; Skrivan et al., 2019) and eggshell thickness (Konca et al., 2019) in laying hens. Including hemp seeds in the diet instead of rapeseed oil has been suggested as a potential means of enhancing bone health in laying hens and cockerels, as per previous assertions (Skrivan et al., 2019; Skrivan et al., 2020).

3. Conclusion

Industrial plants are one of the major sectors that affect and are linked with many different sectors like food, textile, biofuel, and animal nutrition. They contain nutrients that are important for the poultry industry, which has an important place in world food production, in terms of the development of birds with high protein, vitamins, minerals, amino acids, and omega-3 content and the production of the products expected from them, and they constitute a source of raw materials for the poultry industry. The nutritional content, taste and digestibility of meat and eggs obtained from poultry are directly related to the environment in which the animals live and their diet, and has been addressed by scientists for many years as a subject that arouses interest and is worth researching. For years, the effects of many different plants on poultry nutrition have been investigated for this purpose. Although the plants discussed in this article have been studied for many years and are mostly used in the poultry nutrition industry, scientific studies on the subject are continuing and the effects of different industrial plant varieties on poultry nutrition can be evaluated.

Author Contributions

The percentage of the author(s) contributions is presented below. All authors reviewed and approved the final version of the manuscript.

	R.V.Ş.	H.A.Ş.
C	50	50
D	50	50
S	100	
L	50	50
W	90	10
CR	50	50
SR	50	50

C=Concept, D= design, S= supervision, L= literature search, W= writing, CR= critical review, SR= submission and revision.

Conflict of Interest

The authors declared that there is no conflict of interest.

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GENERAL STATUS OF RUMINANT LIVESTOCK IN THE TURKISH REPUBLIC OF NORTHERN CYPRUS

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Abstract: Among other agricultural activities, animal production has the most important strategic importance for the country's economy. In the Turkish Republic of Northern Cyprus (TRNC), animal production constitutes 45% of the total agricultural production. In response to the increasing population, the need for animal food continues to increase day by day. State hatcheries and many private companies run animal production activities along with small-scale family enterprises. Almost all animal feed raw materials are imported. On the other hand, most of the food of animal origins that is marketed (e.g. meat, milk, egg etc.) is produced in TRNC and the rest is imported when it is necessary. Halloumi, which covers almost all animal-based imported goods, is imported into many countries especially Turkey and Kuwait and contributes to the country's economy. This study concentrates on the general state of animal production in TRNC and aims to present the current state of ruminant animals (66 thousand head of cattle, 197 thousand head of sheep and 78 thousand head of goat) in the country's livestock farming, their contributions to the economy and the type of their production.

Keywords: TRNC, Agriculture, Animal husbandry, Import-export, Halloumi

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1. Introduction

Animal production, which is a branch of agriculture, has a strategic importance in terms of its contribution to other fields of agriculture and the country's economy (Görgülü, 2009). Grain crises (difficulties in finding grain and sudden increases in price) due to recent epidemics and conflicts between countries with strategic importance have disrupted production in the food sector. For this reason, food prices have doubled in countries that are foreign-dependent in food production, and it has become difficult for human beings to reach the nutrients they need (Gürlük and Turan, 2008, Doğruyol A. 2021.). Due to these factors, it has once again proven the importance of countries to carry out their own agricultural activities. Animal production outputs constitute the largest share of agricultural production in the economy. Animal products such as meat and meat products, milk and dairy products, leather and fleece, which are needed by the society, are met through bovine and ovine breeding (Paksoy and Özçelik, 2008; Semerci and Çelik, 2016).

Thanks to the Mediterranean climate of the island of Cyprus, it has a suitable structure for plant and animal production (Anonymous, 2022a). It is known that food resources should be used more efficiently with the increase in consumption due to the increasing population in the Northern Cyprus (Anonymous, 2022b).

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2. Agricultural Sector in North Cyprus

2.1. Geographical and Economic Structure

The island of Cyprus is the third largest island in the Mediterranean after Sicily and Sardinia. The island, with a total surface area of 9251 km², consists of three natural geographical structures: Beşparmak Mountains, Troodos Mountains and Mesarya plain. The climate that is effective in Cyprus is the Mediterranean climate. The characteristic feature of the climate is hot and dry summers, mild and less rainy winters (Anonymous, 2022c, Anonymous. 2022g).

Due to the internal turmoil in the 1960s, the island of Cyprus was divided into two regions, Turks in the north of the island and Greeks in the south, in 1974. The Turkish Republic of Northern Cyprus was established on November 15, 1983, and its surface area is 3242 km² (Koday, 1995; Anonymous, 2022c). Its population in 2011 was 286,257. The majority of the population is also located in non-rural areas, mainly in the cities of Nicosia and Famagusta (Anonymous, 2022d). In addition, 800,000 people come from Turkey and other countries for touristic purposes, especially in the summer months. Therefore, with the increasing population, the North Cyprus' need for animal and vegetable products will increase. According to the statistical data of 2021, approximately 8.38% of the Gross National Product (GNP) originates from the agriculture sector and approximately 45% of this is the livestock sector (Anonymous, 2022d).

2.2. General Condition of Livestock

The agricultural sector in Northern Cyprus consists of plant and animal production (bovine and ovine animals and fisheries). According to the 2021 data of the Ministry of Agriculture and Natural Resources (TDKB), animal production in Northern Cyprus is a large, medium, and small-scale business model.

There are 890 cattle breeding, 3550 sheep and 2510 goat breeding enterprises in the northern part of Cyprus. There are very few large-scale companies in the poultry sector. In 2021, 8,124,764 dozen eggs were produced throughout the country, and 15 thousand tons of chicken meat was produced. Chicken meat has the highest share in meat production in 2021. Poultry production and the processing and distribution of the products obtained from these animals within the country and abroad are also carried out by private companies. Chicken feet, which are slaughterhouse waste in poultry, are exported to the People's Republic of China. Chicken and piece chicken products (such as hips, breasts) are exported to Middle East countries in the country. In addition, 1 turkey production enterprise operates. In recent years, advertising activities to promote turkey meat have made turkey meat in demand in the country and paved the way for production by private enterprises.

Although North Cyprus is an island country, the contribution of fisheries to national income is limited and below the expected level due to the low fish stocks on the coasts outside the Karpaz region and the inability to engage in open sea fishing. According to 2018 data, fish production is reported to be approximately 650 tons (Anonymous, 2022e) (Table 1, Figure 1).

Table 1. The condition of the agricultural sector in the TRNC between the years 2016-2021 (Anonymous, 2022e, Anonymous. 2022f.)

Years	2016	2017	2018	2019	2020	2021
Agricultural s-Sector	5,6	4,5	6,2	5,5	6,0	8,3
Herbal Production	2,7	1,9	2,3	2,6	2,8	4,2
Animal Production	2,5	2,1	3,5	2,5	2,7	3,8
Fisheries	0,3	0,5	0,4	0,4	0,4	0,3

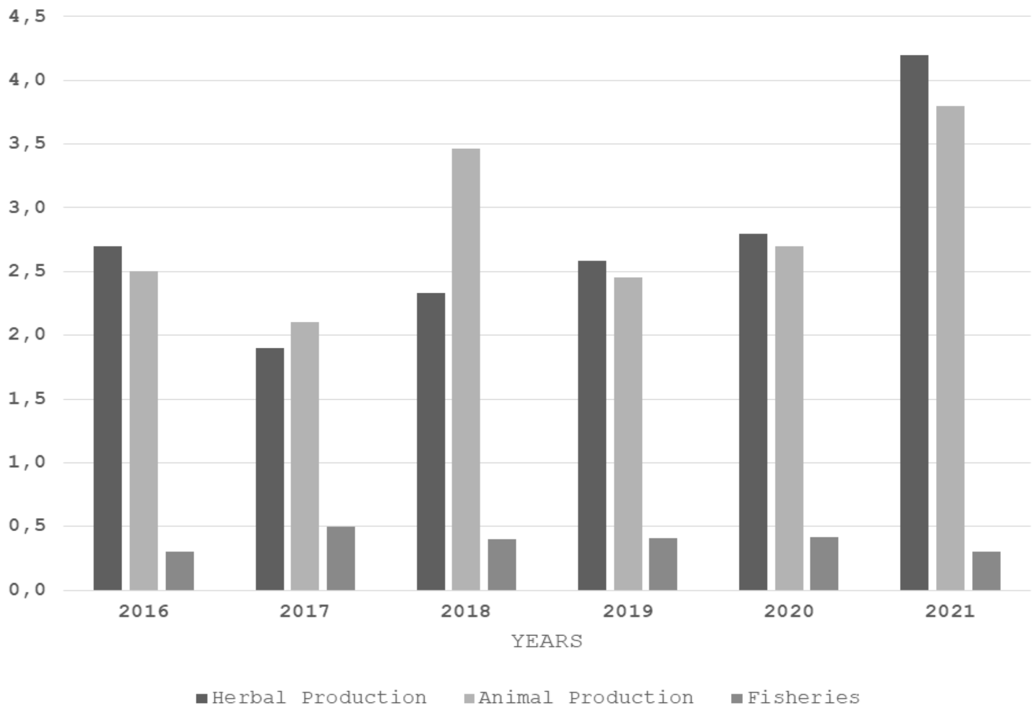

Figure 1. The situation of the agricultural sector in the TRNC between the years 2016-2021 (Anonymous, 2022e).

2.3. Cattle and Sheep Breeding

In today's livestock, there are products of animal origin mostly obtained from cattle breeding. Therefore, cattle are a factory producing edible and usable animal products such as meat, milk and leather. For this reason, cattle breeding are widely carried out in almost all parts of the world, especially in the developed and intensive regions of plant production (Canbolat, 2015; Ergün and Bayram, 2021). According to the statistical data of the Ministry of Agriculture and Natural Resources of Northern Cyprus in 2021, there is a total of 65701 cattle. Most of the milk needed by the TRNC is met by the Holstein breed, which is widely used in production. Depending on the rearing conditions, 6500 kg of milk per cow and a total of 159894 tons (2021) of milk are produced annually. 86.87% of milk production in the northern part of Cyprus is provided by dairy cows. Males of the Holstein breed, which are good in terms of milk yield, are used for fattening. In recent years, artificial insemination of Simmental breeds is carried out with Holstein breeds fourth lactation and above cows, which are combined productive, in order to increase cattle fattening performance and to obtain better quality carcasses among producers. Thus, the fattening performance is tried to be increased (Anonymous, 2022a).

Ovine breeding, which is one of the other branches of the livestock sector, has a wide area of use by obtaining products such as meat, milk, wool, mohair and leather (Semerci and Çelik, 2016). According to the statistical data of the Ministry of Agriculture and Natural Resources in 2021, the number of small-scale enterprises engaged in sheep and goat breeding is 4500, the number of medium-sized enterprises is 1480 and the number of large enterprises is 80. There are a total of 196,890 sheep and 77,852 goats in these enterprises (Anonymous, 2022i). There are two state breeding farms engaged in small cattle breeding. Genetic and breeding studies are carried out in these enterprises and they contribute to the country's livestock. (Anonymous, 2022e)

While a decrease was observed in the number of sheep and goats in 2017-2021, the Ministry of Agriculture and Natural Resources and the European Union regarding the registration of Halloumi/Halloumi as a Protected Product of Origin and Protected Geographical Indications (PDO-Protected Designation of Origin) in the European Union (EU). Grant supports have increased in order to develop small cattle breeding and increase production (Anonymous, 2022a). In Table 2, when 2017 and 2021 years are compared, it is given that while the number of cattle producers decreased, the number of cattle increased.

Chios, Awassi, Asaf and their hybrid breeds are used in sheep breeding in North Cyprus. In goat breeding, production is made with Hair, Aleppo (Damascus), Saanen, Alpine, and hybrids. 79% of the 24 tons of ovine milk produced in 2021 is sheep milk and 21% is goat milk (Anonymous, 2022h).

2.4. Production and Marketing of Bovine and Ovine Products

Population growth in the Turkish Republic of Northern Cyprus is ensured every year by the number of tourists and the number of students coming to the island for higher education (Anonymous, 2022d). Thus, it is estimated that the demand for food in Northern Cyprus will increase exponentially. Northern Cyprus is under an embargo (North Cyprus is a country recognized only by Turkey in the world, and is an independent state founded on November 15, 1983. Since its establishment, it has been under embargoes in economic, social and cultural aspects by the whole world, especially the Greek Cypriot part, foreign expansion has been prevented, the fact that the domestic industry is very weak, and that it is dependent on foreign sources for many products emphasizes the indispensable importance of agricultural production (Doğan, 2009).

Milk production is a universal agricultural production, people milk their dairy animals in almost all countries around the world and almost one billion people live on dairy farms (Anonymous, 2022i). For this reason, while milk production plays a major role for the world food sector, it is also very important for the development of rural areas. When the share of products constituting agricultural exports in terms of value for 2015 is analyzed, it is seen that dairy products have a significant share with 58%. Until the 1960s, families in the villages of Cyprus extensively raised sheep and goats, and from the milk of these animals, they obtained dairy products, mainly halloumi, nor, talar cheese and yoghurt. Industrial type production in the dairy sector started in 1957 in the TRNC, for the first time, with the collection of milk from the producers, and the production of halloumi and perforated cheese. TRNC started to export halloumi for the first time to England, and with the increase in milk production, exports increased with the introduction of private factories. Halloumi was the second leading export product until 1994 (Anonymous, 2022k; Anonymous, 2022b). Until the Abat Decisions, a significant amount of halloumi was exported to other European countries and Arab countries, especially England. As a result of the embargoes applied to the Turkish Cypriots after the Abat Decisions, exports to England and other European countries were prevented. This isolation still continues (Aran, 2006).

Halloumi, which is widely produced in the country among dairy products and is unique to the island; it is exported to many countries, especially Turkey, Kuwait, Saudi Arabia and the United Arab Emirates. The contribution of the state to this export increases the production of halloumi day by day. In 2021, the European Union Commission decided to register the halloumi product as the name of origin (PDO) and included Cyprus as the base country. It has been decided that the milk to be used for the production of traditional halloumi within the scope of PDO should be prepared with 51% ovine (sheep-goat) and 49% bovine (cattle) milk (Anonymous, 2022a). TRNC Ministry of Economy and Energy Chamber of Commerce 2021 halloumi export data are in Table 3 below (Anonymous, 2022c).

Table 2. Number of animals and producers between 2017-2021 (Anonymous, 2022i)

Species	2017		2021	
	Number of Producers	Number of Animals	Number of Producers	Number of Animals
Cattle	998	63,270	890	65,701
Sheep	3,619	203,419	3,550	196,890
Goat	2,560	83,467	2,510	77,852

Table 3. 2021 Halloumi export data (Anonymous, 2022c)

Countries	Quantitiy	Turkish Lira	Dollars
USA	82,577,00	₺ 4,186,192,77	$ 509,043,50
Australia	10,004,00	₺ 244,763,78	$ 26,774,71
Bahrain	96,042,00	₺ 4,208,040,91	$ 445,043,10
United Arab Emirates	1,088,192,00	₺ 41,854,831,20	$ 4,628,825,92
Palestine	3,000,00	₺ 109,691,21	$ 13,300,00
Iraq	60,202,00	₺ 2,683,887,69	$ 281,805,09
Qatar	83,103,00	₺ 4,416,724,88	$ 507,479,81
Kuwait	2,733,342,00	₺ 89,807,766,75	$ 10,270,363,59
North Korea	27,700,00	₺ 964,577,13	$ 107,180,00
Saudi Arabia	1,278,500,00	₺ 47,437,442,80	$ 5,348,001,00
Thailand	210,00	₺ 7,515,58	$ 903,00
Turkey	3,366,094,00	₺ 107,656,159,78	$ 12,427,984,50
Oman	24,214,00	₺ 1,066,664,12	$ 131,054,40
Jordan	562,550,00	₺ 19,585,067,82	$ 2,332,815,00
Total	9,415,730,00	₺ 324,229,326,42	$ 37,030,573,62

In addition, bottled pasteurized milk production was started in 1963. The KOOP Milk Factory, which is still operating today, was established in 1969 (Anonymous, December 2022k; Anonymous, 2022b). (Anonymous, 2022i) (Table 4). Icebox: It is the event that small-scale producers carry and pour their milk, which they milk due to the lack of electricity in animal shelters, into the freezers in a hygienic environment in their homes by means of cans or jugs.

Foods of animal origin play an important role in nutrition in terms of the proteins, minerals and vitamins they contain. Especially meat and meat products contain essential amino acids needed in human nutrition in ideal proportions. However, due to the availability of iron in the body and being a very good source of vitamin B12, it shows that it is a food that plant-based foods cannot replace meat and meat products (Derinöz et al., 2021). In a healthy diet, 40-50% of the body's protein needs are composed of foods of animal origin. The access of the individuals who make up the society to animal protein sources is affected by the agricultural policies of the countries and the implementations of these policies.

In terms of the belief, tradition and custom of the society we live in, cattle, sheep and goat species are preferred in the production of meat and meat products (Gürer, 2021). According to the Northern Cyprus' 2021 statistical data, chicken has the highest share in meat production, while cattle take the second place. These values are given in Table 5.

According to the data of 2021, approximately 49% of the red meat production in our country is beef, followed by mutton with a share of 40% and goat meat with a share of 11%. In Table 6, it is observed that the amount of beef has not changed in the last three years, and the amount of sheep and goat meat has decreased. When the data of 2021 is examined, it is noteworthy that the production of sheep and beef is similar (Anonymous, 2022a). Red meat production amounts for the years 2019-2021 are given in Table 6.

Leather, which has a lot of usefulness with its perfection and many aspects, and has been used by human beings since ancient times, is a product that is rarely mentioned among animal products, but has very valuable features. The biggest share in the rapid development in the leather industry belongs to sheep skins, especially sheep skins. The skin is an organic material and it is an armour that has the task of protecting the animal in general, with the hair or wool cover on it, the connective tissue fibres called collagen that make it up (Yakalı, 1979). A total of 271,679 leathers were produced in the North Cyprus in 2021. Approximately 66% of the total leather production is sheepskin and 26% is goatskin (Anonymous, 2022a). The amount of leather produced according to the species is given in Table 7.

Table 4. Milk production by years (Anonymous, 2022i)

	Products	2016	2017	2018	2019	2020	2021
Cow's milk (L)	Open	31,028,251	25,504,241	19,456,443	14,119,610	9,993,945	5,708,314
	Cold	117,257,288	124,128,258	134,080,826	120,075,838	132,027,865	142,670,744
	Icebox	0	2,917,334	5,406,147	5,236,872	6,054,464	10,267,393
Total		148,285,539	152,549,833	158,943,415	139,432,320	148,076,274	158,646,451
Sheep milk (L)	Open	1,873,376	2,028,173	1,904,583	1,545,583	1,342,962	1,271,021
	Cold	374,583	485,043	521,598	667,542	729,402	914,399
	Icebox	0	0	0	78,867	150,957	213,015
Total		2,247,959	2,513,216	2,426,181	2,291,992	2,223,321	2,398,435
Goat's milk (L)	Open	2,039,838	2,237,191	2,305,969	1,701,284	1,372,031	1,049,118
	Cold	454,846	612,07	575,306	661,613	653,926	655,807
	Icebox	0	0	0	257,775	448,77	515,860
Total		2,494,684	2,849,261	2,881,275	2,620,672	2,474,727	2,220,785

Table 5. Meat production by species in 2021 (Anonymous, 2022i)

Species	Meat Production (Tons)
Chicken	15,045
Cattle	4,891
Lamb	4,078
Goat	1,134

Table 6. Red meat production (Tonnes) for the last three years (Anonymous, 2022i)

Species	2019	2020	2021
Cattle	4,891	4,891	4,891
Lamb	6,910	3,715	4,078
Goat	1,157	1,150	1,134

Table 7. Leather production amounts by species in 2021 (Anonymous, 2022i)

Year	Leather Production (Number)			
	Cattle	Sheep	Goat	Total
2021	19,566	181,215	70,898	271,679

Sheared dirty wool from sheep is called "fleece". In a broad sense, fleece means all the hairs that are removed from the animals as shirts during shearing and that can be twisted and made into yarn (Kaymakçı and Sönmez, 1992). Wool is the sheared, washed and cleaned form of the fleece shirt covering the sheep (Tüfekçi and Olfaz, 2015). In fabric production, the washed and cleaned form of fleece is used (Kaymakçı and Sönmez, 1992).

Although animals have not been exported as living material in the Northern Cyprus, leather and fleece are exported to Turkey at certain rates. Turkish Republic of Northern Cyprus Trade Office, leather and wool export values for the years 2017-2021 are given in Table 8 (Anonymous, 2022h).

Bovine and ovine manures are a valuable nutrient provider for the soil and a regulator of soil conditions. When properly matured and applied to the soil, it is a better and more economical nutrient provider than commercial fertilizers. Animal manure is a fertilizer rich in organic matter content. Therefore, it increases the water holding capacity of the soil and provides the soil with nutrients such as nitrogen (N), phosphorus (P), potassium (K) and sulfur (S) (Kacar and Katkat, 2009; Konca and Uzun, 2012). Due to the exorbitant increases in chemical fertilizer prices in recent years, the value of ruminant fertilizers, whose value has not been understood for years and has been launched as if they have no economic value, has started to gain importance today (Teoman and Yaşar, 2016). In parallel with the increase in the number of animals in the North Cyprus in 2017 and 2021, there was an increase in the amount of manure. In Table 9, the amount of bovine and ovine manure produced in the North Cyprus is given in tons (Anonymous, 2022i).

Table 8. Leather and wool exports in TRNC for the years 2017-2021 (Anonymous, 2022h)

	TRNC Leather and Wool Export				
Type of Good	2017	2018	2019	2020	2021
Leather (Number)	207,770	182,660	205,573	154,601	157,280
Wool Fleece (Kg)	262,200	175,280	168,620	77,600	-

Table 9. Amount of bovine and ovine manure produced in North Cyprus (Anonymous, 2022i)

Years	Bovine (Tonnes)	Ovine (Tonnes)	Total (Tonnes)
2017	116,035	21,474	137,509
2021	127,511	24,329	151,84

2.5. Feed Raw Materials and Production

Animals need nutrients such as water, carbohydrates, proteins, fats, vitamins and minerals to survive and produce various products. Animals meet their needs with this nutrient through feed and water consumption. Feeds can be of vegetable and animal origin, as well as their processing residues or by-products (Gürsoy and Macit, 2020).

Feeds are generally examined in three classes. These include roughage, dense (concentrated) feeds and feed additives. Forages are plant-based feeds with high cellulose content, low protein and energy content used as animal feed in fresh, dried or silage form. Dense (concentrated) feeds are those that are rich in energy and protein content and have a high digestibility of nutrients. Feed additives, on the other hand, are substances used to increase feed efficiency, improve the quantity and quality of animal products, reduce costs, and protect animal health (Kutlu and Çelik, 2016). It is stated that more than 60% of livestock operating expenses in our country, as in the world, are feed expenses (Görgülü, 2009).

Producers mostly meet their roughage needs from the lands they cultivate or by renting lands belonging to the state. The negativities seen due to climate change affect the roughage needs of the producers. The state allows the import of roughage in order to eliminate the disruptions in production depending on the climatic conditions, and provides certain amounts of support to animal producers in order to eliminate the problems experienced and for sustainable production. In addition, the grant feed contribution is made by the state. Quality roughage is produced in some of the cultivated lands, while grain group (barley, wheat and oat) is produced in the remaining parts. According to the data of the North Cyprus Ministry of Agriculture and Natural Resources, the amount of roughage produced by region for 2021 is given in Table 10 (Anonymous, 2022i).

The producers separate and preserve some of the grain produced as seeds for the next year. On the other hand, producers who make both plant production and animal production together use the excess grain to meet the concentrated feed needs of the animals. On the other hand, producers who only produce plants sell the remaining part of the seed product to the TRNC Soil Products Authority (TÜK) according to the price determined by the TRNC Ministry of Agriculture and Natural Resources. The distribution of cereals produced according to the statistical data of 2021 is shown in Table 11 (Anonymous, 2022i).

In the TRNC, the most barley is produced, followed by wheat. Producers who make their own feed, registered with the Ministry of Agriculture and Natural Resources Livestock Department of the TRNC, benefit from the discounted barley purchase given by the ministry and reduce the cost of barley ration purchased below the current price.

In our country, almost all of the raw materials used in feed production are imported, as in other areas. According to the statistical data of the TRNC Ministry of Agriculture and Natural Resources, the raw materials imported in 2021 and their quantities are given in Table 12 (Anonymous, 2021a, b).

There are 6 feed factories in the Northern Cyprus. While only 1 of these factories is state supported, the others are privately owned. However, there is one feed additive manufacturing enterprise in North Cyprus.

Table 10. Amount of roughage produced by regions in 2021 (Anonymous, 2022i)

Regions		Nicosia	Famagusta	Kyrenia	Morphou	Trikomo	Total
Barley production	Area, Acres	12,921	27,900	2,830	3,750	-	47,401
	Yield, Kg/Acre	-	-	-	-	-	-
	Production (Tonnes)	-	-	-	-	-	-
Grain bale	Area, Acres	120,424	243,905	50,030	40,564	129,380	584,303
	Yield, Kg/Acre	136	89	140	117	139	621
	Production (Tonnes)	16,350	21,700	7,000	4,750	18,000	67,800
Legumes bale	Area, Acres	32,980	32,592	21,982	4,908	34,882	127,344
	Yield, Kg/Acre	144	135	308	244	231	1,062
	Production (Tonnes)	4,750	4,400	6,780	1,200	8,060	25,190
Clover	Area, Acres	703	600	25	280	105	1,713
	Yield, Kg/Acre	6,000	6,000	-	6,000	6,000	24,000
	Production (Tonnes)	4,218	3,600	150	1,680	630	10,278

Table 11. The amount of grain produced in the TRNC in 2021 (Anonymous, 2022i)

Raw Materials	Sown Area	Yield	Production
	Acres	Kg/Acres	Tonnes
Barley	545,005	225	122,447
Hard Wheat	86,735	225	19,540
Soft Wheat	24,905	233	5,800
Oat	3,735	227	848

Table 12. Imported raw materials and quantities in 2021 (Anonymous, 2021a, b)

Raw Materials	Unit	Import Amount
Barley Feeder	Tonnes	102,126,20
Sunflower Seed Meal	Tonnes	18,528,68
Wheat bran	Tonnes	3,500,02
Wheat Bran Pellet	Tonnes	1,250,00
Ddgs Corn	Tonnes	4,402,82
Degame Soybean Oil	Tonnes	14,355,52
Low-Quality Semolina Flour	Tonnes	100,00
Molasses	Tonnes	27,34
Soybean Meal	Tonnes	27,388,27
Feed Wheat	Tonnes	3,000,00
Feed Corn	Tonnes	105,119,77

3. Discussion

The island of Cyprus has two separate political entities: the Turkish Republic of Northern Cyprus (TRNC) and the Greek Cypriot Administration of Southern Cyprus (GCASC). The livestock sector is significant agriculturally and economically in both regions. However, economic and political disparities have led to divergent development paths in these two regions' livestock sectors.

According to the 2021 statistics of TRNC, approximately 45% of the Gross Domestic Product (GDP) is constituted by the livestock sector. Large livestock production, which holds a significant share in this sector, includes approximately 65,000 heads of cattle with a production of 158,646 tons of cow milk. 97% of the produced milk in the country is cow milk. Sheep and goat farming is carried out through enterprises of various scales. Of the produced 4,619 tons of small ruminant milk, approximately 52% is sheep milk, and the remaining 48% is goat milk. As for red meat production in TRNC, beef holds a 49% share, while sheep and goat meat holds 40% and 11% shares, respectively (Anonymous, 2022i).

The Greek Cypriot Administration of Southern Cyprus (GCASC) accounts for approximately 45% of its GDP in the livestock sector, according to statistical data from 2017. The same data indicates the existence of 66,000 cattle with a production of 215,370 tons of milk. Production includes 321,000 sheep and lambs, 257,000 goats and kids, and 350,000 pigs. 52% of the produced small ruminant milk is sheep milk, and 48% is goat milk. In red meat production, pork constitutes a significant share of 80%, followed by beef with 9%, sheep meat with 6%, and goat meat with 5% (Anonymous, 2022i and Papachristoforou and Markou, 2006).

GCASC's membership in the EU enables it to benefit from EU support and funding in the agricultural sector, facilitating the adoption of modern technology and management practices (Papachristoforou and Markou, 2006). On the other hand, TRNC must rely on its internal resources, as it faces international trade embargoes, which restrict access to external markets. While GCASC has alternative sources of red meat production like pork, enhancing product diversity, TRNC's livestock sector needs more access to international markets due to trade embargoes.

Statistics emphasize the importance of the livestock sector in both regions. However, the more diverse economic structure of GCASC provides broader opportunities for external trade in the livestock sector, making it more competitive internationally. In conclusion, although the livestock sectors in both TRNC and GCASC share similar characteristics, different economic and political factors influence their development. While the livestock sector in TRNC contributes significantly to the national economy, its potential is hindered by international embargoes. To enhance its contributions further, the sector requires better internal support and lifting international embargoes.

4. Conclusion

The Turkish Republic of Northern Cyprus is a country rich in agriculture due to its climatic characteristics. Especially animal production, which is one of the branches of agriculture, is increasing day by day with the use of resources and the formation of international market network and population growth. State-supported export promotion activities continue for the development and expansion of animal production. Despite the development of the cattle and sheep livestock sector, it is necessary to continue the activities in the development of the sector due to the problems and limitations such as the standardization of animal products, the lack of an effective marketing system, and the lack of information in small family businesses.

Author Contributions

The percentage of the author(s) contributions is presented below. All authors reviewed and approved the final version of the manuscript.

	Ç.H.K.	M.B.
C	50	50
D	50	50
S	50	50
L	50	50
W	50	50
CR	50	50
SR	50	50

C= Concept, D= design, S= supervision, L= literature search, W= writing, CR= critical review, SR= submission and revision.

Conflict of Interest

The authors declared that there is no conflict of interest.

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Review

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USABILITY OF HEMP PLANT IN POULTRY NUTRITION

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Abstract: Hemp (*Cannabis sativa* L.) is an annual plant with 2n=20 chromosomes, one-year, C3 group, cultivated for its long and strong fibers and seeds. It is a plant that should be cultivated in a controlled manner due to the presence of THC (tetrahydrocannabinol) in its natural structure. Producers who avoid control and monitoring have turned to alternative products instead of hemp farming. Countries that cultivate cannabis in large areas; France, China, and Canada. Some countries are updating their cannabis-related laws and making efforts to increase hemp acreage. It is known that hemp farming has been practiced in Anatolia since 1500 BC. Various products such as hemp seeds, hemp pulp, hemp oil have been used in various studies in poultry feeding studies, while no negative results have been encountered, but various positive results have been suggested and their use is recommended. It is of great importance to investigate the effects of cannabidiols, which have strong antimicrobial, antioxidant and immunostimulant effects, as they are expected to support the immune system in poultry, especially broilers. Some of the studies in which hemp products are used in poultry nutrition are as follows; Addition of hemp meal to laying hen diets has been reported to make no significant difference in egg production, feed consumption, feed utilization, body weight gain or egg quality, but results in lower palmitic acid concentrations and higher Linoleic acid (LA) and alpha-linolenic acid (ALA) concentrations, which are healthier for human consumption. Hemp seeds and hemp oil used in chicken rations caused an increase in the omega-3 polyunsaturated fatty acid content and color intensity of egg yolks, but no adverse effects were observed on the sensory profiles of cooked eggs. Addition of cannabis meal to fast growing broiler diets did not affect performance or mortality, and no effect on the number of *Clostridium perfringens* in the cecum was reported. Hemp seeds have a remarkable effect on the growth of broiler chicks and can help reduce feed expenditures for broiler rearing. In this paper, the use and usability of the hemp plant, whose production areas are expanding rapidly, in poultry will be examined.

Keywords: Poultry nutrition, Hemp, Antioxidant, Immune system, Feeding performance

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1. Introduction

For the assessment and analysis of different feed sources to ensure the long-term viability and sustainability of the livestock and animal products sectors, it is crucial to conduct a thorough investigation into the presence and accessibility of lesser-known and underutilized feed sources (Salami et al., 2019).

Cultivated hemp, belonging to the annual plant species within the *Cannabinaceae* family, is characterized by its unique features. This plant, which has been the subject of foreign fertilization, possesses a chromosome count of 2n=20, showcasing its genetic makeup. As described by Small and Cronquist in 1976, hemp exhibits both dioic and monoic types, presenting a diverse reproductive system. In the dioic variety, male and female flowers are segregated on distinct plants, highlighting a clear distinction in their reproductive structures. Conversely, in monoic types, the male and female flowers coexist on the same plant, albeit in different sections of the inflorescence, demonstrating a fascinating botanical phenomenon. Renowned for its multifaceted utility, hemp serves as a pivotal industrial plant that caters to various sectors, utilizing almost all parts of its anatomy. Its significance within the industrial realm stems from its widespread applications across different industries, positioning it as a versatile botanical resource. Within the realm of industrial plants, hemp is classified into various types, including *Cannabis sativa, Cannabis indica,* and *Cannabis ruderalis*, each possessing distinct characteristics and properties (Schultes et al., 1975). Over the years, the fibers, seeds, leaves, and flowers derived from the stems of hemp have emerged as the most valuable and extensively utilized components, underscoring their economic importance. The chemical composition of hemp is subject to multiple factors such as varietal differences, processing techniques during pressing, and seed processing methods, as expounded by House et al. (2010), shedding light on the intricate chemical profile of this industrially significant plant.

The aim of this study is to evaluate the impact of hemp plant utilization in poultry farming on the nutrition, health, and production performance of chickens. Our hypothesis suggests that hemp-based feed may enhance the growth rate of chickens, increase egg production, and strengthen the immune system of poultry. Additionally, we anticipate that the utilization of hemp as poultry feed could offer environmental and economic sustainability advantages. This study aims to provide a comprehensive assessment to understand the potential role of hemp in the poultry industry.

2. Hemp Parts Used in Poultry Feeding

2.1. Hemp Seeds

Most varieties of hemp are cultivated with the primary goal of seed production, with the most valuable output being hemp oil (Callaway, 2004). The hemp seed typically contains 30-35% seed oil, which is extracted through the cold pressing method, ensuring the preservation of the oil's physical and chemical properties (Hazekamp et al., 2010). The remaining solid byproduct after oil extraction is known as hemp pulp. Depending on the processing technology used, a portion of the oil (0.4-10%) may still be retained in the hemp pulp (House et al., 2010). Hemp seeds are predominantly utilized in animal nutrition, primarily for ornamental birds that are not intended for food production, accounting for approximately 95% of their usage. The remaining 5% is allocated to the food sector. The chemical contents of hemp seeds are given in Table 1.

Table 1. Nutritional value of hemp seeds in terms of vitamins and minerals (Göre and Kurt, 2021)

Source	(mg/100g)
Vitamin E (total)	90.00
alpha-tocopherol	5.00
gamma-tocopherol	85.00
Thiamine (B1)	0.40
Riboflavin (B2)	0.10
Phosphorus (P)	1.16
Potassium (K)	859.0
Magnesium (Mg)	483.0
Calcium(Ca)	145.00
Iron (Fe)	14.00
Sodium (Na)	12.00
Manganese (Mn)	7.00
Zinc (Zn)	7.00
Copper (Cu)	2.0

Hemp seeds are known for their rich protein content and as a source of omega-3 fatty acids. Recent findings suggest that incorporating omega-3 and omega-6 fatty acids into poultry feed can have beneficial effects on immune responses, egg quality, meat nutrition, and growth. Performance within hemp seeds, essential fatty acids such as linoleic acid (omega-6) and α-linolenic acid (omega-3) can be found (Smith, 2000). The chemical contents of hemp fatty acids are given in Table 2.

Gakhar et al. (2012) demonstrated that adding 20% hemp seed to egg-chicken rations increased egg weight and omega-3 fatty acid content without impacting egg yield or specific gravity.

Khan et al. (2009) observed that including up to 20% dried and crushed hemp seeds in broiler diets led to increased breast and thigh weights. This positive outcome was attributed to the high-quality protein and lipid combination, along with the beneficial properties like the absence of trypsin inhibitors and the antioxidant activity of cannabidiol. Another study by Khan et al. (2010) showed that feeding broiler chickens with 20% hemp seed improved feed conversion rate, live weight gain, slaughter age, and mortality rate. Kalmendal (2008) explored the use of hemp seed cake in organic broilers and found that its nutritional value was comparable to rapeseed pulp. Mahmoudi et al. (2012) discovered that including hemp seed in broiler diets up to 7.5% did not negatively impact performance and even reduced serum cholesterol levels. Their subsequent study revealed that incorporating hemp seed meal in the diets of fast-growing organic broilers had no adverse effects on production performance or mortality rates. These studies collectively suggest that hemp seeds can be safely incorporated into poultry diets up to 30% without compromising their intended purpose.

2.2 Hemp Flowers and Cannabinoid Extract from Flower

Cannabis sativa L. has been extensively studied, leading to the identification and isolation of over 500 compounds, as reported in various studies (Pellati et al., 2018; Al Ubeed et al., 2022). Among these compounds, a total of 566 have been pinpointed and grouped into more than 18 categories of secondary metabolites, showcasing the remarkable chemical diversity present in this plant species.

Table 2. The chemical contents of hemp fatty acids (Siano et al., 2019)

Source	Component	Flour oil	Cold pressed oil	Seed oil
1	Palmitic, C16:0	7.35	7.15	7.03
2	Stearic, C18:0	2.62	2.73	2.78
3	Oleik, C18:l ω-9c	12.79	12.75	12.74
4	Linoleic, C18:2 ω-6c	56.42	56.08	56.16
5	Arachidic, C20:0	0.74	0.89	0.81
6	γ-Linolenik, C18:3ω-6	3.00	3.03	2.94
7	cis-II-Eicosinoic C20:l	0.45	0.26	0.37
8	α-Linolenik, c18:3 ω-3	14.55	14.89	15.02
9	cis-ll, 14-Eikosinoic C20:2	0.82	1.03	0.99
10	Behenik, C22:0	0.29	0.20	0.27

Notably, the flowers and leaves of *Cannabis sativa* L. are particularly rich in these bioactive compounds, as highlighted in recent research (Kopustinskiene et al., 2022). Specifically, the identified compounds include 125 cannabinoids, 198 non-cannabinoids, and 120 terpenes. Recent investigations in 2021 have further expanded this list to reveal the presence of 2 alkaloids, 34 flavonoids, 42 phenols, and 3 sterols within the plant matrix (Al Ubeed et al., 2022). This comprehensive characterization underscores the complexity and pharmacological potential of *Cannabis sativa* L., offering a wealth of chemical entities for further exploration and exploitation in various fields of science and medicine. Moreover, the distinct aromatic profile of Female Hemp plants can be attributed to terpenes such as pinene, limonene, terpineol, and borneol, which are synthesised within the plant tissues (McPartland and Russo, 2001). These terpenes not only contribute to the sensory experience associated with Hemp consumption but also play a crucial ecological role by repelling insects and inhibiting the growth of competing vegetation. A key defensive mechanism employed by *Cannabis sativa* L. involves the production of resin by glandular trichomes, which possess antibiotic and antifungal properties, serving as a natural shield against pests and pathogens. Within these trichomes, a myriad of secondary metabolites, including phytocannabinoids and terpenoids, interact synergistically to safeguard the plant from external threats while also imparting its distinctive odor profile (Andre et al., 2016).

2.2.1. Some cannabinoids and their mechanism of action

The most well-known and studied cannabinoids in the Hemp plant are THC (tetrahydrocannabinol) and CBD (cannabidiol)The therapeutic potential of CBD, a prominent cannabinoid in *Cannabis sativa* L., has garnered significant attention due to its reputed health benefits across diverse medical conditions. CBD has been linked to an array of therapeutic effects, including relaxation, anxiety relief, and pain management, with documented efficacy in alleviating symptoms associated with cancer chemotherapy-induced vomiting, glaucoma, anorexia, neuropathic pain, spasticity, and other ailments. Approved for medical use in numerous countries, particularly in North America, CBD-based products are widely available in various formulations such as oils, capsules, topicals, and dietary supplements, catering to different consumer preferences. While CBD shares a molecular weight with THC, the psychoactive component of Hemp, it stands out for its analgesic, antiepileptic, antibacterial, anti-inflammatory, and antidepressant properties, making it a valuable therapeutic agent for both acute and chronic pain management (Beşir et al., 2022).

The multifaceted immunomodulatory and antioxidant actions of CBD are underpinned by intricate molecular mechanisms that involve interactions with various immune cells and inflammatory pathways. CBD exerts modulatory effects on activated B cells and interferon-β/signal transducer and activator of transcription pathways, influencing cellular inflammation cascades such as the nuclear factor kappa-light chain enhancer pathway. By targeting adenosine receptor A2A and modulating adenosine reuptake, CBD can finely tune the activities of immune cells like neutrophils, macrophages, and T cells within the inflammatory milieu. Additionally, CBD impacts cytokines including interferon-c, interferon-γ (Lee ve Erdelyi, 2016), tumor necrosis factor α (Magen et al., 2009; Rajesh et al., 2010; Khaksar ve Bigdeli, 2017; Wang et al., 2017), interleukin (IL)-1β (IL-1β) (Pazos et al., 2013; Wang et al., 2017), IL-6 (Lee ve Erdelyi, 2016) as well as adhesion molecules like ICAM1 and VCAM1, thereby regulating inflammatory responses at multiple levels (Rajesh et al., 2010). Furthermore, CBD exhibits anti-apoptotic effects by reducing caspase 9 activation (Castillo et al., 2010) and inhibiting caspase 3 (Rajesh et al., 2010; Da Silva et al., 2014; Santos et al., 2015), key components involved in apoptotic pathways. Importantly, CBD boosts the production of the anti-inflammatory cytokine IL-10, further enhancing its immunomodulatory properties and underscoring its therapeutic potential in managing inflammatory disorders (Kozela et al., 2017).

The endocannabinoid system is a complex network within the human body that includes cannabinoid receptors, endocannabinoids, and enzymes responsible for the synthesis and breakdown of these compounds. It has been extensively studied in recent research as a potential target for treating various pathological conditions. This intricate system plays a crucial role in numerous physiological processes such as regulating energy balance, stimulating appetite, controlling blood pressure, providing analgesia, managing nausea and vomiting, facilitating memory and learning, and modulating immune system responses, as highlighted in studies by Balpınar and Aytaç (2021). Anandamide and 2-arachidonylglycerol are well-known endocannabinoids that act as signaling molecules within the brain, allowing for the adjustment of input signals from parent cells. Moreover, the endocannabinoid system has its own hemp molecules, which operate in a retrograde manner from dendrites to axon terminals, aiding in the fine-tuning of neuronal communication.

The endocannabinoid system has garnered significant attention due to its potential therapeutic implications in various health conditions. Notably, it interacts with a nuclear receptor called PPAR-γ, which is involved in regulating metabolic and inflammatory processes, as pointed out by O'Sullivan and Kendall (2010). Cannabinoids found in hemp, other than THC, interact with the endocannabinoid system receptors at a lower rate and with less affinity, as reported in studies by Pertwee (2008) and Elsohly et al. (2017). Among these compounds, cannabidiol (CBD) has emerged as a prominent phytocannabinoid with non-psychoactive properties, as emphasized by Aydoğan et al. (2020). CBD has been recognized for its anxiolytic and antipsychotic effects, as highlighted in research by Zuardi et al. (1995) and Crippa et al. (2009). Additionally, CBD is known to counteract the psychoactive effects induced by THC, showcasing its potential therapeutic value in mitigating adverse reactions associated with THC consumption, as mentioned by Mechoulam et al. (2006).

3. Hemp Products and Poultry

Hemp seeds are reported to be abundant in various vitamins, minerals, essential amino acids, and essential fatty acids, making them a popular choice in poultry nutrition, particularly as bird feed (Silversides and LeFrancois, 2005; Goldberg et al., 2012; Eriksson and Wall, 2012; Konca et al. 2014). The utilization of hemp-derived CBD in research is quite limited, with a focus on clinical rather than nutritional studies. Clinical trials involving CBD are predominantly conducted pre-human use, with rats being the primary subjects, alongside occasional use of dogs and monkeys. Poultry nutrition commonly incorporates products derived from hemp seeds and seed derivatives, although it is essential to note that hemp seeds do not inherently contain CBD. Konieczka et al. (2023) explored the impact of CBD and CBD+Se (selenium) additives in chicken diets, revealing a protective effect against DNA damage in the intestinal mucosa, leading to improved interaction and enhanced fattening performance. Langer and Scilcher (1999) conducted a study on muscle pain in rats, administering 100mg/kg of 99% pure CBD intramuscularly after a series of intense workouts, noting a mild effect on muscle. However, CBD displayed anti-inflammatory properties on skeletal muscle, suggesting its potential use as an analgesic and anti-inflammatory agent. Moreover, the removal of cannabidiol (CBD) from the prohibited substances list allows athletes access to this non-psychoactive hemp component, aligning with the World Anti-Doping Rules International Standard Prohibited List 2023.

Gustafsson and Jacobsson (2019) explored CBD's impact on embryo development by administering in-ovo CBD injections to chicken chicks on days 1, 4, and 7, leading to a 20% decrease in chick incubation efficiency due to developmental interference. Recent years have seen intensified research on in-ovo injection in poultry feed, focusing on amino acid development, growth performance, immune response, and digestive organ enhancement (Bhanja and Mandal, 2005). Studies have suggested that in-ovo feeding can bolster the population of bacteria resistant to enteric pathogens (Ferket 2006, Smirnov et al. 2006) and enhance intestinal resistance to *Salmonella enterica* in young chickens through in-ovo CpG-ODN administration. Furthermore, the in-ovo injection of oligosaccharides has been shown to impact digestive and storage capacities, with reports indicating that chick weight and growth are accelerated with the injection of amino acids, trace elements, fatty acids, and vitamins (Bakyaraj et al., 2012).

4. Conclusion

In conclusion, various hemp products like seeds, pulp, and oil have been studied in poultry feeding, yielding positive outcomes without encountering adverse effects, thereby recommending their utilization. The antimicrobial, antioxidant, and immunostimulant properties of Cannabidiols are anticipated to benefit the immune system of poultry, particularly broiler chickens, underscoring the importance of further investigations into their effects. Despite extensive research on hemp seeds and their derivatives in poultry nutrition, studies on the impact of CBD and other cannabinoids remain scarce. Only a single study on CBD nutrition and embryonic development was identified in our literature review. While one study facilitated embryo development (Gustafsson and Jacobsson, 2019), another utilized hemp extract (Konieczka et al., 2023).

The cost of 99.56% pure CBD was recorded at $6000 per kilogram in the year 2016, but has since plummeted to the range of $450 to $375 per kilogram by 2024. This substantial reduction in price, amounting to approximately 15 times less in less than a decade, can be attributed to various factors such as the issuance of permits for hemp cultivation dedicated to CBD production within our nation, the steady expansion of hemp production areas, and the continuous advancements in technology related to CBD extraction processes. These developments have collectively contributed to the potential consideration of CBD as a viable additive for enhancing animal nutrition. The ongoing expansion of CBD production sites coupled with the continuous technological enhancements in extraction methods are driving the rapid decline in CBD prices, making it increasingly feasible for utilization across various industries provided it demonstrates positive outcomes.

Author Contributions

The percentage of the author(s) contributions is presented below. All authors reviewed and approved the final version of the manuscript.

	H.A.Ş.	R.V.Ş.
C	50	50
D	50	50
S	100	
L	50	50
W	90	10
CR	50	50
SR	50	50

C=Concept, D= design, S= supervision, L= literature search, W= writing, CR= critical review, SR= submission and revision.

Conflict of Interest

The authors declared that there is no conflict of interest.

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Review
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NUTRITIONAL ASPECTS FOR MODULATION OF POULTRY IMMUNE STIMULATION

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Abstract: The immune system's defense mechanism has been affected by the management and nutrition conditions in poultry production. In biological aspects, Bursa Fabricius and Thymus are primary lymphoid organs that defend the body against diseases. The spleen, cecal tonsils, immunoglobulins, and various forms of mucosal immunity, BALT (bronchus-associated lymphoid tissue), MALT (mucosa-associated lymphoid tissue), CALT (conjunctiva-associated lymphoid tissue), and GALT (gut-associated lymphoid tissue), are also vital to their overall health. The management program (environmental conditions, heating, lighting practices) and feed (feed ingredients, composition, and feed additives) significantly affect birds' immunity and performance. Dietary supplementation enhances immune system activation by improving the lymphoid tissues and beneficial immune modulators and responses. During the past fifteen years, alternative feed additives (amino acids, minerals, vitamins, probiotics, prebiotics, synbiotics, and organic acids) have impacted animal production performance and immunity. Besides, feed additives, such as probiotics, prebiotics, vitamins, minerals, and organic acids, are essential for sustaining hormonal, physiological, and immunological processes. These additives, probiotics, vitamins (A, C, D, E), mineral (selenium) supplementations, and organic acids boost the immune system's activity against microbial pathogens and physiological stress mechanisms. Finally, this paper aims to review the current improvement in the relationship between nutrition and immunity in poultry.

Keywords: Immune system, B and T cells, Vitamins, Minerals, Organic acids

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1. Introduction

The immune system is characterized by the innate (maternal) and adaptive immunological developmental processes against with inadequate defence mechanism and health issues, predisposing individuals to microbial infections (Wynn and Levy, 2010; Alkie et al., 2019). To prevent the spread of viral, bacterial, fungal, and parasitic diseases in the body, the immune system plays a major role with its activity. The body produces defense molecules called antibodies, which recognize and deactivate pathogens (Sarıca et al., 2009). Besides, different pathogens potentiate the cellular and humoral response by altering the immune system's reaction (Shaji et al., 2023).

The immune system consists of various organs and tissues, including the Bursa Fabricius, thymus, bone marrow, spleen, the harderian gland, lymph nodes, circulating lymphocytes, and lymphoid tissue in the alimentary tract in poultry (Panda et al., 2015). Lymphoid tissue may be specialized into two types: primary and secondary. The thymus and Bursa Fabricius are considered primary organs, whereas the spleen is a secondary type of lymphoid tissue. The Bursa Fabricius belongs to birds and is absent from mammals due to evolution. In both hens and mammals, primary lymphoid tissue reduces after puberty, with the effects of sex hormones (Junior et al., 2018).

Animals have a precise immune system mechanism that resists pathogens and adverse environmental conditions (Korver, 2023). Among the immunosuppressive components are management, feeding programs, and nutrition deficiencies, which cause health and welfare issues (Wlazlak et al., 2023). Also, immunosuppression decreases body weight gain and production performance and increases mortality and morbidity rates mainly due to secondary viral and bacterial infections (Fussell, 1998; Rehman et al., 2016). Immune system activation on metabolism has a significant impact on maintaining broiler health to optimize performance and cost-efficient production. Thus, acute activation of the immune system leads to inflammatory pathways with reduced feed intake. The hypothalamic-pituitary-adrenal axis is activated when the immune system detects a foreign substance and releases chemical messengers known as cytokines. These cytokines are responsible for initiating the production of acute phase proteins (APP) in the liver, transmitting feedback to the brain, resulting in common illness symptoms such as fever and decreased appetite

(Silverman et al., 2005; Rochell et al., 2016).

It has been stated that immunity and production performance in poultry are positively correlated. Antibody production and immunity regulation depend on non-genetic factors, which include nutritional concentrations in the diet. At the same time, it has been proven that imbalance between nutrients or toxicity, disorders in the bird's physiology may occur due to immunosuppression. The immune system's reaction to harmful microorganisms penetrating the animal's body is related to its nutritional condition. Immune system suppression may result in inadequate body weight gain and feed conversion ratio, high mortality rate, uniformity issues, secondary bacterial infections, and lymphoid organ atrophy (Aviagen, 2009; Abo-Al-Ela et al., 2021). Currently, modern broilers have a rapid growth rate, high body weight, and efficient feed conversion, which makes them vulnerable to high disease rates and necessitates strong immune function. Because the nutrients in the feed are utilized for muscle growth, fast-growing modern broilers tend to have low disease resistance and are susceptible to diseases (Song et al., 2021).

Numerous factors, including diseases, environmental conditions, management practices, vaccination programs, physical type of feed material, and nutrition-related stress, weaken the immune system, potentially increasing susceptibility to infections (Abo-Al-Ela et al., 2021; Wlazlak et al., 2023). Nutritional deficiencies in the feed supplementation may result in deterioration in the growth and development mechanism of the immune system. Additionally, insufficient vitamin levels may compromise the immune system, enhancing susceptibility to infection and inflammation. During metabolic processes, vitamins of A, D, E, and C have been shown to significantly impact immune system function (Khan et al., 2023). For this reason, the review focused on the relationship between nutrition and immune system modulation of poultry.

2. Primary Immune Organs

The formation of the immune system organs begins in the embryonic stage and entirely functions with advancing age. The immune system organs generate functional lymphocytes and release them into the peripheral immune system to actively participate in immune responses (Naukkarinen and Hippelãinen, 1989; Gordon and Manley, 2011). In the avian immune system, there are two primary organs. The first one is Bursa Fabricius, associated with B-cells, and the second is the Thymus, associated with T-cells. Both organs produce B and T cells to improve poultry immunity. The thymus is located in the neck's ventral region and under the thyroid gland in front of the chest cavity. This gland is surrounded by a thin capsule composed of connective tissue. The compartments of the thymus gland contain reticular cells and lymphocytes. The thymus gland's primary function is to protect the body from infection by activating lymphocytes before and immediately after birth. Autoreactive T cells are responsible for eliminating killing cells and synthesizing thymic hormones during the maturation of T lymphocytes in poultry (Sarıca et al., 2009). T and B cells progress to the secondary lymphoid tissue to provide a defense, which includes the spleen and mucosa-associated lymphoid tissue (MALT). The primary lymphoid tissue is crucial in selecting lymphocytes (including T-cells and B-cells) for a robust immune response while preventing autoimmunity (Yasuda et al., 2003).

The lymphoid stem cells in the bone marrow generate the T and B cell precursors (Ratcliffe and Jacobsen, 1994; Ratcliffe, 2006; Garcia et al., 2021). Bursa Fabricius is placed in the dorsal of the cloaca and is responsible for the maturation of B lymphocytes, the killing of autoreactive B cells, and the synthesis of hormones. The Bursa Fabricius produces B-cells, which are responsible for synthesizing antibodies. Moreover, bone marrow-derived stem cells that resemble lymphoid cells mature in the thymus and Bursa Fabricius before proceeding via the bloodstream and lymphatic circulation to peripheral immune organs (Gordon and Manley, 2011; Davison, 2022). During the exposure to foreign antigens, the immune cells exhibit proliferation and differentiation. Additionally, in peripheral blood lymphocytes, the proliferative activity indicates a strengthening functional activity of T and B cells, reflecting an elevated cellular immune function (Dekruyff et al., 1980; Naukkarinen and Hippelãinen, 1989).

3. Secondary Lymphoid Organs

It has been stated that spleen, bone marrow, harderian gland (in orbit), pineal gland (in the brain), mucosa-associated lymphoid tissues (MALT), bronchus-associated lymphoid tissue (BALT), gut-associated lymphoid tissue (GALT), conjunctiva-associated lymphoid tissue (CALT) are secondary lymphoid organs in birds. MALT, BALT, GALT, and CALT lymphoid tissues comprise approximately 50% of the cells in the spleen. These lymphoid tissues accumulate on the skin or mucosal surface, where foreign antigens enter the body (Gurjar, 2013). The spleen is the largest of the secondary lymphoid organs and is surrounded by a capsule composed of connective tissue. It has several functions for the aging erythrocytes, erythrocytes production in fetal life, and granulocytes in postnatal life, to contribute to the formation of antibodies through B lymphocytes, phagocytosis through macrophage, and for accumulation of red blood cells (Júnior et al., 2018). On the other hand, spleen size increases through hyperplasia tissue, known as splenomegaly, after exposure to pathogens. Lymphocyte hyperplasia has also been observed in MALT. The germinal center is where avian antibodies are effectively produced (Junior et al., 2018; Lewis et al., 2019). Additionally, chickens have three classes of immunoglobulins similar to mammals: IgA, IgM, and IgY (equivalent to IgG). Although it has been suggested that chickens also have antibodies similar to mammalian IgE and IgD, this has not been proven. Chicken IgY and mammalian IgG characterize immunological similarities, and the DNA sequence of chicken IgY is similar to human IgE (Shimizu et al., 1992; Aizenshtein et al., 2016; Pereira et al., 2019).

4. Nutrition and Immunity

Birds' immune systems benefit considerably from a well-balanced nutrition program. The function of the immune system is to struggle with the negative impacts of stress and protect against pathogenic diseases. The regulation of the immune system in poultry involves the progress of anatomy in lymphoid tissues, mucus production, immunologically active substances synthesis, cellular proliferation, activation, movement, intracellular killing of pathogens, and modulation and regulation of the immune process. The nutritional intake may influence chickens' immune reactions, substantially benefiting their well-being and health. Therefore, a balanced diet could enhance chickens' overall health by preventing stress-related immune suppression (Butcher and Miles, 2002). The stimulation of immune system reactions in poultry nutrition has been revealed (Montout et al., 2021; Selim et al., 2021; Yu et al., 2021).

Poultry production has been focused on improving feed efficiency, decreasing disease risk, and increasing performance (Korver, 2023). Feed additives in poultry nutrition have been used as an alternative to antibiotics due to their potential positive effects on the growth rate, feed conversion, and resistance against pathogenic diseases (Fonseca et al., 2010; Ganan et al., 2012). It is widely known that antibiotics have extensively impacted poultry production in terms of maintaining gut microorganism balance and promotion (Selaledi et al., 2020). Due to food safety concerns and the public demand for antibiotic-free farm animal products, many countries have banned of antibiotics in poultry nutrition as a routine of growth promotion (Neveling and Dicks, 2021). So that, alternatives to antibiotics are needed to sustain poultry productivity and promote their performance and immunologic response (Wickramasuriya et al., 2024).

Nutraceuticals, including essential minerals and vitamins, are fundamental to animal nutrition. Nutritional components significantly benefit by preventing diseases, exhibiting immunomodulatory properties, promoting overall health, and enhancing productivity, regulating gut microbiota (Alagawany et al., 2021; Shehata et al., 2022). Feed additives essentially comprise amino acids, minerals, vitamins, fatty acids, enzymes, prebiotics, probiotics, synbiotics, pigments, medicinal herbs, herbal extracts, antioxidants, organic acids, and flavoring agents (Alagawany et al., 2018; Mohammed et al., 2019; Elgeddawy et al., 2020; Adhikari et al., 2020; Rehman et al., 2020; Shehata et al., 2022). Synthetic supplements include essential amino acids (such as lysine, methionine, threonine, and tryptophan), vitamins, and minerals. Besides, nutraceutical dietary elements may enhance digestion, absorption, utilization, metabolism, and positive health status (Ravindran, 2010; Haq at al., 2016; Alagawany et al., 2021) (Table 1).

The nutrients have been known to potentially affect embryonic development and hatchability with the prevention of musculoskeletal, immunological, and circulatory issues (Uni et al., 2012). During embryogenesis, nutrients are mainly acquired from yolk, which mainly contains lipids and low levels of carbohydrates (Santos et al., 2010). Supplementing with bioactive substances such as amino acids, polyphenols, and prebiotics will enhance the immune system, reduce osteoporosis, and lower the risk of heart diseases (Chalamaiah et al., 2018). The application of in-ovo injection for various biological agents has been recognized for its efficacy in poultry production. The application of in-ovo entails using nutritional supplements such as carbohydrates, proteins, amino acids, vitamins, and minerals (Ohta et al., 1999; Bhanja et al., 2005; Zhai et al., 2011; Bakyaraj et al., 2012). L-Arginine (100 μg/μL/egg) in-ovo injection on the 14th day of the embryonic stage enhanced survival rates, body weight, and immune response (IgM) in Subramaniyan et al. (2019) research.

After hatching, the early feeding program has gained immense importance for the developmental process of immunity in birds. Firstly, innate immunity is considered the defense mechanism, and adaptive immunity is for the protection against specific pathogens by the functions of lymphoid cells and antibodies. It has been stated that innate immunity is essential to secure all living organisms' cellular integrity, homeostasis, and livability (Buchmann, 2014; Romo et al., 2016).

The formation of birds' defense mechanisms begins in embryogenesis and continues to function for several days after hatching (Yasuda et al., 2003). Maternal antibodies in the yolk protect embryos and chicks (approximately one month) against microbial infection during egg incubation and after hatching. The secondary lymphoid tissues complete their development one week after hatching, facilitating an effective immune response and specific antibody production in chick vaccination (Yasuda et al., 2003; Hamal et al., 2006). Additionally, the post-hatching period is significant due to a lack of maternal immunity (approximately one week) (O'Neal and Ketterson, 2012).

Table 1. Dietary supplementation in poultry immune stimulation

Dietary Supplementation	Species	Effects	Reference	Access Web
Probiotics *Bacillus coagulans, Lactobacillus plantarum*	Broilers	The higher level of serum IgY, IgA, IgM concentration	Yu et al., 2022	https://pubmed.ncbi.nlm.nih.gov/35265699/
Probiotics *Lactobacillus fermentum, Saccharomyces cerevisiae*	Broilers	The higher proportions of CD3+, CD4+, and CD8+ T-lymphocytes	Bai et al., 2013	https://pubmed.ncbi.nlm.nih.gov/23436517/
Probiotics *DFM supplementation*	Broilers	Regulation of gut microbiota by increasing the log concentrations of beneficial bacteria (*Bacillus, Bifidobacterium, C. butyricum,* and *Lactobacillus*)	Heak et al., 2018	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6212764/
Probiotics *Bacillus subtilis, Lactic acid bacteria, Saccharomyces*	Laying hens	Decreased the expression level of proinflammatory cytokines such as *IL-1*, *IL-6* and *TNF-α* in ovary	Xu et al., 2023	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9902371/
Prebiotics *Mannan-oligosaccharides, Beta-d-glucan*	Broilers	Improved the chicken gut microbiome and alleviated the negative effects of heat stress	Sayed et al., 2023	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10460421/
Amino acids *Glutamine, arginine, threonine*	Broilers	Improve the immune response against an *Eimeria and E. coli* challenge	Gottardo et al., 2017	https://www.scielo.cl/scielo.php?script=sci_arttext&pid=S0719-81322017000300175
Aminoacids *l-threonine*	Laying hens	Linearly increasing levels of IgG and total Ig	Azzam et al., 2011	https://www.sciencedirect.com/science/article/pii/S1056617119312589
Minerals *Organic and inorganic Zinc, selenium, chromium*	Broilers	Increased humoral immune response and upregulation of chTLR4 gene expression in bursa and spleen indicates a beneficial effect of OTM in augmentation of the immune system	Jain et al., 2021	https://pubmed.ncbi.nlm.nih.gov/34220108/
Minerals *Chelated form Manganese, selenium, copper, iron, zinc*	Broiler Breeder	Significant increase in the antibody titre against Newcastle disease	Mohammadi et al., 2023	https://www.tandfonline.com/doi/full/10.1080/1828051X.2023.2215248
Minerals *Zinc, copper, manganese chelated with the hydroxy analogue of methionine*	Laying hens	Trace minerals in the chelated form improved bird immune response to antigenic challenge at wk 63	Manangi et al., 2015	https://www.sciencedirect.com/science/article/pii/S1056617119303046
Vitamins *Vitamin A and K3*	Laying hens	Improved the intestine antioxidant capacity	Li et al., 2022	https://www.scielo.br/j/rbca/a/FDydzRcrPkdG93B6mwKfSYq/?lang=en
Vitamins *Vitamin E*	Broilers	There was no increase in antibody titer against the IB virus with 300mg Vitamin E /kg feed additive	Sadiq et al., 2023	https://dx.doi.org/10.36380/jwpr.2023.13
Organic Acids *SAS- Formic acid, propionic acid, soft acid SAP- Propionic acid, citric acid, soft acid*	Laying hens	Significant increase in small intestinal villi with the addition of SAS and SAP	Gül et al., 2014	DOI: 10.1399/eps.2013.5
Organic acids and essential oil *Sorbic acid, fumaric acid, thymol*	Broilers	Higher villus height of the duodenum and jejunum and muscular layers of the duodenum and ileum (0.30 g/kg EOA during the grower period)	Yang et al., 2018	https://pubmed.ncbi.nlm.nih.gov/30564758/

5. Nutritional Aspects in Poultry Immunity

5.1. Amino Acids

Dietary supplementation has been essential in optimizing poultry production due to obtaining better performance and health status with lower feed efficiency. The immune system consistently functions with sufficient levels of protein, energy, and micronutrients, vitamins, and minerals in nutrition (Butcher and Miles, 2002; Alagawany et al., 2021). Amino acids are the fundamental components of protein, the primary substances contributing to the growth of chickens and the production of eggs (Baker, 2009). The mechanism of lymphocyte activation, natural killer cells, and macrophages regulating intracellular redox balance, gene expression, and cytokine production related to amino acid supplementation. Therefore, appropriate dietary amino acids are critical for inhibiting infectious disorders, particularly viral infections (Chandra ve Kumari, 1994; Calder, 2013; Montout et al., 2021).

Several amino acids, such as methionine, threonine, and arginine, were studied to determine their contribution to a beneficial host immunological response (Montout et al., 2021). It has been indicated that different methionine supplementation levels of 0.60% and 0.90% in turkeys and broilers respectively resulted in increased methionine levels in the peripheral blood (Mirzaaghatabar et al., 2011; Kubinska et al., 2014). Also, in broilers, the dietary supplementation of %0.65 methionine and %0.13 choline may result in higher antibody levels (Swain and Johri, 2000).

Arginine has been characterized as a regulator of both innate and adaptive immunity (Lindez and Reith, 2021). Dietary arginine supplementation in metabolic processes may affect birds' immunological responses to physiological hemostasis under stressful conditions. A group of enzymes known as nitric oxide synthases are responsible for converting arginine into citrulline and nitric oxide as the sole route of nitric oxide synthesis (Förstermann et al., 1991; Fernandes et al., 2009). Nitric oxide exhibits cytotoxic effects on immuno-activated cells and regulates the immune system (Hibbs et al., 1988). Furthermore, arginine enhances interleukin production and T lymphocyte proliferation in broiler chickens (Rodriguez et al., 2017; Montout et al., 2021). Increasing dietary arginine over 0.45% may affect macrophage phagocytosis by stimulating the production of key cytokines, particularly IL-1, IL-2, INF, and TNF-a in broiler chickens (Emadi et al., 2010; Xu et al., 2018).

Supplementing lysine and methionine enhanced antibody production in broiler chickens against Newcastle and Gumboro infections (Bouyeh, 2012). A deficiency in dietary lysine inhibits protein synthesis, including cytokines, and lymphocyte proliferation, impairing immune responses in chickens and leading to morbidity and mortality in response to infection (Kidd, 2004). Insufficient dietary lysine levels may result in hen antibody responses and cell-mediated immunity (Chen et al., 2003).

Several essential amino acids (leucine, isoleucine, and valine) have been used in poultry nutrition. These amino acids contribute to protein synthesis, immune response modulation, intestinal tract health, and villi development (Kim et al., 2022; Liu et al., 2023). Leucine, isoleucine, and valine amino acids provide the amino groups for the synthesis of glutamine and recreate a crucial role in maintaining the gut barrier functions for epithelial cells. Furthermore, the immune system considerably depends on protein synthesis to produce cytokines, immunoglobulins, immune cells, and other essential immune molecules (Morgan, 2021; Montout et al., 2021). According to Liu et al. (2023), there were no significant differences between the effects of reduced-protein diets supplemented with arginine or branched-chain amino acids on the short-chain fatty acid profile in the cecal content of broiler chickens challenged with Eimeria spp on day 21.

L-carnitine is present in high lymphocyte concentrations for biological functions. Two essential amino acids (lysine and methionine), three vitamins (ascorbate, niacin in the form of nicotin amide adenine dinucleotide and vitamin B6), and reduced iron ($Fe2+$) are required as cofactors for the enzymes involved in the metabolic pathway of L-carnitine synthesis (Borum, 1983; Rebouche, 1992; Leibetseder, 1995; Adabi et al., 2011). These amino acids inhibit the apoptosis of immune cells and enhance their proliferative response to mitogens (Adabi et al., 2019). It has been reported that supplementing the diet of broiler chickens with 100 mg/kg of L-carnitine enhances the innate immune response by boosting acute phase protein production, and L-carnitine reveals glucocorticoid effects (Buyse et al., 2007). The supplementation of L-carnitine considerably enhanced total IgG and IgA responses but not IgM in broilers (Mast et al., 2000). In a study, the addition of 100 mg/kg L-carnitine supplementation indicated significantly effect on higher antibody response and Newcastle disease virus in broiler. Besides, 100 mg/kg L-carnitine supplementation group showed the highest Bursa Fabricius, spleen and thymus weight compared to 0, 25 and 75 mg/kg L-carnitine group (Golzar et al., 2007).

5.2. Probiotics, Prebiotics and Synbiotics

Bacterial population in the intestinal tract is necessary for appropriate immune function and obtaining better feed efficiency with probiotics in poultry. Primary, probiotics consist of live beneficial microorganisms for the host animal's health and welfare due to stimulating effects for intestinal microbial balance (Moreno et al., 2006). Probiotic species consist of Lactobacillus bulgaricus, Lactobacillus plantarum, Streptococcus thermophils, Bifidobacterim bifidum, Aspergillus oryzae (Khaksefidi and Rahimi, 2005; Ashayerizadeh et al., 2009; Kabir, 2009). Bacteria have a mutually beneficial relationship with the intestinal cells and microorganisms in the gastrointestinal tract. Probiotics significantly contribute to changes in the intestinal structure and digestive processes by stimulating the immune system. They also inhibit the growth of pathogenic bacteria, leading to an improvement in overall performance (Awad et al., 2009; El-Shenway and Soltan, 2015). Probiotics have importance for the immune system with including boosting the activity of macrophages, lymphocytes, and NK cells. They also enhance the oxidative burst of heterophils, resulting in increased production of immunoglobulins (IgG, IgM, and IgA). Also, probiotics have the potential effects to regulate the gastrointestinal tract and maintain an optimal balance between anti-inflammatory and pro-inflammatory cytokines. Besides, the population of lamina propria lymphocytes (LPL) and intestinal epithelial lymphocytes (IEL) has increased with the probiotics activity in the small intestine while restricting the proliferation of detrimental microorganisms (Yeşilyurt et al., 2021).

Bacillus subtilis-based probiotic supplement has been approved to improve immune and oxidative responses in shackled broiler chickens under pre-slaughter stress challenge. The levels of IgG, IgA, and IgM of the shackled broiler chickens exposed to preslaughter stress were investigated. In the result of this study, IgG and IgA levels (mg/dL) in serum concentration were found similar between control, 0.25 g/kg feed, and 0.5 g/kg feed supplementation groups. In contrast, the level of IgM (mg/dL) in serum concentration was higher in the control group compared to 0.25 g/kg and 0.5 g/kg treatment groups (Mohammed et al., 2024).

Prebiotics are non-digestible feed ingredients that benefit by promoting the growth or activity of some bacterial species in the colon to improve host health (Ganguly, 2013). Prebiotics are small carbohydrate fragments, possibly commercially used as galactose, fructose, and mannose oligosaccharides. There are some prebiotics, such as fructooligosaccharide (FOS), transgalactooligosaccharide (TOS), inulin, glucooligosaccharide, xylooligosaccharide, isomaltooligosaccharide, soybean oligosaccharide, polydextrose, and lactosucrose (Vulevic et al., 2004; Propulla, 2008; Ganguly, 2013). Furthermore, mannan oligosaccharide (MOS) may be derived from the outer cell wall of Saccharomyces spp. yeast promotes gut health with pathogenic bacteria in type-I fimbriae or agglutinating various bacterial strains and increasing villi length, uniformity, and integrity (Spring et al., 2000; Loddi et al., 2004). Oligosaccharides are prebiotics that boost chickens' intestinal morphology and stimulate the activation of the immune system (Sayed et al., 2023). Oligosaccharides may be more active on macrophages to regulate the production of inflammatory cytokines and cytokines by T-helper cells (Th) during the immunological processes (Csernus et al., 2020).

Sittiya and Nii (2024) investigated the effects of oligosaccharides on the immune reactions in laying hens challenged with dextran sodium sulfate. Consequently, BOS (oligosaccharide extract from bamboo shoots) also increased *IFN-γ* in the liver and Th-17 cytokines in the intestine in laying hens. In contrast, there are no significant differences in intestinal or liver morphology. On the other hand, BOS (oligosaccharide extract from bamboo shoots) suppressed an increase in leukocyte accumulation in the liver under DSS (dextran sodium sulfate treatment). These results approved that BOS (oligosaccharide extract from bamboo shoots) may enhance egg quality and Th-1 and Th-17 immune function without causing tissue damage under normal conditions, and it may suppress the excessive inflammatory responses during inflammation.

Synbiotics are a combination of probiotics and prebiotics that act as effective substitutes for antibiotics in feed (Dong et al., 2016; Mohammed et al., 2018; Ren et al., 2019). The beneficial effect of the synbiotics has impacted the gastrointestinal tract and health status in animals. Moreover, different synbiotics comprise probiotic strains, Lactobacillus plantarum, Lactobacillus reuteri, Lactobacillus pentosus, and Saccharomyces cerevisiae (Śliżewska et al., 2020). Due to the regulation of physiological balance and modifying both innate and adaptive immune responses against stress, synbiotics have gained immense importance in poultry nutrition (Seifert et al., 2011). It has been demonstrated that different levels of the synbiotic supplementation significantly changed plasma levels of the antioxidant enzyme GPx in heat-stressed broiler chickens (Mohammed et al., 2019).

5.3. Minerals

Minerals are essential micronutrients for activating optimal physiological processes and health status. The inclusion of microelements in poultry diets is common in commercial practice due to their importance in reproduction and immune function (Saripinar-Aksu et al., 2012). An adequate mineral supply in the diet is crucial for optimal poultry production. The lack of minerals in the diet may lead to various health issues in chicks (Pal, 2017). In poultry nutrition, optimizing animal health may be associated with adding zinc, selenium, chromium and zeolite to the diet program for rearing broilers and laying hens (Park et al., 2004; Tayeb and Qader, 2012; Jain et al., 2021; Elsherbeni et al., 2024).

Dietary zinc decreases feed intake and stimulates avian antibody production with plasma corticosterone levels (Onbasilar and Erol, 2007). It has been shown that dietary zinc supplementation of up to 80 ppm level enhances humoral and cell-mediated immune responses in broilers by Sunder et al. (2008). On the other hand, dietary zinc (up to 110 ppm) and higher doses (up to 10,000 mg/kg) in the diet result in inhibiting the colonization of Salmonella enteritidis (SE) in laying hens (Kubena et al., 2001).

Selenium is essential for optimal immune response and involves innate and acquired immune systems. This essential trace element is a component of selenoproteins, which are involved in various animal physiological processes. Although plants and fungi do not need selenium, they can convert mineral forms of selenium present in the soil into various organic forms, such as selenomethionine and methyl selenocysteine, as a strategy of adaptation. Selenoproteins influence immunity through multiple mechanisms, and nutrition could modulate the immune system to resist pathogens. Selenium regulates oxidative stress, redox, and other cellular processes in all tissues and cell types, including immune responses. Selenium interacts with vitamin E in tissues to protect biological membranes from oxidative damage (Allmang et al., 2009). On the otherside, in Jain et al. (2021) study, the plasma IgG concentrations (μg/mL) showed significant differences between groups at 21, 28, 35 day age of broilers with feed different concentrations of organic and inorganic trace minerals (zinc, selenium, and chromium) supplementation.

Zeolite is a silicate mineral that is considered highly effective and non-toxic. Dietary supplementation of zeolite has been used as a feed additive. Additionally, the use of zeolite directly impacts on production performance and meat quality (Zhou et al., 2014; Abd El-Hady, 2020; Dashtestani et al., 2021). Zeolite has been used in biological processes to reduce ammonia and smell emissions from poultry production by absorbing nitrogenous metabolites such as ammonium (NH_4^+) and ammonia (NH_3) (Schneider et al., 2017). Elsherbeni et al. (2024) investigated the effects of using zeolite on lymphoid organs (%) in 42-day-old broiler chickens. In this study, thymus and Bursa Fabricus weights (%) were found to be higher in the 10g/kg zeolite diet supplementation group. In another study by Abdelrahman et al. (2023), it was shown that dietary zeolite supplementation at levels of 0.5%, 1.0%, 1.5%, and 2.0% resulted in a statistically significant reduction in spleen weight of broiler chicks compared to the untreated group. However, the different zeolite treatments did not significantly affect the thymus and Bursa Fabricus weights.

5.4. Vitamins

The use of vitamins in nutrition is essential for maintaining a healthy immune system in poultry. It has been stated that vitamin level insufficiency has led to compromised immune function, increased susceptibility to infections, and inflammation. In poultry nutrition, vitamins (A, D, E, and C) significantly impact the immunologic process with various activation mechanisms. Firstly, vitamin A enhances mucosal immunity, reduces free radicals, and maintains epithelial cell integrity. Vitamin A comprises several brightly colored and fat-soluble molecules involving retinol, retinal, retinoic acid (RA), and pro-vitamin A carotenoids. Carotenoids have multiple functions: immune regulation and stimulation, antioxidant, antimutagenic, and anticarcinogenic properties. Avian and mammalian species may not synthesize carotenoids, unlike plants and microorganisms. Therefore, chickens must obtain carotenoids from their diet as the yolk initially provides vitamin A during embryonic development. However, after hatching, they require dietary sources of vitamin A (Khan et al., 2023). Post-hatch immune system function improved with the addition of vitamin A to the diet (Shojadoost et al., 2021).

Vitamin D is a type of fat-soluble vitamin that is obtained through sunlight exposure or supplements. Vitamin D is absorbed by the small intestine and then taken up by the liver, where it is converted into 25-hydroxyvitamin D3 (25(OH)D3), the stored form of vitamin D in the body. Vitamin D3 (1,25(OH)2D3), the physiologically active form of the vitamin, is produced in the kidneys by the enzyme 1a-hydroxylase. This form is responsible for the biological actions of vitamin D, regulating bone and mineral metabolism and modulating immune responses (Fakhoury et al., 2020; Wei et al., 2024). It has been demonstrated that 25(OH)D3 increases the synthesis of nitric oxide, promotes the activity of innate immune cells, modifies adaptive immunity, and produces antimicrobial proteins and inflammatory cytokines in chickens (Shanmugasundaram et al., 2019; Fakhoury et al., 2020; Sharma et al., 2024).

Vitamin C, commonly known as L-ascorbic acid, is a water-soluble vitamin that the body converts from glucose. In the body, vitamin C does not accumulate, and excess levels are promptly excreted by the kidneys, resulting in decreased absorption (Johnston et al., 2006; Shojadoost et al., 2021; Hieu et al., 2022). Vitamin C is an antioxidant that protects cells from damage caused by free radicals generated by infection or toxins. Birds may produce vitamin C due to an enzyme called L-gulonolactone oxidase in their renal tissue, which converts l-gulono-g-lactone into ascorbic acid. However, vitamin C requirements increase when chickens experience stressful conditions such as beak trimming, vaccination, transportation, thermal stress, or infection. Therefore, supplementing vitamin C alleviates the adverse effects of these stressful conditions (Abidin and Khatoon, 2013).

Vitamin E is a fat-soluble antioxidant with four distinct functional forms. Among these forms, a-tocopherol is the most biologically active and naturally abundant. This vitamin is well-known for its potential to counteract the adverse effects of free radicals on cell integrity that can occur during normal cell metabolism and inflammation. In poultry, it is crucial to supplement the diet with vitamin E to maintain fertility and hatchability in parent stocks and to prevent nutritional encephalopathy and myopathies in chickens and turkeys. Vitamin E supplementation (or other antioxidants) becomes even more critical when oxidizable fats are included in the feed. The supplementation of vitamin E may prevent the oxidation of unsaturated fats. However, the level of active vitamin E and unsaturated fat used in poultry nutrition may be adequate in intestinal absorption, potentially decreasing the antioxidant status by increasing lipid peroxidation (Pompeua et al., 2018). Vitamin E boosts immune system activity by inhibiting the synthesis of prostaglandins, which may cause inflammation and hinder the immune response. Vitamin E also prevents oxidation, which is responsible for the production of prostaglandins. Vitamin E is primarily known for its antioxidant properties, effectively reducing the damage caused by free radicals during metabolic stress and immunological disorders. Vitamin E regulates the production of free radicals and gene expression caused by free radical signaling gene expression (Packer and Suzuki, 1993). Deficiency of vitamin E and selenium may impair the immune response in poultry, as indicated in the research conducted by Lewis et al. (2019).

5.5. Organic Acids

Organic acids are a type of feed additives that may promote good health and stimulate immunity in poultry. These acids are categorized as organic chemical compounds that contain the carboxyl group COOH in their structure. It is also known that formic, acetic, propionic, malic, fumaric, and citric acids are commonly utilized in poultry nutrition (Hajati, 2018; Khan et al., 2022). Besides, organic acids upregulate harmful microorganisms' inhibition mechanism by reducing the environment's pH level. By penetrating the biological membranes of microorganisms and disrupting their cell function through electrolytic dissociation, organic acids may also restrict bacterial growth (Feye et al., 2021; Pope et al., 2022). It has been stated that formic acid supplementation has beneficially affected broiler chicken performance (body weight gain, feed intake, and feed conversion ratio). It may also enhance the growth of intestinal villi and increase the number of lymphocytes in the spleen and antibody levels for the prevention of disease (Tawfeeq and Al-Mashhdani, 2020).

Organic acids have been significantly effective in body growth rate, feed efficiency, nutrient digestibility, meat quality, immune response, and suppressing pathogenic bacteria (Yang et al., 2018; Adhikari et al., 2020). The enhancements may be completed by lowering the pH in the gastrointestinal tract, optimizing nutrient utilization in diets, inhibiting pathogen growth, and improving immune response in poultry (Alagawany et al., 2021). Recently, Liao et al. (2020) found a strong correlation between gut microbial communities and organic acids, contributing to the gut health status of broilers. The function of gut microbiota is known as an endocrine organ regulating the immune system through synthesizing interferon/cytokines and immunoglobulins (IgG, IgM, and IgA), activating white blood cells like lymphocytes and natural killer cells, and boosting the activity of macrophages and heterophils (Clarke et al., 2014; Abd El-Hack et al., 2020).

Moreover, acetic acid (0.30 g/kg of) may be responsible to prevent gastric apoptosis and stimulate mucin synthesis (Liu et al., 2017). Also, butyric acid plays a crucial role in promoting intestinal development and maintaining the integrity of intestinal epithelial cells (Sun and O'riordan, 2013). Numerous studies have shown that dietary organic acids can inhibit the growth and spread of harmful opportunistic pathogens such as Salmonella, E. Coli, and Clostridium while also promoting the growth of beneficial microorganisms such as Lactobacillus, Bacillus, and Bifidobacterium in the intestine (Lee et al., 2015; Nguyen et al., 2018; Gao et al., 2019). Additionally, in organic acids treatment group, the relative weights of lymphoid organs, such as Bursa Fabricius, thymus, and spleen, were found to be higher compared to the control treatment group, which is strongly related to immunological responses in chickens (Ghazala et al., 2011; Yang et al., 2018). These organic acids stimulate specific and non-specific immune responses in broiler chickens by activating macrophages, increasing cytokine production, and IgA, IgG, and IgM levels. Besides, organic acids inhibit bacterial infection growth, proliferation, and intestinal mucosa inflammation (Abd El-Hack et al., 2022).

5. Conclusion

A balanced diet with essential feed supplements (amino acids, probiotics, prebiotics, synbiotics, minerals, vitamins, and organic acids) stimulates the immune system. Dietary deficiencies may cause several health issues and economic losses in profitability for production. Besides, nutrition has been associated with immunologic processes in commercial production systems under various management conditions. Because of that, understanding the patterns of these feed additives is necessary for optimizing strong immunity.

Author Contributions

The percentage of the author(s) contributions is presented below. All authors reviewed and approved the final version of the manuscript.

	M.G	A.S	Ü.Ç
C	60	30	10
D	60	30	10
S	60	40	-
L	70	20	10
W	70	20	10
CR	70	20	10
SR	60	30	10

C=Concept, D= design, S= supervision, L= literature search, W= writing, CR= critical review, SR= submission and revision.

Conflict of Interest

The authors declared that there is no conflict of interest.

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