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Impact of Selected Feed Additives in Broiler Nutrition on Breeding and the Meat Quality Features

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Abstract

The aim of the study was to overview the results of scientific research on the impact of feed additives used in broiler nutrition on breeding and meat quality. Selected additives used in feeding broilers with immunomodulatory properties, prebiotics and probiotics, herbs and herbal extracts and protein additives were characterised. The application of insects in poultry feeding as a good source of proteins and fat as a substitute of expensive feed rich in proteins was presented. Further research is needed on their nutritional value, levels of incorporation into diets and the performance of this feed ingredient. However, there are many challenges that need to be overcome by adopting suitable strategies to produce antibiotic-free broiler meat with regards to food safety and chicken welfare issues. The additives available on the market should be used in accordance with the manufacturers' recommendations and the grace period should be observed in order to obtain the expected production results and a high-quality product.

Keywords: feed additives, broiler nutrition, meat quality

1. Introduction

Commercial breeding programs are aimed at the maximisation of production results (rate of growth, fodder use, meat content, layer production), achievable in typical environmental conditions. The task of rational animal feeding is the achievement of a maximum production results but also keeping good state of health by favourable influence on gastrointestinal tract, metabolism and stimulation of immune system. It is especially important in feeding animals of a big production potential, including poultry.

In broiler nutrition special attention should be paid to additives of immunomodulating action like: pre- and probiotics, yeast extracts, herbs and herb extracts.

The aim of the study was to overview the results of scientific research on the impact of feed additives used in broiler nutrition on breeding and meat quality.

2. About feed additives in general

Feed additives are the substances, microorganisms or preparations intentionally added to full-portion mixes and feeding doses in order to get improvement of their

feeding usability: flavour, taste, consistency, dietetic values as well as extension of validity time (shelf-life). By applying them in animal feeding, including broilers, one can achieve higher daily growths, better fodder use, higher resistance to diseases, improvement of animal product quality and reduction of harmful effect of animal droppings on environment. In order to avoid improper dosage and uneven dispersion of an active substance in the mix, their application, both during production of mixes and direct feeding in farms should remain under constant control [1, 2]. Administration of functional feed additives, including direct-fed microorganisms (DFM), dietary prebiotics, and phytogenic preparations, has been demonstrated to improve growth performance, animal health, and microbial food safety in poultry and is thought to be a potentially important component of antibiotic-free poultry production [3, 4].

Additives applicable to feed and water are an inherent feeding poultry component. Their application is connected with numerous advantages, but – at the same time – is subject to a strict control aimed mostly at avoidance of application not in accordance with their intended use. The classification, kind and scope of application of feed additives are regulated by the EU Law and regulations of Member States [5]. Additionally, consumer demand for antibiotic-free broiler meat is increasing. However, there are many challenges that need to be overcome by adopting suitable strategies to produce antibiotic-free broiler meat with regards to food safety and chicken welfare issues (**Table 1**) [6].

Following the withdrawal of antibiotic growth stimulators in poultry feeding, feed additives are applied, aimed at a favourable effect on bird's health and production parameters. The following additives are distinguished: those completing lacks of determined feeding components in the applied feed; supporting digestion processes; maintaining microbiological balance in gastrointestinal tract; improving productivity; reducing negative effect of droppings on natural environment; improving animal origin product quality; improving feeding value of feed additives; preventing diseases (in poultry production: coccidiosis and histomoniasis); facilitating production of feed mixes (binders, sticks). From the farmers' point of view the most important are the additives that have a direct influence on metabolism of the gastrointestinal tract of birds and regulate the level of provision in biologically active substances, since they increase production results. Among them we can include: vitamins and provitamins; mineral additives; amino acids, their salts and hydroxy analogues; digestion stimulators; stabilisers of intestinal microbiome; coccidiostatics [5]. While determining the dose of fodder and additives for hens and other poultry one should take into account their specie, body mass, age, production intensity, physiological state, gender, environment temperature and maintenance system [10].

The use and development of enzymes, phytogenics, prebiotics and probiotics has gained momentum in poultry feeding. The enzymes widely used by the industry are the non-starch polysaccharidases that cleave the non-starch polysaccharides in viscous cereals, microbial phytases that target the phytate-complexes in plant ingredients. Proteases are of interest to improve protein and amino acid digestibility, particularly in very young animals. Phytogenics are an alternative to in-feed antibiotics to prevent the risk of developing pathogens and also to satisfy consumer demand for a food chain free of drugs. Probiotic feed additives generally consist of one single strain or a combination of several strains of bacteria, *Bacillus* spores or yeasts species. Prebiotics are non-digestible food ingredients, such as fructo-oligosaccharides, xylooligo-saccharides, mannan-oligo-saccharides and galacto-oligosaccharides that are also used in feeds to protect poultry against pathogens [9].

Alternatives to antibiotics	Active ingredients	Basic functions	Effects on broiler
Probiotics	<i>Bacillus subtilis</i> , <i>Enterococcus faecium</i> <i>Lactobacillus acidophilus</i> , <i>Bacillus licheniformis</i> , <i>Bifidobacterium bifidum</i>	Appetite and digestion, stimulant, antioxidant	Increased body weight and FCR Improved absorptive surface of duodenum and ileum Increase nutrient retention
Prebiotics	Fructo-oligosaccharides (FOS), inulin, galacto-oligosaccharides (GOS), trans-galacto oligosaccharides	Digestion, stimulant	Increased growth performance Stimulation of metabolic activity in intestine
Organic acids	Citric acid Ascorbic acid Propionic acid and sodium bentonite Butyrate	Digestion, stimulant, increased feed efficiency	Increased body weight Improved ileal nutrient digestibility, cell proliferation, and epithelial and villi height
Amino acids and enzymes	Phytase, lysins	Digestion, stimulant	Improved growth performance
Phytogenic feed additives	Pepper	Digestion, stymulant	No effect on live performance
	Garlic	Digestion, stimulant, Antiseptic	Higher body weight
	Ginger	Gastric stymulant	No effects on performance
	Rosemary	Digestion, stimulant, antiseptic, antioxidant	Improved live weight and feed efficiency
	Thyme		No significant effect on BW/FCR
	Mint	Appetite, digestion, stimulant, antiseptic	Decreased serum total cholesterol, triglycerides, and low-density lipoprotein concentration
Nanoparticles (NPs)	Silver NPs Selenium NPs Copper NPs Metal NPs such as zinc oxide, zirconium dioxide, and platinum Zn-bearing zeolite clinoptilolite NPs Nanosuspensions of clay minerals	Digestion, Stimulant	Increased body weight and FCR

Source: [4, 6–9].

Table 1.
Alternatives to antibiotics and their functions and impacts on broiler production.

3. Additives of immunomodulating action applicable in broiler feeding

Contagious diseases, in spite of ever improving prevention programs, cause big losses in poultry production, and foodstuffs contaminated with pathogens may be dangerous for consumers. In order to increase poultry resistance against pathogenic factors, more and more additives of immunomodulating character are applied in fodder industry. The effect of immunomodulators consists in their direct action on the cells of the immune system that ensure an immune response. Modification of the process of determined immune reactions in this way increases the organism resistance to viral, bacterial and parasite infections. The immuno-modulating feed additives include: pre- and probiotics, components of baker's yeast cell walls (mannooligosaccharides, β -glucan and nucleotides) and herbal extracts (echinacea, aloe and ginseng). Certain amino acids (arginine, methionine), vitamins (E, A, C), microelements (Zn, Sn) and fatty acids (LC PUFA n-3, CLA) also play an important role in the immune processes in poultry [5, 11].

The withdrawal of antibiotic growth stimulators resulted in increased interest in immunomodulators that stimulate GALT. These are, among others, prebiotics. They are applicable in fodder industry in order to increase poultry resistance to pathogenic factor action [12, 13]. Recently, interest in probiotics and prebiotics as feed additives that may constitute an important factor inhibiting multiplication of intestinal pathogens at poultry fed with mixes non containing antibiotic growth stimulators has increased [14]. Immunostimulating action of this kind of feed additives is also an important issue.

Lipiński and others [12] examined the effect of application of a prebiotic preparation containing mannanoligosaccharides in mixes for broiler chicken, for their health status and meat quality. In fodder mixes, instead of a plant stimulator and acidifier (control group), the prebiotic preparation Biolex MB 40 (mannanoligosaccharides) was applied in the quantity of 2 kg/t of mix (group II). In the experimental group III the preparation Biolex MB 40 in the quantity of 2 kg/t and acidifier were applied. In result of studies at chicken fed with mixes with the participation of the tested preparation, the activation of non-specific defence mechanism against infection was noted, proved by the increase of the level of lysozyme in blood serum. The meat of the test chicken was characterised by a similar content of dry mass, raw ash, total protein and raw fat. The application of the tested preparation at the chicken for slaughter had no influence on the chemical composition of meat (Table 2).

Vidanarachchi et al. [15] examined the effect of action of two different extracts of carbohydrates soluble in water (extract from renga renga lily and acacia) and two prebiotic compounds available in the market, Fibregum and Raftifeed-IPE, on productivity of broiler chicken subject to the provocation of necrotic (necrotising)

Item	Control	Biolex MB 40	Biolex MB 40 + acidifier	SEM
Lysozyme [mg/l]	6,84a	7,99b	9,14c	0,261
Dry matter [%]	26,24	25,90	25,92	0,105
Ash [%]	1,20	1,18	1,18	0,013
Protein [%]	22,30	22,07	21,96	0,079
Fat [%]	2,92	3,01	2,86	0,085

a, b – different letters in a row differ significantly $p \leq 0.05$.
Source: [14].

Table 2.
Level of lysozyme in blood serum of broiler chickens and chemical composition of breast meat.

enteritis (NE). These therapies were compared to the negative and positive controls (bacitracin Zn). Total 8,8% death rate connected with NE was noted, with the average assessment of changes in jejunum and ileum at dead birds in the range of 3,03 to 3,90 at all provoked groups except for positive control groups. Neither specific deaths for NE nor clinical irregularities with unquestioned control groups and positive control groups were noted. In result of the studies it has been proved that supplementation with carbohydrates soluble in water from two plant (herbal) sources was not effective against NE controlling. It has been proved, however, that the prebiotic compound Fibregum has certain immunomodulating action. Addition of bacitracin Zn and monensins was highly effective in counteracting negative effects of the disease.

4. Pre- and probiotics applicable in poultry feeding

Prebiotics are the substances that have to fulfil certain requirements. They must not be digested in upper sections of the gastrointestinal tracts, they should stimulate development of a favourable intestinal microbiome, and products of their decomposition should lower pH of the digestive tract content. Prebiotics are substrates selectively and in a better way utilised by bifidobacteria and other species of favourable bacteria, and mainly fermentation products of these compounds. Short-chain fatty acids lower pH of intestinal environment and worsen conditions of development of bacteria undesirable in poultry breeding (*Clostridium*, *Salmonella*). The bioactive substances in the form of prebiotics, most frequently applicable to birds, comprise fructooligosaccharides, inulin obtained from chicory roots, oligofructose and manno oligosaccharides. Moreover, one can meet isomaltooligosaccharides, soya oligosaccharides, galaktooligosacharydy, maltooligosaccharides, glucooligosaccharides and xylooligo-saccharides [5]. Probiotics can replace antibiotics by changing the intestinal microbiome, thereby producing some of the effects of antibiotics. For example, feed supplementation with probiotics improves the feed efficiency and intestinal health and, ultimately, facilitates the faster growth of broilers by reducing the intestinal pH, altering the intestinal bacterial composition, and improving digestive activity. Probiotics stimulate endogenous enzyme production, which reduces the production of toxic substances and increases vitamins and/or antimicrobials such as bacteriocins [6].

Probiotics are the preparations containing desired intestinal microflora, among others *Lactobacillus acidophilus*, *L. bulgaricus*, *L. casei*, *L. reuterii*, *Bifidobacterium bifidum*, *B. longum* and others. Administered in the form of live bacteria or endospores they have a favourable effect on host health improving intestinal microbiological balance. The mechanism of activity of probiotics is multiway and it consists, among others, in: restoring and maintaining natural balance of gastrointestinal tract microflora; protection of gastrointestinal tract against pathogens; production of bacteriocins, short-chain organic acids; synthesis of vitamins of group B, vitamin K and digestion enzymes; stimulation of immune system; reduction of concentration of toxic substances in gastrointestinal tract and in blood; lowering pH of intestinal content, cholesterol and triglycerides level in blood and tissues [5].

Broiler feed supplemented with *B. subtilis* increased the body weights by 4.4%. The H₂S and NH₃ concentrations in chicken excretions were also reduced after treating chickens with probiotics, leading to less odour. Probiotics increased the meat quality of poultry by affecting the fat and protein contents [6].

Mixed feed additives called synbiotics (preparation containing pre- and probiotics at the same time) are also worth consideration, containing in their composition lactic acid bacteria of the species *Lactobacillus*, *Bacillus*, *Bifidoacterium* and *Enterococcus* [8].

Immunomodulating action of pre-, pro- and synbiotics is connected with the action of lactic acid bacilli in the organism. It is manifested, first of all, by favourable influence on development and activities of immune system at the level of intestinal mucosa (GALT). Feed additives with an immunomodulating effect constitute a valuable supplement compound feed for poultry. Their influence is based on the direct stimulation of the cells of the immune system, which increases the efficiency of the processes immunological and leads to lower susceptibility of birds to pathogenic microorganisms [11].

In studies on poultry it has been proved that chicken for slaughter, given probiotic preparation containing *Lactobacillus acidophilus*, *Bifidobacterium bifidum* and *Streptococcus faecalis* characterise, as compared to the control group, with higher immunoglobulin level (especially IgM) in blood serum directed against SRBC antigen, but there was no effect of probiotic in response to BSA antigen [11, 16].

At chicken for layers the preparation containing live *Lactobacillus casei* strains had a positive effect for humoral mechanisms of resistance, substantially increasing production of antibodies after immunisation with virus of supposed poultry pest or with BSA antigen [11, 17].

Broiler chicken Ross 308 fed with diets with addition of symbiotic containing bacteria *Bacillus subtilis* C-3102 and yeast (*Saccharomyces cerevisiae*) in the ratio 1:1 were characterised with higher slaughter productivity. The birds were reared for 42 days. Chickens were given *ad libitum*, wheat-corn-soybean mixtures and wheat-triticale-soybean. Application of fodder additive, irrespective of the kind of grain in mixes resulted in the lowering of the mass of the chicken gastrointestinal tract and increase of the mass of edible giblets. It has been proved that the combination of probiotic and prebiotic bacteria may be a good fodder additive stimulating growth and development of broiler chicken. However, while choosing a given preparation one should take into account many factors, mainly quality and specificity of the preparation, direction of production and kind of diet [8].

The increasing interest in probiotics and herbal additives in poultry feeding results from their favourable influence of health state of the gastrointestinal tract and reduction of intestinal problems. In many research programs a favourable influence of additives stabilising gastrointestinal tract microbiome on poultry production results was proved [18]. The influence of probiotics on production results is less stable than that of herbal additives. Certain researches proved minor influence of probiotics on

Specification	Control	<i>Lactobacillus lactis</i>	Essential oil
Duration of trial (days)	105	105	105
Final body weight (g)	9,03B	9,32A	9,11B
FCR (kg/kg)	2,34	2,36	2,31
Mortality rate (%)	96,25	96,25	96,25
EEI* (pts)	353,4	362,7	361,6
Dry matter (%)	26,72	26,52	26,46
Ash (%)	1,20	1,19	1,20
Protein (%)	25,76	25,36	25,64
Fat (%)	0,41	0,38	0,48

A, B – different letters in a row differ significantly $p \leq 0.05$.
Source: [19].

Table 3.
Productivity results of the turkeys during the trial period and chemical composition of breast meat.

productivity but the majority of them confirm at least favourable trends in production results, equalisation of animals, lowering death and incidence ratio or lowering of treatment costs after application of probiotics in fodder [19, 20].

Results of research works of Lipiński and others [19] on influence of probiotic and herbal additives on productivity and quality of turkey meat proved that application of a probiotic preparation in mixes for turkeys for slaughter resulted in improvement of production results expressed in body mass but had no influence on use of fodder and health of birds. Application of a herbal preparation in mixes for turkeys had no influence on fattening. The meat of test turkeys was characterised with a similar content of dry mass, raw ash, total protein and raw fat (**Table 3**). The analysis of the European efficiency ratio showed that the use of the tested feed additives had a positive effect on the value of this indicator. The best results in this respect were found in birds from group II (362.7 vs. 353.4 in the control group) and III (361.6 vs. 353.4 in the control group); however, the differences found were not statistically significant [19].

5. Herbs and herb extracts

Modern methods of poultry breeding are aimed at elimination or reduction of use of chemical means in animal feeding. One of the ways towards that end is the return to use natural fodder additives, like herbs. Herb fodder additives are at present of growing interest in connection with total prohibition of use of antibiotics.

Herbs and herbal (phytogenic) additives in animal feeding act favourably on increase of animal resistance and reduction of incidence ratio, improving animal welfare. Herbs do not add nutrition substances but they improve taste and digestibility of fodder thus increasing its use. The research enabling identification of active substances in herbs and determination of their action on the organism resulted in their more rational application and better adjustment to the needs. Herbs contain various kinds of active substances like essential oils, dyestuffs, alkaloids, glycosides, phenolic acids, phytosterols, flavonoids. Activity of active substances contained in herbs and medicinal plants is usually multi way. Their action is immuno-stimulating, anti-inflammatory, antibacterial and they improve quality of products of animal origin. They activate secretion of digestive juices, increase appetite and peristaltic of intestines as well as improve processes of absorption of nutritive components (**Table 4**) [5, 26].

Genre / production group	The form of feeding herbs			
	fresh	dried	dried extracts	oils
broilers	0	++	++	++
laying hen	+	++	+	++
gooses	++	0	0	0
turkeys	++	++	+	++
ducks	+	0	0	0

“+” - low efficiency (0-2% improvement);
“++” - desired effectiveness (2.1-5%);
“+++” - high efficiency (over 5%);
“0” - lack of effectiveness or information in the available literature.
Source: [7, 21–25].

Table 4.
Effectiveness of using herbs in animal nutrition.

The compounds of plant origin, the so-called phytobiotics, are also applicable in animal feeding in order to improve productivity and quality of products of animal origin. They are considered as natural and safe additives and their multi way action gives possibility of their wide use in animal feeding [27]. Particularly effective immunomodulating additives include phytogenic preparations (Echinacea, Aloe and Ginseng) [11].

The effectiveness of herbs applied in their natural forms may differ according to the time of harvesting, habitat conditions they grew in, conditions of drying and storage, and thus more and more herbal-mineral-aromatic preparations appear in the market. These are preparations like BioStrong, Dominal as well as Digestarom, containing essential oils of peppermint, marjoram, cloves, anise and dill on an inorganic carrier [28].

Many research works confirm favourable influence of herbs on health of birds. The use of herbs in animal nutrition results not only from the taste preferences of animals, but also due to their influence on the organisms of animals - most often they have a therapeutic effect. Knowing the chemical composition and the effect of individual substances on the animal's body makes it possible to use herbs more rationally. Plants or parts of plants contain many different substances that actively interact with the animal's organism. The action of active substances in herbs and medicinal plants is most often multidirectional. They stimulate the secretion of digestive juices, increase appetite and intestinal peristalsis, and improve the absorption of nutrients. The advantage is also a positive effect on the body through anti-diarrheal, anti-inflammatory, antiparasitic and antipyretic properties [5].

Biologically active substances contained in herbs like essential oils, tannins, glycosides, flavonoids, terpen, mucus, organic acids show various actions: antibacterial [29], antiviral, antimycotic, immunostimulating [30] and antistress [24]. Many active substances contained in herbs improve taste and flavour values of products of animal origin, and first of all discolour egg yolks, as well as bond mycotoxins [5]. In poultry prophylaxis and treatment herbs may be used as entire plants or their particular parts only: in a fresh and dried form, in the form of infusions, brews, essences, extracts, macerates and essential oils [25].

Arczewska-Włosek and Świątkiewicz [31] inform that thanks to the properly selected herb extracts added to the fodder mix there is a possibility of replacing coccydiostatics. It has been proved that the mix of sage extracts (*Salvia officinalis*), garlic (*Allium sativum*), purple echinacea (*Echinacea purpurea*), thyme (*Thymus vulgaris*) and oregano (*Origanum vulgare*) had a positive influence on production results of birds infected with oocysts *Eimeria* sp.. According to Majewska et al. [32], herbs introduced to poultry diet may lower cholesterol concentration in blood and thus affect positively birds' health. Hypocholesterolemic effect results from the fact that chemical compounds contained in plant essential oils, e.g. citral, geraniol, cineol, menton, menthol, fenchon, borneol, fenchyl, may cause inhibition of liver enzyme activity (reductase HMGCoA), that controls quantity of synthesised cholesterol and thus lowers its concentration in blood [24, 33].

Phytogenic feed additives may also improve fodder taste and thus increase its intake and improve production results, including fodder consumption and use and growth of poultry body mass [27]. Unambiguous confirmation of the positive effect of herbs on production results of broiler chicken is still problematic, since obtained results are often contradictory. Kwiecień et al. [22] and Kwiecień and Winiarska-Mieczan [23] proved positive influence of herbs on hen broiler body mass but Brzóska et al. [7] and Gardzielewska et al. [28] drew different conclusions. Gardzielewska et al. [28] examined influence of application of Digestarom preparation and charcoal on quality of fresh meat and after 4-month storage frozen. Tests were conducted on broiler cocks Ross 308. In result of the tests it has been proved that Digestarom preparation resulted in brightening of muscle colour, substantially bigger acidification, increasing of losses of meat juice both during defreezing and

cooking, worsening of sensorial properties of meat and bullion, as well and increase of cholesterol level. It was also proved that the addition of Digestarom preparation affected adversely the majority of tested meat properties after defreezing and cooking. However, the addition of charcoal affected positively the reduction of meat losses after storage and cooking and sensorial assessment of cooked meat and bullion.

Adequate feeding of broiler chicken may, to a certain extent, control fat content in meat and modify its composition leading to the product of desired nutrition and dietetic features. Phytogenic fodder compounds, including resin *Boswellia serrata* are helpful in this matter. In the tests conducted by Kiczorowska et al. [34] it has been proved that the application of *Boswellia* resin in feeding broilers decreased content of C14 and C18:3 acids and increased total KTJN in the fat of breast muscles. However, its use in ecologic fodders resulted in increasing quantity of C18:3 acid in the fat of chicken breast muscles.

Broiler chicken show lower resistance to environmental factors and higher sensibility to stress states what affects negatively their productivity and health [35]. At present growing attention is paid to the possibilities of using herbs in counteracting stress situations during breeding.

From many plants of immunomodulating activities the best known are certain species of echinacea (*Echinacea purpurea*, *E. angustifolia*, *E. pallida*). They come from The North America where they have been applicable as medicinal herbs for ages. The immuno-stimulating property of echinacea covers various kinds of resistance and it is a representative of actions of many substances contained in this plant, i.e. coffee acid derivatives (coffee acid, quornic acid, echinakozide, verbasoside and others), non-starch polysaccharides (heteroxylans, arabinoramnogalactans), alkaloids (mainly isobuthyloamides) and essential oils and flavonoids. Immunomodulating properties of echinacea were duly documented in clinical tests on human and in model tests on rats and mice [11].

Ginseng (*Panax ginseng*) contains active substances of actions stimulating phagocyte activity of macrophages, activity of NK cells, production of relay cytokines and IgM and other immunoglobulins, as well as T lymphocyte proliferation. In experiments with chicken for slaughter infected with *Salmonella gallinarum* bacteria, application of a preparation with ginseng in drinking water reduced rate of death, extent of liver infection and number of birds in droppings of which cultures of tested bacteria were found [11, 36].

In tests on turkey hens for slaughter a preparation containing active substance of aloe, chokeberry and vitamin C increased total quantity of leucocytes and activity of lysozyme in blood, and phagocyte activity of leucocytes against *Staphylococcus aureus* bacteria. At chicken infected with *Salmonella gallinarum* bacteria or virus of supposed poultry pest the addition of aloe reduced rate of death and increased synthesis of IL-6 [11, 37].

6. Protein rich feed additives

Fodder quality and especially quantity and quality of proteins contained therein are of a basic importance in animal feeding. Protein is a component necessary for proper growth and functioning of an animal organism. Its use is optimum if the amino acid composition and mutual proportions of amino acids correspond to the needs that depend on production group, gender, age and body mass of animals [10].

In feeding hens the grain corns are basic being the main source of energy. Grain may constitute 40 to 80% of the dose. Not all grains, however, are recommended. In the poultry diet the first amino acid limiting growth is methionine together with

cystine. The majority of raw fodders is of a big shortage of methionine. It is an important problem for farmers since thanks to methionine the animal organisms are able to produce creatine, choline or epinephrine. Each excess of amino acids is eliminated from the organism in the form of ammonia, and that is why it is so important that the supplied proteins were of full value. Loss of this valuable component results in production cost growth and increases environmental contamination in result of emission of nitrogen to soil, ground waters and air [10].

Rich chemical composition of lucerne concentrate, high content of proteins, amino acids, dyes, vitamins, mineral components, energy and other active substances results in its application in animal feeding as plant fodder additive (phytobiotic) instead of the withdrawn antibiotic growth stimulators [38, 39]. Biologically active compounds contained in lucerne concentrate support immune and haematopoietic system of fed animals [38, 40]. In tests with feed additive Polisavone, extract from lucerne, it has been proved that it increased resistance and lowered the content of lard fat at chicken but did not increase body mass growth and fodder use by these birds [40]. The studies of Ognik and Czech [41] have proved that the addition of lucerne concentrate (PX) to turkey diet resulted in a total growth of antioxidation capacity and growth of vitamin C and copper in blood of these birds.

Goronowicz et al. [42] assessed selected physical and chemical features of breast muscles of chicken for slaughter from ecologic and intensive breeding. Compound feed with additives for chicken of ecologic breeding was prepared according to the criteria, it was poorer as regards basic nutrition components. It contained less proteins and metabolic energy. In result of tests it was proved that muscles of chicken for slaughter of ecologic breeding were characterised with good nutrition value (more proteins, less fat) and they were of a darker colour, what may be a desirable feature for many consumers. However, high pH₂₄ of breast muscles of chicken of ecologic breeding indicates that their meat may be vulnerable to microbiological infections and may be stored for a short time only. Moreover, it needs more force for cutting what may indicate that it has to be subject to a longer thermal processing.

Algae may be an interesting protein additive in poultry feeding. Algae may be obtained from natural sources or cultivated in artificial ponds, e.g. phototrophic microalgae. The most popular alga is spirulina, used in many countries as an additive to food for people and animals due to its big nutrition value. Spirulina (*Arthrospira platensis*) belongs to unicellular microalgae living in natural or artificial water reservoirs. Tests proved that adding microalgae to fodder in poultry feeding increase content of unsaturated fatty acids (NNKT) and carotenoids in egg yolks. The best results were noted in a group of 10% additive of algae in which the biggest growth of body mass, decrease of fat content in blood and liver were noted, as compared to control group [21].

7. New generation of protein rich feed additives (insect and fly protein)

The poultry production market is expected to grow constantly and dynamically. This fact results from, among others, high nutritive value of products (meat, eggs), their relatively low price and lack of consumption contraindications resulting from religious limitations. Moreover, in the time of global warming, poultry is characterised with a relatively low emission of greenhouse gases, as compared to other farm animals. However, intensification of poultry production needs increasing supply of various protein sources in the diet [43].

Recently, the use of various species of insects as the source of protein and fat in poultry feeding has been noted. In many countries, including Asia, Africa and Latin America, invertebrates constitute common source of protein in fodder mixes for

farm animals [44]. Nutrition specialists, looking for new unique protein sources to be used in broiler feeding, conduct studies on influence of share of flours (meal) made of insect larvae on productivity of chicken for slaughter and on development of microbiome in their intestines [45]. Józefiak and others [45] consider insects as a valuable alternative source of proteins and fat in poultry feeding, as a substitute of expensive fodders rich in proteins. Insects may supplement fodders like soya, maize (corn), cereals or fish meal. The production of meal (flour) from insects is ecologic because it does not use water; it is characterised with low emission of greenhouse gases and processing of raw materials of low value into valuable proteins. The chemical composition of various species of insects is highly differentiated and thus it needs standardisation of production processes of meal that, added to broiler fodders, has no influence on breeding results significantly modifying microflora of their gastrointestinal tracts [45, 46]. The concentration of nutrients in the meal supplemented with insects depends on their developmental stage, production conditions and composition of feed and substrates on which they are grown. Insects can play the Essentials role in animal nutrition, therefore studies on their nutritional value are required [2].

The composition of meals made from insects depends on insect species, their development stadium, production conditions, fodder composition and components of substrate they were bred on. Protein content in meal made from insects varies from 40–60%. Insect protein characterises with high digestibility (ca 85%) and its amino acid composition is more favourable than that of cereal proteins. Insect larvae contain also more fat than cereals or leguminous plants and thus they form a good source of energy. This fat is highly digestible and has a favourable profile of fatty acids (Table 5) [47].

Item	<i>Gryllus assimilis</i>		<i>Musca domestica)</i>		<i>Hermetia illucens</i>	<i>Tenebrio molitor</i>	<i>Blatta lateralis</i>
	Imago	subimago	pupae	larvae	larvae	larvae	nymph
Per kg DM							
Gross energy [MJ]	21.5	19.3	20.1	20.24	22.1	26.8-27.3	—
Crude fibre [g]	70	94	157	16-86	70	51-88	86-89
ash [g]	64	54	55-98	31-173	146-284	10-45	46-54
Phosphorus[g]	8.0	8.6	—	9.2-24.0	6.4-15.0	4.4-14.2	0.6-0.7
Calcium [g]	9.9	3.1	—	3.1-8.0	50.0-86.0	0.3-6.2	0.2
Crude protein [g]	564	638	630-762	380-604	411-450	451-603	543-734
Crude fat [g]	238	168	144-161	90-260	150-350	250-431	176-261
Fatty aids per kg fat							
SFAs [g]	351	352	476	417	749	229-334	28.7
MUFAs [g]	298	261	307	314	155	407-536	46.3-50.2
PU As [g]	336	369	291	399	74	254-323	138-219
Total PUFA n-3 [g]	22	17	—	—	2	2-4	1-11
Total PUFA n-6 [g]	314	352	—	—	23	81-93	35-207

Source: [2, 43–45].

Table 5.
Nutrient composition of different insect meals.

In tests on feeding of chicken for slaughter the test results concerning use of larvae of domestic flies are available. Test results show that addition of these insects in a mix may reach up to 25% without unfavourable effect on growth of body mass, fodder consumption and fodder use coefficient. High digestibility of amino acids was noted, in 95% at turkeys and in 91% at chicken for slaughter fed with meal from domestic fly larvae [43].

Insects' capacity of synthesising of anti-microorganism peptides encourages to use them in feeding of farm animals. High level of biocidal peptides (defensins) may play potential role of improvement of health and animal welfare. Józefiak and others [45] proved that a relatively small addition of *Shelfordella lateralis* (up to 0,2%) of peptides dried in low temperature (50°C) improved growth of body mass of chicken for slaughter. The obtained results suggest that addition of these insects may have influence on numerical amount of chicken intestinal microflora population and thus act anti-bacterially.

The published results concerning application of insect meal show that insects have a big potential in animal feeding. As a protein source they have an adequate amino acid profile. Histidine, lysine and tryptophan are limiting amino acids that may be included in the diet. Moreover, it is necessary to make assessment of profiles of amino acids of other insect species in order to select species of the best amino acid profile or improve the profile using genetic methods. In order to introduce insects as fodder component in the food chain (fodder chain) additional studies concerning their nutritive value, level of introduction in diets and functional properties of this kind of fodder ingredient are necessary [2, 48].

At present an insufficient supply of insects, i.e. lack of professional high productivity farms as well as impossibility of guaranteeing constant deliveries, is an important barrier in the use of insect meals in animal feeding. Lack of technologies dedicated to insect production results in the cost of production being at present too high to compete with the currently used protein sources. However, the works on implementation of new fodder materials, i.e. insect meals in full proportions for farm animals including poultry are on the way and their expectations are promising [43, 48]. There are also concerns about the safety of the food that uses insect meal for animal nutrition. It is currently unclear whether insect protein contains viruses or prions. Some researchers are not sure if any heat treatment can neutralise these factors. Virologists are also not of the same opinion on this point. Therefore, further research is needed in this area.

8. Main conclusions

1. The use of feed additives to improve the efficiency of growth and/or eggs production, prevent disease and improve feed utilisation is a strategy to improve the efficiency of the poultry industry.
2. The use of feed additives in poultry production is inevitable and results from breeding progress, shortening the time of breeding, resulting in increased susceptibility of birds to environmental and nutritional conditions.
3. The additives available on the market should be used in accordance with the manufacturers' recommendations and the grace period should be observed in order to obtain the expected production results and a high-quality product.

4. The feed additives with immunomodulatory properties constitute a valuable supplement to the feed mixtures for poultry.
5. Promising results relate to the use and implementation of insect meal for poultry. Further research is needed on their nutritional value, levels of incorporation into diets and the performance of this feed ingredient.

8.1 Suggestions for practice

1. The growing global demand for poultry meat and changes in consumer preferences as regards the quality of poultry products have an impact on the modification of feeding methods and composition of poultry feed mixtures.
2. Adopting appropriate strategies for the production of broiler meat without antibiotics presents challenges in terms of food safety and chicken welfare.

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