Chapter 1

Assessment of Maize (*Zea mays*) as Feed Resource for Poultry

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Additional information is available at the end of the chapter

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Abstract

Maize, also known as corn (*Zea mays* L), has been recognised worldwide as a major energy feed ingredient in the diets of poultry. Its major nutritional limitation has been the low protein content and poor protein quality, which necessitates the use of expensive high-protein supplements or synthetic amino acids such as lysine in diets containing large proportion of maize. Therefore, extensive research has been conducted by maize breeders on the world maize germplasms collection with the aim of improving its nutritive value, particularly protein quality for monogastric animals. This chapter assesses the genetic upgrading of the nutritional quality of maize protein that culminated in the development of a new class of maize known as "Quality Protein Maize (QPM)". Various studies on the nutritionally improved maize for poultry as well as future challenges confronting maize utilisation in poultry production are highlighted.

Keywords: maize (*Zea mays*), energy, protein quality, nutritive value, poultry

1. Introduction

Poultry (avian species) have been recognised as affordable source of high-quality protein worldwide in the forms of meat and eggs. The poultry sector has been shown to become the world's largest meat sector by 2020 (**Figure 1**). Besides, the sector continues to record high global output of eggs (e.g. 70 million metric tonnes in 2014) as additional high-quality protein food.

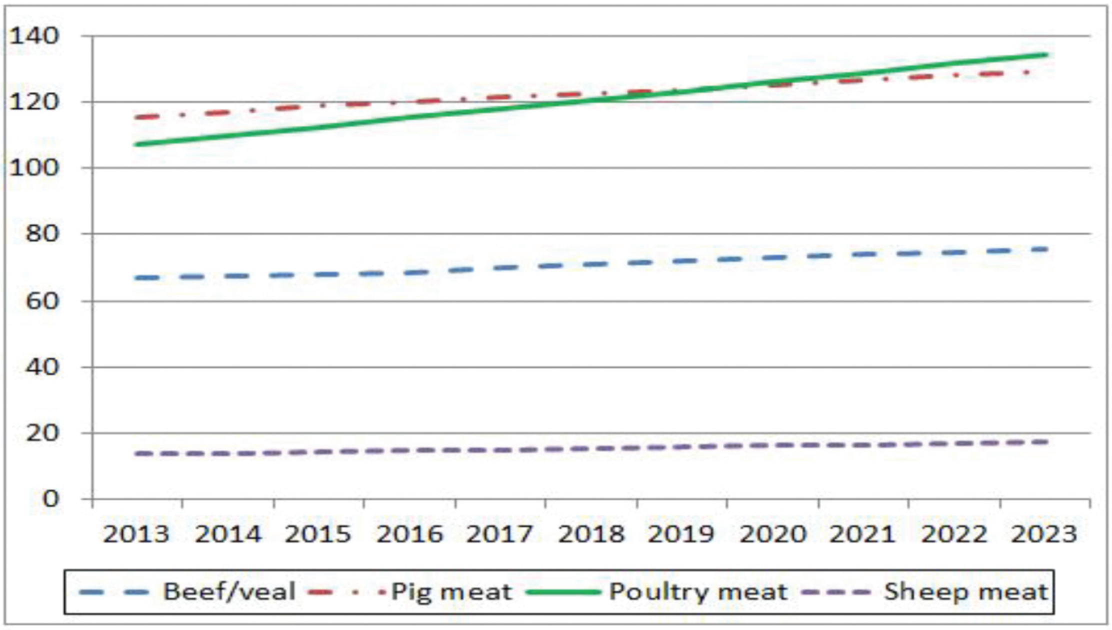

Figure 1. Global meat production (million metric tonnes) [1].

The rapid growth of the poultry sector is fuelled by several factors such as an increasing human population, greater purchasing power in developing economies, increased urbanisation and industrialisation in developing countries, development and transfer of feed, relatively short production cycle and advances in poultry breeding, and improved processing technologies. Of these factors, feed has been recognised as the most important factor controlling profitability and product quality [2].

Protein and carbohydrate are by far the two most important nutrients in poultry diets due not only to their marked effect on voluntary feed intake of the bird, but also the fact that they represent approximately 90% of the total cost of the ingredients in a ration [3]. Cereal grains constitute a large proportion (>50%) of poultry diets and contribute largely carbohydrates and to some extent proteins. They are mainly dietary source of energy, but can vary widely between grain types and animal species [4]. The common feed grains for poultry are corn or maize (*Zea mays*), wheat (*Triticum aestivum*), barley (*Hordeum vulgare*) and sorghum or milo (*Sorghum bicolor*).

Maize is by far the major feed grain grown worldwide, particularly in the United States. Although it is the preferred grain for feeding poultry [5], it is found to be low in protein content as well as protein quality [6], thereby limiting its nutritional value. This has necessitated a search for nutritionally improved maize varieties as well as alternative feed ingredients. The former has resulted in extensive research on the world maize germplasm collection with the aim of improving its nutritive value, particularly the protein quality for poultry.

This chapter discusses maize production and consumption, its genetic upgrading to improve the nutritional value with regard to feeding poultry.

2. Importance of maize in human and animal nutrition

Maize (*Zea mays* L.) tops other cereals in terms of worldwide production (**Figure 2**), with the United States being the largest producer as well as consumer (**Table 1**).

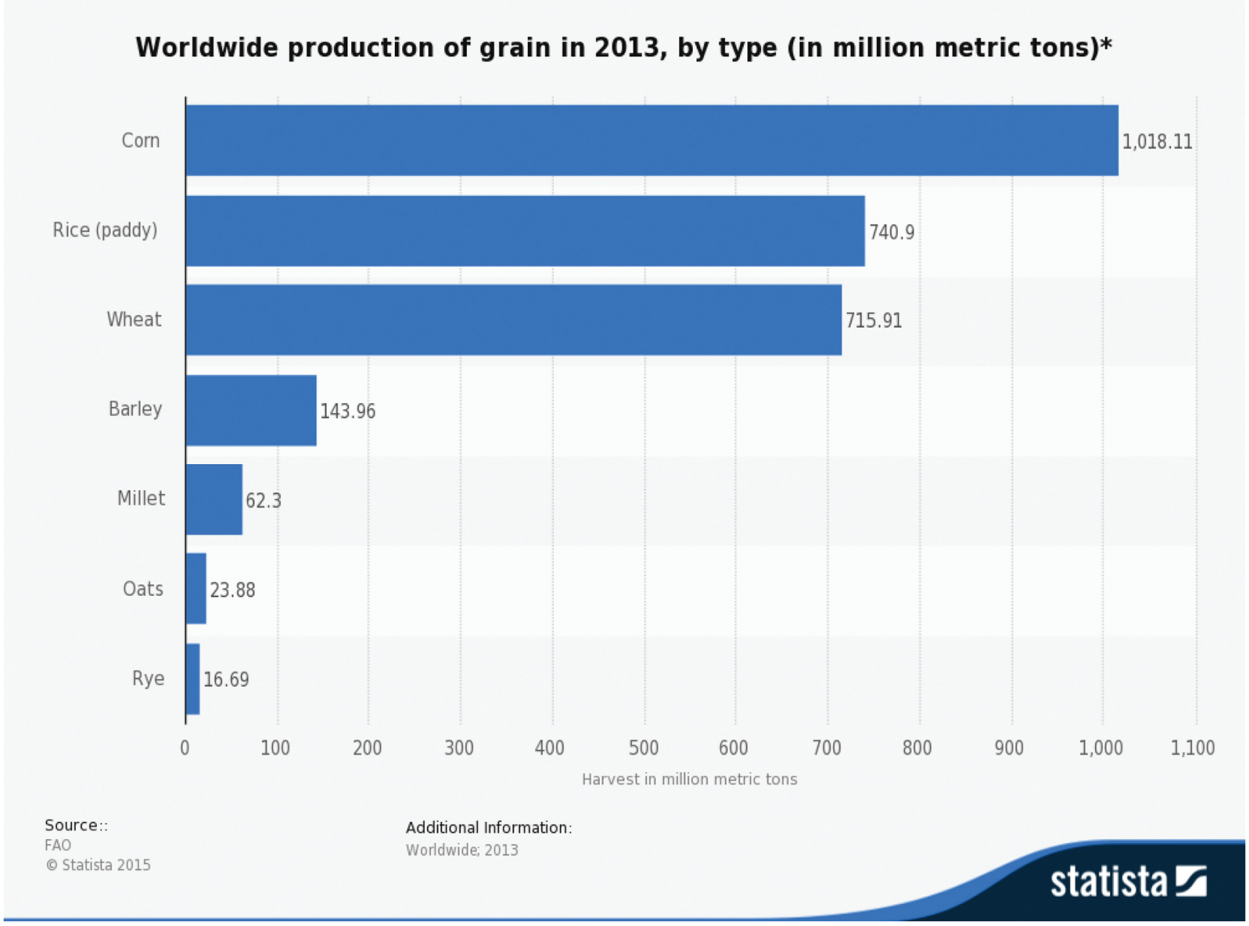

Figure 2. Global maize production [7].

On worldwide basis, much of the maize produced is fed to livestock, whereas only a small portion goes directly to human food [9]. The grain provides the world with 19% of its food calories and 15% of its annual production of food crop protein [6]. It is the basic staple cereal grain for large groups of people in Latin America, Africa and Asia [6], where the grain is consumed directly or in modified form as a major item of the diet.

Maize provides more feed for livestock than any other cereal grain [6]. For instance, 65% of the maize grown worldwide is used for livestock feed [10], of which the United States is the highest consumer. Also, rapid increase in poultry production in developing countries in Latin America, Africa and Asia is a major factor contributing to the increased use of maize for livestock feeding. In fact, maize is the preferred grain for feeding domestic birds, because its dietary energy value is the highest among cereals with very low variability between years for a given region [2].

Country	Production (million mt)[a]	~Production share (%)	Consumption (million mt)[b]	~Consumption share (%)
United States	345.5	36	301.5	31
China	224.6	23	214.0	22
Brazil	81.5	8	59.0	26
European Union-27	57.8	6	76.0	8
Argentina	25.6	3	–	–
Ukraine	23.5	2	–	–
Mexico	23.5	2	34.3	4
India	21.0	2	21.4	2
Canada	13.6	1	13.4	1
Russia	13.0	1	–	–
Japan	–	–	14.7	2
Egypt	–	–	14.5	2
Indonesia	–	–	12.7	1
Others including sub-Sahara Africa	138.4	14	204.8	21

[a] Total production (967.9 million mt).
[b] Total consumption (966.2 million mt).

Table 1. Worldwide maize production and consumption [8].

Over five hundred products [11] are obtained from industrial processing of maize, particularly from the main end-products of the "wet-milling" process of starch and nutritive sweeteners. The by-products include germ, bran and gluten which are suitable for feeding farm animals [12]. The gluten, in particular, is high in protein and metabolisable energy as well as a concentrated source of xanthophylls pigments, which make it popular in poultry production [2].

Besides, maize has long been an important ingredient in the manufacture of alcoholic beverages [9] including maize beer and whiskey. It is also an essential raw material in the production of industrial alcohols (25.4 kg of maize can yield 9.7 L of anhydrous ethanol plus useful by-products) [9]. The ethanol has a potential use as a partial replacement for gasoline due to increased fuel costs. The main by-product is referred to as "draff" or "distillers dried grains" (DDG), and it is high in protein. The DDG can be added another by-product called "solubles," which comprises the smallest residual particles of maize and yeast. The DDGS is high in protein, trace element and vitamins as well as increased availability of phosphorus, thereby making it popular feed ingredient for poultry production [2].

3. Nutritive value of normal hybrid maize grain

The maize grain (**Figure 3**) on dry matter basis is made up of 82.9% endosperm, 11.1% germ, 5.2% pericarp and 0.8% tip cap [13].

Table 2 shows the per cent chemical composition of the maize grain and grain fractions. In general, maize grain is low in protein content (9.1%), oil (4.4%) and ash (1.4%), but very high in starch content (73.4%) when considered on dry matter basis.

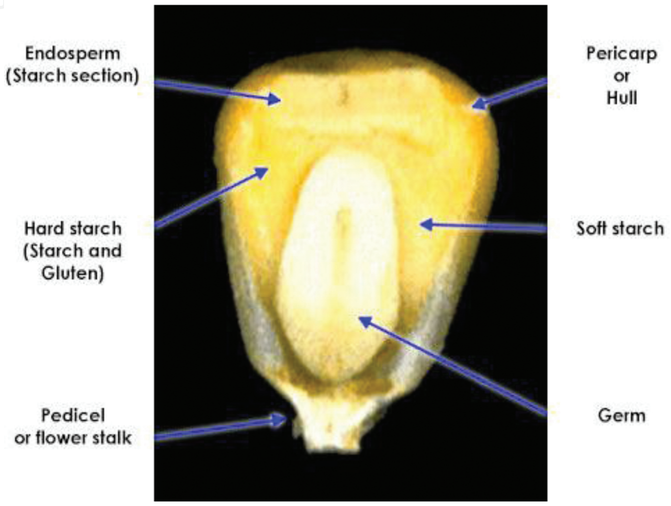

Figure 3. Structure of maize kernel (source: www.fao.org).

	Starch	Protein	Oil	Sugar	Ash (minerals)
Whole grain	73.4	9.1	4.4	1.9	1.4
Endosperm	87.6	8.0	0.8	0.6	0.3
Germ	8.3	18.4	33.2	10.8	10.5
Pericarp	7.3	3.7	1.0	0.3	0.8
Tip cap	5.3	9.1	3.8	1.6	1.6

Table 2. Chemical composition of normal maize grain and grain fractions (%DM) [14].

3.1. Carbohydrate content of maize grain

The relative proportions of the various carbohydrates are 77% starch, 2% sugars, 5% pentosans [15] and 1.2% crude fibre [16]. The carbohydrate which forms more than 70% of the maize grain [15] is concentrated in two starchy fractions, floury and flinty, of the endosperm. The sugar in the grain is found in the germ and dietary fibre is in the bran [13].

The endosperm consists of starch granules embedded in a protein matrix. Flinty endosperm has a more rigid protein structure and is also higher in protein content than floury endosperm

[13, 17]. The starch in the flinty endosperm consists of 100% amylopectin (large branched molecules), whereas that in the floury endosperm comprises about 27% amylose (linear molecules) and 73% amylopectin [16]. This variation in starch structure does not have any effect on the nutritional value of maize for poultry [2]. The distribution of flinty or floury endosperms in the maize grain determines whether a maize variety is classified as flint or floury (dent) maize. The starch which is the main source of energy in the grain has a digestible energy content ranging from 3.75 to 4.17 kcal/g dry matter [18], thereby making maize one of the highest in energy among the cereal grains (**Table 3**).

Cereal	Gross energy (MJ/kg DM)	Metabolisable energy (MJ/kg DM)
Barley	18.3	13.7
Sorghum	18.8	13.4
Maize	19.0	14.2
Millet	18.7	11.3
Wheat	18.4	14.0
Oats	19.0	11.5

Table 3. Gross and metabolisable energy of cereals [19].

The crude fibre content of maize grain averages about 2.7% of dry matter [20]. The crude fibre interferes with nutrient availability of the grain [21]. For instance, the range of protein digestibility of maize is 83–90% [21], while digestibility of carbohydrate is 99% [22]. Nevertheless, the maize grain is highly digestible due to its low crude fibre content [16].

3.2. Lipid content of maize grain

Maize oil (**Table 4**) is good quality oil both from nutritional standpoint (**Table 5**) and in terms of cooking quality [13]. Another desirable property of maize oil is its very low concentration of linolenic acid and high level of natural antioxidants [13, 23], thereby making the grain less susceptible to rancidity in storage.

Fatty acids	Structure[a]	Amount (%)
Palmitic	16:0	11.0
Stearic	18:0	3.0
Oleic	18: 1	43.4
Linoleic	18:2	41.8
Linolenic	18:3	0.6

[a] Number of carbon atoms: number of unsaturated bonds.

Table 4. Concentration of fatty acids in maize oil triglycerides [23].

Grain fraction	Starch	Protein	Oil	Sugar	Ash
Endosperm	97.8	73.8	15.4	28.9	17.9
Germ	1.5	26.2	82.6	69.3	78.4
Pericarp	0.6	2.6	1.3	1.2	2.9
Tip cap	0.1	0.9	0.8	0.8	1.0

Table 5. Proportion of chemical constituents contained in each fraction of normal maize grain (% DM basis) [14].

The maize grain is a fair source of alpha-tocopherol (Vitamin E) which ranges from 0.6 to 2.1 mg/100 g grain [24]. Most of the carotenoids found in maize lipid are xanthophylls which are present only in yellow maize grain, and form about 12,511 mg/100 g grain [25]. Yellow maize, therefore, is one of the best sources of pro-retinal carotenoids [17]. These pigments cause yellow colouration of shanks and skin of broilers and yolks of eggs [26]. However, the pigmented grain tends to colour the carcass fat, which in the United Kingdom is not considered desirable [16].

3.3. Protein content of maize grain

The maize grain is deficient in protein, but its variability is low with standard error of the order 7 g/kg of crude protein [2]. The protein content of maize grain ranges from 8 to 11 g/100 g grain of dry matter [14, 23, 27]. The various fractions of grain vary considerably in protein content (**Table 5**). Even though the majority of protein in the grain occurs in the endosperm, the germ (184 g/kg DM) is considerably higher in protein content than the endosperm (80 g/kg DM) [14].

Generally, the low protein content of the grain limits its nutritive value as the only source of food for both humans and livestock.

The amino acid composition of whole maize grain is determined by both the relative proportions of the various protein fractions and the amino acid composition of each fraction [21]. Maize grain endosperm proteins are usually referred to as albumins, globulins, prolamins and glutelins, depending on their solubility in different solvent systems [21]. Prolamins and glutelins (also referred to as storage proteins) are confined to the endosperm, whereas albumins and globulins (also referred to as water-soluble proteins) are also found in the aleurone layer and the germ. The proportion of each protein fraction is presented in **Table 6**. In normal maize grain, the prolamin content exceeds that of glutelin and represents about 50–60% of the total protein [21]. Each protein fraction tends to have a characteristic amino acid composition (**Table 7**), and the relative proportion of each fraction strongly affects the level of individual amino acids in the total grain protein [28]. Prolamins are most deficient in lysine, thereby rendering maize protein poor in terms of nutritional quality. The general deficiency of lysine in maize grain is essentially the consequence of its low content of albumin and globulin, which besides having high lysine content exhibit a well-balanced amino acid composition similar to that of animal proteins of superior nutritional value [21]. Moreover, maize prolamins are characterised by larger quantities of leucine than isoleucine, thus causing the typical amino acid imbalance that further reduces the protein quality of maize [29].

Protein fraction	Amount (g/100 g protein)
Salt-soluble fraction (including NPN), i.e. albumins and globulins	6
Alcohol-soluble fraction (in the presence and absence of reducing agents), i.e. prolamins	64
Acid or alkali-soluble fraction (in the presence of reducing agents and nonextractable N), i.e. glutelins and residue	30

NPN, nonprotein nitrogen; N, Nitrogen.

Table 6. Protein fractions of normal maize [21].

	Protein fractions		
Amino acid	**Albumin+globulin**	**Prolamin**	**Glutelin**
Isoleucine	3.9–4.6	4.4–4.4	4.9–5.0
Leucine	5.4–6.4	20.3–20.5	9.4–10.1
Lysine	6.1–6.3	0.1–0.2	6.4–7.0
Cystine	0.3–1.6	0.1–0.7	0.2–0.5
Methionine	1.7–2.5	1.9–2.2	2.4–4.0
Tyrosine	2.8–4.5	5.5–6.1	2.4–2.7
Phenylalanine	2.4–4.2	7.8–8.0	5.3–5.6
Threonine	4.2–5.3	3.4–3.4	4.2–5.2
Valine	4.7–6.2	4.1–4.2	7.0–7.1

Table 7. Essential amino acid compositions of the endosperm protein fraction of normal maize (g/16 gN) [21].

The real significance of the poor nutritional quality of maize protein, therefore, is that the other food components of the diets of livestock and human may fail to provide adequate amounts of essential amino acids, particularly lysine to offset the nutritional deficiencies of maize protein [30].

3.3.1. Ways of improving the protein quality of maize

Although maize grain is relatively low in total protein and generally low in lysine and tryptophan, these shortcomings can be overcome by appropriate blending with animal products or legumes or oilseed products. The most obvious result of such blending is that the mixture is higher in protein than the maize component alone. Beyond this, animal products, legumes and various oilseed cakes improve the quality of maize protein by supplementing them with limiting amino acids such as lysine and tryptophan. This is called protein supplementation [31]. On the other hand, legumes and some oilseed cakes, which are deficient in methionine, can be supplemented by maize grain, which is not deficient in this amino acid. Such mutual balancing of each other's amino acids is known as protein complementation [31].

Besides, the quality of maize protein can be improved by the addition of synthetic amino acids like lysine. It also appears that a consistent enrichment of the nutritional quality of maize protein can be accomplished by developing new cultivars with a reduced content of prolamins with a parallel increase in glutelins and salt-soluble protein [21].

3.3.1.1. Protein supplementation of maize-based diets

Protein supplementation consists of adding small amounts of proteins which are rich sources of the amino acids deficient in normal maize [31]. Various protein supplements that have been tested on rats [32] include fish protein concentrate, soyabean flour, cottonseed flour, torula yeast, casein and egg protein. The recorded protein efficiency ratio values were normal maize (1.00), fish protein concentrate (2.44), soyabean flour (2.25) cottonseed flour (1.33), torula yeast (1.97), casein (2.21) and egg protein (2.24). This effect on protein quality was attributed to the contribution that the protein supplements made in lysine, tryptophan and protein content.

It has been reported that the supplementation of maize with soyabean flour increased usable protein from about 2.5% for maize alone to 10.6% when 20% of the soyabean flour was included in the diet for children [33, 34].

3.3.1.2. Protein complementation

Protein complementation comprises various food mixtures of maize with other ingredients of plant origin which are higher in protein quality and protein content [33, 35, 36]. One example of the favourable effect of protein complementation was established in rats [37].

Mixtures of cornflour and soyabean flour were fed to rats, and their weight gains per gram of protein consumed (protein efficiency ratio) were measured. Optimum results were obtained with the 40% cornflour and 60% soyabean flour ratio. With less soyabean flour in the mixture, lysine became limiting, but with more soyabean flour in the mixture, methionine was limiting (**Table 8**).

	Amino acid content (g/16 gN)			
Maize:soyabean protein ratio	**Lysine**	**Total sulphur amino acids**	**Tryptophan**	**Protein efficiency ratio**
100:0	2.88	3.15	0.60	1.6
80:20	–	–	–	2.3
60:40	–	–	–	2.7
40:60	4.95	3.14	1.07	2.9
20:80	–	–	–	2.8
0:100	6.32	3.12	1.38	2.6

Table 8. Complementation effects in rats fed combinations of soyabean flour and whole normal maize flour at a constant level of dietary protein [37].

The nutritive values of vegetable mixtures comprising 38% cottonseed flour plus 58% maize flour, 38% soyabean flour plus 58% maize flour, and 19% cottonseed flour plus 19% soyabean flour plus 58% maize flour with milk and egg proteins were compared in children [37]. The researchers reported biological values of the vegetable mixture which were close to those of high-quality reference proteins, milk and egg. The biological values registered were: milk (69%), egg (64%), soyabean plus maize (63%), cottonseed plus soyabean plus maize (53%) and cottonseed plus maize (50%). For normal maize alone, the biological value was 31%.

3.3.1.3. *Amino acid supplementation of maize-based diets*

The addition of synthetic amino acids such as L-Iysine and L-tryptophan either singly or in combination with maize-based diets to improve their protein quality has been demonstrated in feeding studies involving rats [38], pigs [39, 40], humans [34, 41] and poultry [42]. In all these trials, these amino acids have been found to improve protein quality of normal maize-based diets. **Table 9** shows substantial improvement in protein quality of normal maize-based diets supplemented with amino acids.

Amino acid added (g/kg)	Protein efficiency ratio of normal maize
None	1.21
Lysine (3), (1)	1.51
Tryptophan (0.5)	1.18
Lysine, tryptophan (3, 0.5); (1, 0.5)	2.66
Lysine, tryptophan, isoleucine (3, 0.5, 2.5)	2.58
Lysine, tryptophan, threonine (3, 0.5, 2)	2.56

Table 9. Biological confirmation of essential amino acid deficiencies in normal maize [43].

3.4. Vitamin content of maize grain

Vitamins in maize grain are concentrated mainly in the aleurone layer and the germ [13]. Analysis of the vitamin content of maize (**Table 10**) indicates that the grain furnishes significant quantities of riboflavin, panthothenic acid, choline and pyridoxine which are sufficient to satisfy the requirements of most livestock [44]. However, the most significant feature of the vitamin pattern in maize is the low niacin content. Besides, much of niacin that occurs in the grain is in a bound form (niacytin), which is not available to monogastric animals [13].

Furthermore, the high level of the essential amino acid, leucine, in the maize grain increases niacin requirement in humans [45]. Thus, people who live only on a diet of maize suffer from the disease pellagra, associated with niacin deficiency [6]. Nevertheless, niacin shortage alone would not cause pellagra if normal maize were rich in tryptophan [46] or heat-treated with alkali [30]. One approach for improving niacin intake in maize-based diet is complementation with either legumes or animal products [13].

Vitamin	Concentration (g/kg)
Carotene	4.6
Vitamin E	0.46
Thiamine (B_1)	4.83
Riboflavin (B_2)	1.61
Nicotinic acid	25.29
Pantothenic acid	6.44
Pyridoxine (B_6)	8.74
Choline	655.17

Table 10. Vitamin content of normal maize [16].

Yellow maize shows vitamin A activity, whereas white maize does not [47]. The vitamin A potency of yellow maize results primarily from the presence of carotenes in the grain. The carotene content of yellow maize is 0.46 mg/100 g of grain [16].

The occurrence of vitamins mainly in the aleurone layer and the germ implies that food preparations that do not retain these parts of the grain further decrease vitamins in the diet.

3.5. Mineral content of maize grain

The inorganic or mineral component (ash) of maize grain constitutes less than 2% [15]. Of this, about 75% is found in the germ. The grain is most abundant in phosphorus and potassium, but deficient in calcium and trace minerals except iron (**Table 11**). Much of the phosphorus, however, is present in the form of phytic phosphorus which is not digested by monogastric animals [48]. The little calcium that is normally present also has low bioavailability [13] because it forms complexes with phytic phosphorus.

Mineral	Concentration (mg/100 g)
Calcium	6.0
Phosphorus	300.0
Magnesium	160.0
Sodium	50.0
Potassium	400.0
Chlorine	70.0
Sulphur	140.0
Iron	2.5
Manganese	6.8
Copper	4.5

Table 11. Mineral content of normal maize grain [15].

3.6. Moisture content of maize grain

A moisture content of 10–14% is typical of properly ripened and dried maize grain [9]. The grain, therefore, furnishes a very high amount of dry matter. A moisture content of the grain higher than this may enhance the growth of moulds and cause the grain to rot in storage. Some of these moulds produce toxic metabolites like aflatoxins which can cause disease in humans and animals consuming the grain [9].

4. Factors affecting the chemical composition of maize grain

The factors that generally influence the chemical composition of maize grain are either genetic or environmental.

4.1. Genetic factors

Varieties of maize have been developed through breeding that contain up to 21% crude protein [49, 50–52]. However, maize varieties having more than 12% crude protein do have somewhat lower yields [51, 53], thus not suitable for commercial production.

New varieties of maize collectively called "high-lysine maize" contain nearly double the percentages of lysine and tryptophan of normal maize, even though the two types of maize are similar in overall protein content [6].

Maize varieties also differ in niacin content. For instance, inbred lines of dent maize have niacin content ranging from 13.9 to 53.3 μg/g of grain [44], whereas hybrids tend to be intermediate between their parent lines in concentration of this vitamin. Maize grain with a sugary endosperm had niacin content higher than that of waxy maize grain, which in turn had more niacin than dent grain [54].

The oil content of maize grain is largely characteristic of the particular variety. Breeding for high oil maize gave rise to strains of maize containing up to 20% oil in the grain [24, 55]. The existence of low oil maize varieties with average oil content of 1% [56] has been reported.

4.2. Environmental factors

Soil nitrogen appears to be the critical environmental factor that affects the protein content of maize [44]. Excess soil nitrogen beyond that required for maximum growth of the plant may increase the protein content of the grain [44]. It is reported that heavy application of nitrogen and phosphate fertilisers increased the thiamine content but decreased the level of niacin in maize grain [49].

Production year (rainfall and temperature) and location are often responsible for variation in the protein content of maize grains of the same variety of maize [52, 57, 58].

5. Maize grain as animal feed

As livestock feed, it is the grain that is most important. The stalks, leaves and immature ears are used as forage for ruminants [44]. Maize grain is recognised as giving the highest conversion of dry matter into meat, milk and eggs in relation to other cereal grains [13]. It is used extensively as the main source of calories in the feeding of poultry, pigs and cattle [6].

Maize grain has a digestible energy content of 3.75–4.17 kcal/g [18]. For chicken and pigs, the metabolisable energy values recorded when maize was fed were 3.6 and 3.8 kcal/g, respectively [18, 59], and corresponding gross energy digestibilities were 86% in chickens and 92% in pigs [18]. Maize, therefore, is popular for feeding monogastric animals, particularly poultry. For instance, maize is the basis of the high-energy poultry rations that are recognised throughout the United States whenever "broilers" are fattened [60].

In the feeding of poultry, maize grains are either fed directly or are milled and compounded with other ingredients and thoroughly mixed. The mixture is then fed or converted into forms most desired by specific animals.

The by-products obtained from both wet-milling and dry-milling industrial processes of maize grain are potential feed ingredients for poultry [12, 61–63] as depicted by the favourable nutrient composition of these by-products (**Table 12**) particularly in terms of protein content. The major by-product ingredients include the germ, bran and gluten [64]. These by-products of maize are usually mixed to produce a feed ingredient called maize gluten feed [62]. Despite the nutritional potential of maize gluten feed as a feedstuff for poultry, its use has been minimal due variously to paucity of research information available [65], perceived low metabolisable energy content [12, 66] and unknown quality of the protein [12] even though the protein content is fairly high.

	Moisture	**Ash**	**CP**	**CF**	**EE**	**NFE**	**Ca**	**P**
Maize feed meal	10.8	1.9	10.5	2.9	5.5	68.6	0.04	0.38
Maize bran	10.0	2.1	10.0	8.8	6.6	62.5	O. 03	0.14
Maize germ meal	7.0	3.8	20.8	7.3	9.6	51.5	0.05	0.59
Maize gluten meal	8.0	2.2	43.0	3.7	2.7	40.4	0.1	0.47
Maize gluten feed	9.5	6.0	27.6	7.5	3.0	46.4	0.11	0.78
Maize oil meal	8.7	2.2	22.1	10.8	6.8	49.4	0.06	0.62

Table 12. Chemical composition (%) of feedstuffs from maize and maize by-products [67].

6. Nutritionally improved maize grain

It has been known since 1914 that the quality of maize proteins is poor because they are deficient in the essential amino acids, lysine and tryptophan [38]. These deficiencies were attributed to the high zein fraction of maize protein in the maize grain of most varieties [68, 69]. Results obtained from extensive studies of zein indicated that it contains very low levels of lysine and tryptophan [70, 71]. Several researchers studied the factors that affected the protein quality of maize and reported that both the variety of maize and the environment had in several cases, a significant effect on lysine content [69, 72, 73]. It has been shown that the *opaque-2* gene in maize caused a genetic increase in lysine concentration of maize protein [74]. These researchers further reported that the lysine increment in *opaque-2* maize was the result of a change in the distribution of endosperm protein fractions, of which the *opaque-2* maize contained approximately 22% zein compared with 50% zein in normal maize. Chemical analysis of maize protein for amino acids [74–76] showed that *opaque-2* maize contained 60–130% more lysine than did normal maize, plus a 12–40% reduction in leucine as well as elevated level of tryptophan. Since these findings, several other mutant genes of maize have been identified. Collectively designated "high-lysine" genes, all of them control the level of zein accumulation during endosperm development. These "high-lysine" genes include most importantly *floury-2* [77]; *opaque-7* [78]; *opaque-6* and *floury-3* [79]. Of these genes, *opaque-2* has proven superior in zein reduction [80, 81].

The development of these nutritionally improved maize varieties is of particular significance to those who rely on maize as basic food and animal feed, and can thereby improve such diets nutritionally at no added cost.

6.1. Shortcomings of *opaque-2* gene as tool for improving protein quality in maize

Although the *opaque-2* gene favourably alters the amino acid spectrum in maize, it has several shortcomings that limit its widespread commercial use.

6.1.1. Grain yield

In general, *opaque-2* maize varieties have 10–15% lower grain yields than do normal maize varieties [82, 83]. Besides, *opaque-2* maize grain is 10–15% lighter in kernel weight [82, 83]. The lower grain weight can be attributed to loose packing of starch particles in the endosperm [84].

6.1.2. Moisture content of grain

Mature *opaque-2* maize grains are higher in moisture content by 1.8–4.2% than their comparable normal maize grains [80, 82]. Higher moisture content of the grains requires additional drying after harvest.

6.1.3. Grain appearance

Opaque-2 maize kernels are chalky and dull in contrast to the hard and shiny kernels of normal maize varieties [6]. The soft endosperm in *opaque-2* grains coupled with the dull appearance restricts acceptance by farmers, millers and consumers.

6.1.4. Susceptibility of grains to pests and diseases

Opaque-2 maize grains have been found to be more vulnerable to attack by *Sitophilus oryzea* [85] than normal type grains, in terms of both infestation and loss in weight of grains. *Opaque-2* varieties have also been reported to be more susceptible to *Chilo zonellus* [86]. Besides, *opaque-2* grains are more susceptible to seed rot caused by fungi such as *Cephalosporium acremonium and Fusarium moniliform* [87].

7. Development of quality protein maize (QPM)

Extensive field trials have been carried out at the International Center for Maize and Wheat Improvement (CIMMYT) in Mexico to identify the most productive *opaque-2* maize cultivars which are high in lysine and tryptophan contents as well as to change the soft endosperm in *opaque-2* grain into a conventional hard vitreous type [88–90]. Through backcrossing and several cycles of recurrent selection of maize, CIMMYT's maize breeders have successfully combined the high-lysine potential of the *opaque-2* gene with genetic endosperm modifiers. These new genotypes, collectively called "quality protein maize" (QPM), are becoming of major interest to seed producers, breeders, geneticists and industrialists for their large-scale production and for their potential advantages in human nutrition and animal feeding. The QPM grains are indistinguishable from normal types except by chemical analysis [6].

QPM cultivars retain the protein quality of conventional *opaque-2* maize but have improved agronomic traits, notably high yields and hard grain endosperm [6, 23, 81, 90–92].

Several experimental QPM cultivars yielded grains equal to those of the latest experimental releases of normal maize [6, 81, 90–92] in several regions of the world. Mexican QPM cultivars tested at more than twenty locations around the world have shown yields fully comparable to those of normal maize [93].

QPM grains are shiny, transparent and as hard as those of normal maize [6, 23, 94]. The QPM grain now has mostly the same density as that of normal maize, 1.29 g/cm^3 [6]. Grain sizes of both QPM and normal maize are similar [6]; however, some of the new QPM hybrids have a grain size greater than that of normal maize [23].

The moisture content of QPM grains at harvest is essentially identical to that of normal maize [6, 91]. On average, the QPM cultivars show higher incidence of ear rots but not disastrously so in humid regions [6]. Apart from ear-rotting organisms, other maize diseases seem to attack both QPM and normal maize with comparable severity [6].

As a result of the hard endosperm of QPM grains, the excessive incidence of broken grains and the accompanying storage damage have been eliminated. Thus, insect infestation is reduced and no worse than in normal maize [6].

7.1. Nutrient levels in QPM

The nutrient composition of QPM is similar to that of normal maize with the exception of lysine, tryptophan, leucine and isoleucine contents [6]. The protein content of QPM grains ranges from 7.4% to 10.5% of dry matter [23, 81, 90, 95–97], which is about the same as that of normal maize [6, 81].

The lysine and tryptophan contents of QPM grains are about twice those of normal maize. There is also reduced imbalance between isoleucine and leucine. The grains of most available QPM cultivars contain on the average 3.5–4.5% lysine of total protein in the grain [6, 81]. Also, the lysine content of the gluten of QPM grains is higher than that of normal maize grains [23].

The starch yielded by QPM grains is comparable to normal maize grains [98]. Starch contents of 56.6% grain for QPM and 55.0% grain for normal maize have been reported [23].

The fat content of QPM grains ranges from 3% to 7% [23, 94, 99]. Of the triglycerides, QPM grains contain significantly more palmitic acid and linoleic acid than normal maize grain but less of stearic, oleic and linolenic acids [23]. Yellow grain types of both QPM and normal maize contain similar levels of carotenoids [6].

8. Evaluation of protein quality of nutritionally improved maize

Many nutritional studies have demonstrated the benefits for monogastric animals of the high protein quality of nutritionally improved maize varieties collectively called "high-lysine maize" (of which *opaque-2* maize and QPM are outstanding) as compared with normal maize.

A summary of nitrogen balance studies with weanling rats to evaluate the protein quality of normal maize, *opaque-2* maize and QPM is presented in **Table 13**. The data indicate that *opaque-2* maize and QPM show significantly higher nutritional values than normal maize. The nutritional values are similar for *opaque-2* maize and QPM. The high efficiency of protein utilisation of high-lysine maize is explained on the basis of its good protein quality [95, 99–101].

Maize variety	Lysine (g/kg protein)	Biological indicator of nutritional quality			
		True digestibility (%)	Biological value (%)	Net protein utilisation (%)	Protein efficiency ratio
Normal maize[a]	27	–	62	55	1.5
Opaque-2 maize[a]	45	–	87	70	2.8
Normal maize[b]	–	–	–	–	1.6
Opaque-2 (soft)[b]	–	–	–	–	2.8
Opaque-2 (hard)[b]	–	–	–	–	2.9
Normal maize[c]	26	98	63	62	–
Opaque-2 maize	42	96	78	75	–
QPM[c]	40	97	76	74	–
Normal maize[d]	23	–			0.7
QPM[d]	36	–	–	–	1.3

Sources: [a]Bressani et al. [100];
[b]Mertz et al. [101];
[c]Villegas et al. [95];
[d]Ahenkorah et al. [99].

Table 13. Nutritional evaluation in rats of normal maize, *Opaque-2* maize and QPM.

Numerous feeding trials were carried out on rats to study the effect of protein quality of normal maize, *opaque-2* maize and QPM on weight gain, feed intake as well as efficiency of feed utilisation. Some of the published work are summarised in **Table 14**. These growth studies highlighted the superior feed value of QPM over normal maize. One of the nutritional benefits of improved protein quality of maize is a higher food intake from diets made up of the high-lysine maize as compared with normal maize diets [30]. This is because a diet of good protein quality stimulates food intake and a higher diet intake raises calorie intake [36, 100]. Also, efficiency of feed utilisation by rats fed high-lysine maize is better than for normal maize indicating the superior quality of high-lysine maize. The performance of rats fed high-lysine maize was only slightly lower than that observed for their counterparts fed casein (**Table 14**).

Diets	Average gains (g)	Average feed intake (g)	Feed/gain	Sources
Normal maize	25^a	248^a	9.92^a	[100]
Opaque-2 maize	130^b	455^b	3.50^b	
Casein	132^b	408^b		
Normal maize	50^a	211^a	4.22^a	[102]
Opaque-2 maize	122^b	281^b	2.20^b	
Normal maize	15^a	131^a	9.4^a	[103]
QPM	27^b	162^b	7.0^b	
Normal maize	9^a	115^a	12.78^a	[99]
QPM	18^b	154^b	8.56^b	
Casein	28^c	156^b	5.57^c	

Values in the same column with different superscripts are statistically different (P<0.01).

Table 14. Comparative average weight gains, average feed intakes and feed conversion efficiencies in rats fed normal maize, high-lysine maize and casein.

8.1. Evaluation of nutritionally improved maize in poultry diets

In initial studies with young chicks [104, 105], only slight differences in growth rate and feed conversion efficiency of chicks fed *opaque-2* maize in place of normal maize in maize-soyabean meal diet which contained a dietary protein level of 15%. However, when a deficiency of the first limiting amino acid in this type of diet, methionine was corrected by supplementation, significantly better gains and feed conversions were observed with *opaque-2* maize as compared with normal maize. Since supplementation of normal maize diets with lysine up to the level in *opaque-2* maize diets resulted in equal performance, it was concluded that the beneficial effects of *opaque-2* maize over normal maize were mediated solely through the higher lysine content of *opaque-2* maize. Analyses of plasma amino acids revealed higher lysine levels in chicks fed *opaque-2* maize as compared with chicks fed normal maize. It was reported that chicks given high-lysine maize diets at a dietary protein level of 15% out-performed their counterparts fed normal maize diets at the same dietary protein level [106]. Again, it was found that *opaque-2* corn had higher nutritive value than normal corn as determined in modified chick bioassay of protein efficiency ratio [107].

Other reports that demonstrated the superior feeding value of high-lysine maize are summarised in **Tables 15–17**. Also, it was reported that chicken fed QPM exhibited improved growth rate by 20% as compared with those fed normal maize [92]. The data showed that there was no response to tryptophan supplementation of high-lysine maize. This means that the amount of tryptophan in high-lysine maize is sufficient to meet the requirements of chicks. On the other hand, a significant response is obtained when normal maize is supplemented with tryptophan. Thus, high-lysine maize is superior to normal maize not only for its higher lysine content but also for its higher tryptophan content. Furthermore, there is positive response to methionine supplementation of high-lysine maize as previously reported [104, 105], making the protein quality of the high-lysine maize superior to normal maize for the chick. In addition, the results from the substitution of high-lysine maize protein for soyabean or fishmeal protein indicate that high-lysine maize protein is comparable in quality to that of fishmeal or soyabean meal for the chick. Another interesting observation from these data is that lysine supplementation of high-lysine maize diets resulted in improved performance comparable to that of chicks fed control diets. This indicates that high-lysine maize alone is not adequate as a sole source of protein or lysine for chicks [6].

		Two-week-old chicks	
Source of protein	**Protein level (%)**	**Average body weight (g)**	**Protein efficiency ratio**
Basal protein+SBM	14	124.7^{a}	2.99^{a}
Basal protein+NM	14	77.7^{d}	2.31^{c}
Basal protein+OP (hard)	14	81.6^{c}	2.45^{b}
Basal protein+OP (soft)	14	92.2^{b}	2.81^{a}
Basal protein+Fl-2	14	81.2^{c}	2.46^{b}
BP+SBM+Lys (3 g/kg)	14	122.8^{c}	3.24^{a}
BP+NM+Lys (3.2 g/kg)	14	86.6^{c}	2.74^{c}
BP+OP (hard)+Lys (3 g/kg)	14	114.0^{a}	3.20^{a}
BP+OP (soft)+Lys (2 g/kg)	14	116.0^{a}	3.15^{ab}
BP+Fl-2+Lys (8 g/kg)	14	98.5^{b}	2.94^{b}

BP: basal protein; Fl-2: *floury-2* maize; OP: *opaque-2* maize; SBM: soyabean meal; Lys: lysine. Basal protein: mixture of animal and vegetable proteins of good balance providing 8% protein. Values with the same superscripts are not significantly different from each other (P<0.05).

Table 15. Comparative bodyweights and protein efficiency ratios of chickens fed normal maize and high-lysine maize [101].

Source of protein	Protein level (%)	Weight gain (g)	Feed/gain ratio	Source
Normal maize+safflower meal	20	173^{c}	2.74^{c}	[106]
Opaque-2+safflower meal	20	215^{b}	2.25^{b}	
Normal maize+soyabean meal	20	472^{a}	1.46^{a}	[106]
Normal maize+167.3 g/kg soyabean meal	15	300^{c}	1.86^{c}	
Opaque-2+I 67.3 g/kg soyabean meal	15	413^{b}	1.64^{b}	
Opaque-2+77.1 g/kg soyabean meal	15	293^{c}	1.83^{c}	
Opaque-2+214.5 g/kg soyabean meal	20	480^{a}	1.38^{a}	
Normal maize+289.6 g/kg soyabean meal	20	498^{a}	1.40^{a}	
QPM	9.7	708^{b}	4.28^{b}	[108]
Normal maize	9.7	532^{c}	6.55^{c}	
Normal maize+fishmeal	1.8	2017^{a}	2.30^{a}	
Normal maize+I 95 g/kg fishmeal	21	2149	2.60	[108]
QPM+195 g/kg fishmeal	21	2189	2.60	
QPM+175 g/kg fishmeal	20	2229	2.55	
QPM+155 g/kg fishmeal	19	2140	2.70	
QPM+135 g/kg fishmeal	18	2140	2.80	
Opaque-2+soyabean meal	22	390.2^{c}	1.74^{b}	[109, 110]
Opaque-2+soyabean meal	18	373.2^{b}	1.83^{c}	
Opaque-2+soyabean meal	14	320.5^{a}	2.09^{d}	
Normal maize+soyabean meal	22	411.5^{d}	1.64^{a}	
Normal maize+soyabean meal	18	372.8^{b}	1.79^{bc}	
Normal maize+soyabean meal	14	329.7^{a}	2.09^{d}	
NM+SBM	21	465	1.49	
OP+SBM	21	459	1.51	
NM+SBM	19	438	1.57	
OP+SBM	19	422	1.58	
NM+SBM	17	407^{a}	1.67^{a}	
OP+SBM	17	371^{b}	1.72^{b}	
NM+SBM	15	329	1.85^{a}	
OP+SBM	15	332	1.81^{b}	[104]
NM+SBM+Met	21	458	1.40	
OP+SBM+Met	21	468	1.39	
NM+SBM+Met	18	412	1.52	
OP+SBM+Met	18	428	1.48	
NM+SBM+Met	15	286^{a}	1.84^{a}	
OP+SBM+Met	15	369^{b}	1.64^{b}	

Source of protein	Protein level (%)	Weight gain (g)	Feed/gain ratio	Source
NM+SBM	20	451	1.45	
OP+SBM	20	463	1.42	
NM+SBM+amino acid	20	455	1.41	
NM+SBM	16	359^{a}	1.76^{a}	
OP+SBM	16	423^{b}	1.58^{b}	
NM+SBM+amino acid	16	412^{b}	1.59^{b}	
NM+SBM	12	163^{a}	2.57^{a}	
OP+SBM	12	243^{b}	2.07^{b}	
NM+SBM+amino acid	12	255^{b}	2.09^{b}	

NM: normal maize; SBM: Soyabean meal; OP: *Opaque-2* maize; Met: methionine. Values with the same superscripts are not significantly different from each other (P<0.05). Not significant (P> 0.05).

Table 16. Comparative weight gains and feed/gain ratios of chickens fed normal maize and high-lysine maize at 3 weeks or 8 weeks of age.

Source of protein 2	Protein level (g/kg)	Weight gain (g)	Feed/gain ratio	Source
Normal maize+soyabean meal+methionine (0.2%)	200	481^{a}	1.40^{a}	[106]
Normal maize+safflower meal+methionine (0.19%)	200	158^{c}	2.92^{c}	
Normal maize+safflower meal+Lys+methionine (0.19%)	200	483^{a}	1.53^{a}	
Opaque-2+safflower mal+methionine (0.44%)	200	$2I4^{b}$	2.11^{b}	
Opaque-2+safflower meal+Lys+methionine (0.14%)	200	487^{a}	$l.52^{a}$	
Normal maize+safflower meal+Met (0.26%)	200	145^{d}	2.55^{a}	[106]
Opaque-2+safflower meal+Met (0.25%)	200	211^{c}	2.15^{a}	
Opaque-2 safflower meal+Met (0.26%)+Lys (0.15%)	200	364^{a}	$l.78^{b}$	
Normal maize+safflower meal+Met (0.25%)+Lys (0.15%)	200	270^{b}	$l.92^{b}$	
Normal maize+safflower meal+Met (0.20%)+Lys (0.14%)	150	163^{c}	2.44^{a}	
Opaque-2+safflower meal+met (0.13%)+Lys (0.18%)	ISO	282^{b}	1.99^{b}	
Opaque-2(0. 89 g/kg tryptophan)	95	129^{a}	3.27^{a}	[111]
Opaque-2+0.95 g/kg tryptophan	95	134^{a}	3.09^{a}	
Opaque-2+1.31 g/kg tryptophan	95	138^{a}	2.99^{a}	
Opaque-2+2.00 g/kg tryptophan	95	131^{a}	3.09^{a}	
Norma1 maize (0.59 g/kg tryptophan)	95	83^{d}	4.24c	
Normal maize+0.95 g/kg tryptophan	95	115^{bc}	3.54^{a}	
Normal maize+1.31 g/kg tryptophan	95	127^{a}	3.21^{a}	
Normal maize+2.00 g/kg tryptophan	95	103^{cd}	3.82^{b}	
Opaque-2+sesame meal (0.97 g/kg tryptophan)	120	180*	2.43*	[111]
Opaque-2+sesame meal+1.20 g/kg tryptophan	120	162	2.62	

Source of protein 2	Protein level (g/kg)	Weight gain (g)	Feed/gain ratio	Source
Opaque-2+sesame meal+1.50 g/kg tryptophan	120	181	2.46	
Opaque-2+sesame meal+2.00 g/kg tryptophan	120	183	2.38	
Normal maize+sesame meal+(0.69 g/kg tryptophan)	120	146	2.84	
Normal maize+sesame meal+120 g/kg tryptophan	120	169	2.59	
Normal maize+sesame meal+1.50 g/kg tryptophan	120	166	2.63	
Normal maize+sesame meal+2.00 g/kg tryptophan	120	163	2.62	
Normal maize replacement with QPM	~220			[112]
Diet 1 (100:0)		634^{b}	1.45^{a}	
Diet 2 (75:25)		641^{b}	1.38^{b}	
Diet 3 (50:50)		675^{a}	1.34^{c}	
Diet 4 (25:75)		686^{a}	1.35^{c}	
Diet 5 (0:00)		673^{a}	1.35^{c}	
Diet 6 (100:lys)		676^{a}	1.35^{c}	

NM: normal maize; SBM: soyabean meal; OP: *opaque-2* maize; Met: methionine. Values with the same superscripts are not significantly different from each other ($P<0.05$). *Not significant ($P>0.05$).

Table 17. Comparative weight gains and feed/gain ratios for chickens fed normal maize and high-lysine maize at 3 weeks of age.

In summary, the superior performance of chickens fed high-lysine maize has been attributed by all investigators to its higher lysine content and improved balance of essential amino acids.

Table 18 shows that when laying chickens were fed high-lysine maize at suboptimal protein levels, their egg production was significantly higher than that of their counterparts fed normal maize at the same suboptimal protein level. However, at optimal dietary protein levels, similar egg production was recorded. It was suggested that the difference in egg production at suboptimal dietary protein level was due to the higher lysine content of high-lysine maize [109, 110]. An advantage can thus be taken of the high lysine content of high-lysine maize in reducing dietary protein levels, that is, decreasing inclusion level of high protein feedstuffs like soyabean and fishmeal. A study in Ghana [113] found no significant difference in egg production when dietary protein level was reduced from 170 to 140 g/kg in diets in which QPM was incorporated (**Table 18**). Conflicting results have been obtained as to the effect of high-lysine maize on egg weight. Some studies [52, 109, 110, 113] found no significant difference in egg weight of hens fed either high-lysine or normal maize contrary to earlier results reported [106] that hens fed high-lysine maize produced heavier eggs than those fed normal maize. With respect to internal quality of eggs produced, no beneficial effect was reported when high-lysine maize was fed to hens instead of normal maize [52, 109, 110, 113]. Data presented in **Table 18** indicate that at suboptimal dietary protein levels, hens fed high-lysine maize diets utilised feed more efficiently than those fed normal maize diets even though the mean egg weights were similar.

Treatment	Protein level (g/kg)	Hen-day egg production (%)	Feed conversion (kg feed/kg eggs)	Egg weight (g)	Haugh units	Specific gravity	Source
QPM+SBM+Met	110	76.1^{b}	1.48^{ab}	53.8	86.0^{c}	1.0826	[110]
QPM+SBM	140	80.6^{bc}	1.43^{b}	54.1	86.0^{c}	1.0806	
QPM+SBM	170	84.2^{c}	1.40^{b}	55.5	86.7^{c}	1.0815	
MN+SBM+Met	110	64.5^{a}	1.60^{a}	53.0	78.9^{a}	1.0838	
NM+SBM	140	79.3^{bc}	1.49^{ab}	54.2	83.9^{b}	1.0829	
NM+SBM	170	82.7^{bc}	1.45^{b}	54.8	79.8^{a}	1.0838	
NM+SBM (90 g/kg)+Met	115.0	62.0^{a}	1.91^{a}	60.3	81.8	1.0760	[110]
QPM+SBM (90 g/kg)+Met	115.0	71.1^{c}	1.65^{c}	60.8	81.8	1.0748	
QPM+SBM (674 g/kg)+Met	107.6	71.1^{c}	1.70^{b}	62.0	82.3	1.0753	
QPM+SBM (45 g/kg)+Met	115.0	68.1 b	1.75^{b}	59.9	83.6	1.0745	
NM+SBM	144	69.1	2.56^{a}	64.1	–	–	[52]
HPC+SBM	158	70.7	2.35^{b}	64.7	–	–	
NM+fishmeal (120 g/kg)	170	57.9	3.28	55.8	–	–	[113]
QPM+fishmeal (120 g/kg)	170	60.2	3.28	56.2	–	–	
QPM+fishmeal (100 g/kg)	160	55.6	3.59	56.4	–	–	
QPM+fisluneal (85 g/kg)	150	63.5	3.29	55.7	–	–	
QPM+fishmeal (65 g/kg)	140	60.2	3.36	55.5	–	–	
Normal maize 1	150	77.4^{a}	2.06	58.9	87.1	–	[114]
QPM1	150	77.3^{a}	2	58.5	89.6	–	
QPM2	140	72.0^{ac}	2	58	89	–	
QPM3	140	64.3^{b}	1.99	56.5	93.2	–	
Normal maize 2	140	66.8^{b}	2.01	57.7	91.9	–	
Normal maize +0.07%Lysine	150	89.6^{b}	2.15	59.2	97.1	–	[115]
QPM	149.4	91.0^{a}	2.16	59.1	97.4	–	

Values with the same superscripts are not significantly different from each other ($P<0.05$).

Table 18. Comparative performance of laying chickens fed normal maize or high-lysine maize.

9. Future challenges of maize utilisation in poultry diets

The major future challenges confronting maize utilisation in poultry production include the following:

- Adverse effects of climate change on maize production have been reported in tropical and subtropical regions. These include frequent droughts, heat, increased temperature and inadequate rainfall during the growing season and water-logging. It has been estimated that one quarter of the global maize areas is affected by drought in any given year [116].
- Competition between humans and animal agriculture. Maize is increasingly being used for human food and other industrial purposes including biofuel production. Thus, in a world where the global population is continually increasing, the argument that producing feed for livestock conflicts with feeding hungry people is likely to continue for some years [117].
- Some challenges for widespread adoption of QPM in developing countries have been described [118], which include lack of profitable markets for commercial producers and lack of government incentive to encourage adoption by subsidising the price of QPM seed.

10. Conclusion

Normal maize is the most widely used single grain in poultry feeding due to a combination of desirable nutritional characteristics such as high energy, low fibre and easy digestibility. However, its low protein content and deficiencies of the protein in lysine and tryptophan have been a major nutritional concern for feeding poultry. Therefore, improvement in the protein quality of normal maize through the development of a new class of *opaque-2* maize known as "quality protein maize (QPM)" has been a major boost for poultry production, particularly in developing countries, where dietary supplemental protein is either expensive or imported. The benefits of feeding QPM grain to poultry are greater weight gain and more efficient feed conversion as well as less supplemental protein cost.

There are, however, pertinent challenges confronting maize production such as adverse impact of climate change, stiff competition between humans and animal agriculture, and some challenges of widespread adoption of QPM. There is a need to overcome these and other challenges in order to increase cheap meat production to meet the needs of the growing global population.

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