*International Food and Agribusiness Management Review*
*Volume 17 Issue 4, 2014*

# Potential Economic Impact of Biofortified Maize in the Indian Poultry Sector

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## Abstract

The study examines the current feed use in the rapidly-growing Indian poultry sector and evaluates the potential economic impact of using biofortified maize with higher levels of amino acids as feed. Data collected from 185 poultry firms of South India form the empirical base. A significant share of broiler firms were found using amino acids in quantities above the recommended levels with negligible production and negative profitability effects, demonstrating a clear dearth of managerial skill to obtain and utilize information on poultry nutrition. A linear programming model for estimating the least-cost feed formulation showed that the potential economic impact of biofortified maize is limited by the availability of low-cost protein from the alternative sources, and that the potential cost savings from the technology would be marginal. Similar findings were obtained from additional estimation done by relaxing the assumption that the firms have perfect information on feed formulation. Also, lack of awareness of the small-scale firm management regarding poultry nutrition could pose additional challenges in the development of innovative maize-poultry value chains for diffusion of this innovation.

**Keywords:** biofortification; credence good; feed cost; optimization; quality protein

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## Introduction

Growing at a compound growth rate of 15% per annum over the past two decades, India's poultry sector was recently contributing Rs. 350 (US$ 6.3) billion annually to the country's gross national product (PDP 2011). The industry's substantial growth has largely been driven by the demand from the rapidly expanding population of middle-income households and their changing consumption preferences (Gulati et al. 2007). This, in turn, has spurred the domestic production of poultry feed crops, viz., maize and soybean. Maize is the main source of energy in the feed rations of both broilers and layers, while soybean meal provides the required protein (Hellin and Erenstein 2009). More than 50% of the maize produced in India is currently used by the poultry feed sector (Sethi et al. 2009). Since maize grain is a poor source of essential amino acids for poultry (Atlin et al. 2011), many poultry firms are found depending on synthetic amino acid supplements to meet the required dosage of these nutrients. Hence, the development and distribution of biofortified maize – Quality Protein Maize (QPM) and High Methionine Maize (HMM), containing enhanced levels of limiting amino acids – might hold significant economic potential in India.

Previous research and development (R&D) efforts have focused on QPM, a product of biofortification for higher levels of two essential amino acids for human and poultry nutrition – Lysine and Tryptophan. A dozen QPM varieties have been released in India (Agrawal and Gupta 2010), but only five of them are commercially available, and their adoption rates are marginal (Atlin et al. 2011). More recently, plant breeders started developing maize rich in Methionine – the third essential amino acids for poultry and more limiting in terms of nutrition than Lysine or Tryptophan in India. Products of such biofortification are postulated to have significant positive economic impact in the Indian poultry sector by substantially reducing the requirement for synthetic amino acid supplements (Panda et al. 2013, Panda et al. 2010, Prasanna et al. 2001). An earlier qualitative value chain study by Hellin and Erenstein (2009; p 259) flagged some of the associated challenges of biofortified maize as poultry feed and the innate weaknesses in the maize-poultry value chains in India, which include weak linkages between maize farmers and local poultry firms, limited access to improved technology and to channels of information and other business services for small-scale maize and poultry producers, and low prevalence of value chains with both growth and poverty reduction potential.

There are a number of studies documenting the nutritional benefits of QPM over conventional maize (Lauderdale 2000, Sullivan et al. 1989, Asche et al. 1985). In Brazil and El Salvador, the use of QPM as animal feed could reduce the use of soybean meal by about 50%, besides substantially lowering the usage of synthetic Lysine (Lopez-Pereira 1992). Based on the international prices of feed components, and assuming equal prices of QPM and normal maize, Lopez-Pereira (1993) estimated cost-savings from QPM to be about 3-4% for poultry production. A similar study from Kenya reports a 5% cost reduction (De Groote et al. 2010). In China, the effect of replacing normal maize with QPM was found more prominent for pigs than poultry at various growth stages (Sofi et al. 2009). However, these results depend largely on the relative prices of feed components and the efficiency of maize-poultry value chains. Amino acid content of maize grain is inherently a credence attribute along the value chain, including the poultry firm managers – that is, the naked eye cannot easily distinguish the high protein quality, although this could potentially be done through additional lab analysis.

 

The present study primarily aims to estimate the economic benefits of biofortified maize *ex ante* in the Indian poultry production sector. To our knowledge, no such quantitative study has so far been undertaken in the Indian context. The paper is structured as follows. The next section describes the relevance of biofortified maize (QPM and HMM) development in India. The methodology includes the details on data sources and the analytical framework. A linear programming optimization model, which is applied to derive the least-cost combination of feed ingredients with and without biofortified maize available in the market, is explained. The subsequent section analyses and discusses the feed use structure prevailing in the sample poultry firms, and the cost and return impacts of various sources of essential amino acids. The last section concludes.

## Background

The share of poultry in India's total meat production has grown rapidly in the recent past – from 23% in 2004-05 to 51% in 2009-10 (GOI 2011). Poultry is low-cost relative to other meat products, and has comparatively wider acceptability as a food component across regions and religions (Landes et al. 2004). Demand for poultry products is often cross-correlated with demand for maize, an important feed crop (Marsh 2007). Hence, alongside the expansion of the poultry industry, the cultivation of maize has also spread at a rapid pace in India (Sethi et al. 2009, Singh 2001). The relative importance of maize over other cereals was primarily due to its cost-effectiveness. About 7 million tons of maize is produced annually to feed poultry, supporting 20 million maize farmers (Saxena 2009). With the projected figures on poultry sector indicating continuous growth at a similar rate in the coming decade, an estimated 12 million tons of maize would be required for feed by 2020 (PDP 2011), causing significant spill-over effects and welfare impacts on the maize farming community in India.

Six Indian states account for two-thirds of the country's maize production and area under maize cultivation. Four of these are traditional maize growing states located in a horizontal belt across northern/central India: Rajasthan, Madhya Pradesh, Uttar Pradesh, and Bihar; and two are non-traditional maize-growing states in southern India: Andhra Pradesh and Karnataka. Most of the rapid growth in maize production has occurred in the non-traditional states where the crop is a relatively recent arrival and is primarily produced for the (poultry feed) market, with widespread use of hybrid seeds and external inputs. Although poultry producers range from the small-scale "backyard" farmers to "industrial" undertakings, it is the commercial end of the spectrum, particularly in southern India, that has seen the fastest growth in the recent past. The states of Andhra Pradesh and Karnataka have experienced a drastic expansion in poultry production. Together these two southern states account for 19% of the domestic poultry meat and 37% of eggs produced in India (GOI 2011).

Feed is the single largest cost item in commercial poultry production, comprising 55–64% of the variable costs in India (Landes et al. 2004). Maize is typically the main source of energy in commercial poultry. However, the protein profile in normal maize does not adequately cover the essential amino acids which humans and monogastric animals cannot synthesize and have to acquire through diet (Ferreira et al. 2005). The most common source of protein in poultry meal is soybean (Masuda and Goldsmith 2009). In India, this has contributed to a drastic expansion of the soybean production sector – from 2.6 million tons in 1990 to 11.9 million tonnes in 2013 (FAOSTAT 2014) – making the country the fifth largest soy producer in the world (Masuda and Goldsmith 2009).

 

As emerging market economies expand and food consumption patterns change, there will be an increasing pressure on the global markets for the livestock feeds and the prices are expected to soar (Hansen 2012). The international maize and soybean prices have been volatile over the last decade: for example, during the 2004-08 global food inflation, these crops exhibited rapid price increases in the order of 50–90% (Headey and Fan 2008). It is somewhat unique for India and the other countries of South Asia that fish meal and peanut meal are also common protein sources for poultry (Hellin and Erenstein 2009, Landes et al. 2004).[1] However, the availability and market price of these meals varies widely both spatially and temporally, and with the largely absent futures market, it is difficult to predict and control feed prices.

In recent years, supplementation of feeds with commercially produced and relatively cheap synthetic amino acids has become a common practice in the developing countries, including India (Lauderdale 2000). These feed supplements can be either synthetic amino acids or mineral mixtures. The latter is a combination of essential amino acids, trace minerals, vitamins, medicaments etc. Biofortification of maize with essential amino acids has significant economic potential as it could reduce the poultry firms' dependence on other protein sources, without compromising on poultry production and quality. Whether or not the enhanced amino-acid composition achieved through biofortification of maize would translate into increased profits for (and therefore potential interest and demand from) the livestock producers, depends primarily on the relative price of other feed components and the stage of feed market development.

The existing QPM hybrids provide grains with 125% more Tryptophan and 62% more Lysine than the regular maize (Table 1). The nutritional superiority is linked to *opaque*-2 gene and associated modifiers (Gupta et al. 2009), but in terms of cultivation and phenotype QPM is comparable to normal maize. A detailed history of development of QPM is given by Atlin et al. (2011) and its development in India is summarized elsewhere (Agrawal and Gupta 2010, Hellin and Erenstein 2009). Past research on biofortified maize rich in essential amino acids has primarily focused on QPM – both globally and in the Indian context. Only recently has plant breeding research been initiated in India to include another essential amino acid, Methionine, in maize kernels. It is expected to address concerns within the poultry industry regarding the increasing cost of Methionine in the feed rations (Devegowda and A.K. Panda, *personal communication*). Research has shown that increasing dietary Methionine content in feed substantially increases the weight of broiler chicks (Mack et al. 2010, Panda et al. 2010). Methionine intake also enhances egg output and feather growth (FAO 2011), which can be nutritionally limiting in conventional poultry feeds (Atlin et al. 2011, Panda et al. 2010), and Methionine shortage can be offset through external supplementation. However, synthetic Methionine is often costlier than other synthetic amino acids (B.S. Raghav, *personal communication*). High Methionine Maize (HMM) can potentially be of value to the poultry industry by its implied potential cost savings and increased profitability. HMM is still in the early phases of the R&D pipeline, and is yet to be commercialized. The present study therefore assesses the potential of a prototype HMM (alongside existing QPM), whose likely range of

[1] Fish meal was a conventional, much demanded, protein source for poultry in South Asia, due to its high protein content. But dry fish is also used for human consumption. Due to the high demand, the price of dry fish started increasing drastically, which alongside an unsteady supply, led to its replacement by other protein sources, like soybean meal (Hossain et al. 2003).

 

amino acid levels are based on literature search and expert opinion (for sources cf. Table 1). Therefore, in addition to enhanced levels of Methionine, the HMM prototype has enhanced levels of Tryptophan and Lysine in comparison to normal maize. Methodological details are provided in the next section. Throughout this narrative, the term "biofortified maize" generically refers to QPM and HMM.

**Table 1.** Amino acid profile of normal and biofortified maize and the recommendation for poultry feed in India

| | Normal Maize | Quality Protein Maize (QPM) | Prototype* High Methionine Maize (HMM) | Recommended nutrient level in the poultry feed for | |
|---|---|---|---|---|---|
| | | | | Broilers | Layers |
| Protein (%) | 8 - 11 | 8 – 11<br>[0] | 8 – 11<br>[0] | 19.50 – 22.50 | 15.00 – 18.00 |
| Lysine (%) | 0.26 | 0.42<br>[62] | 0.34<br>[31] | 1.14 – 1.40 | 0.45 – 0.70 |
| Tryptophan (%) | 0.04 | 0.09<br>[125] | 0.07<br>[63] | 0.18 – 0.22 | 0.12 – 0.17 |
| Methionine (%) | 0.18 | 0.19<br>[6] | 0.40<br>[122] | 0.50 – 0.58 | 0.20 – 0.30 |

**Notes.** Figures [in square brackets] show percentage change over the protein content of normal maize.
* Under development and hence assumed indicative levels.
**Source.** Gupta et al. 2009, Hellin and Erenstein 2009, Panda et al. 2009, Vivek et al. 2008, Prasanna et al. 2001, FAO 1992.

## Methodology

### *Primary Data*

The empirical focus of the present study is on the current feeding pattern in the commercial poultry sector in South India, including both broiler and layer production. The Indian states of Andhra Pradesh (AP) and Karnataka were purposively selected as the study area, due to their rapidly growing poultry and maize production sectors. Landes et al. (2004) indicated that the per-capita annual poultry meat consumption (4 kg) in South India is significantly higher than the national average, and the increasing demand for poultry products has triggered an economic opportunity for all the feed components, including maize. Two districts per state (one peri-urban and one rural), representative of the rapid maize and poultry sector expansion, were purposively selected for a survey of poultry firms – Bangalore Rural and Davanagere in Karnataka; and Ranga Reddy and East Godavari in AP (Figure 1).[2] Bangalore Rural and Ranga Reddy districts are peri-urban, covering parts of the metropolitan cities of Bangalore and Hyderabad respectively. Poultry production is increasing rapidly in these districts, owing largely to the increasing urban demand. Although some maize production takes place in these districts,

[2] In a recent (June, 2014) development, Ranga Reddy became part of newly formed Telangana state of India.

 

majority of the maize feed grain comes from other districts and/or states. Maize and poultry production largely co-exist in the two other rural districts (Davanagere and Eastern Godavari).
Poultry firms in each of the districts were randomly selected from a stratified list of member firms of the poultry growers' co-operative societies. The stratification was done by the main product (meat/broiler or eggs/layers) and then by the firm types (independent or integrated along the value chain). The composition and structure of Indian poultry industry and contract farming are detailed by Ramaswami et al. (2005) and Landes et al. (2004). The firm type influences the feeding practice. Integrated units are supplied with a required feed mix from the contracting firm, and the managers are largely unaware of its composition. Therefore, despite their popularity as suppliers of broilers, we purposively under-sampled firms from this category for this study. The resulting sample totalled 185 units, consisting primarily of independent broilers firms (75 firms) and independent layer or egg producing units (72 firms), with 38 contract-based integrated broiler firms (Table 2). No integrated egg production firm was found in the study area.

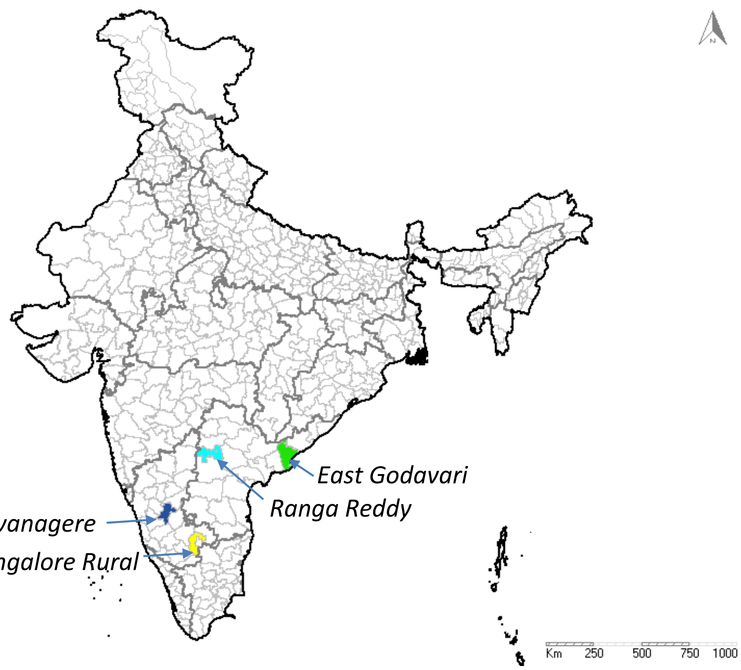


**Figure 1.** Map of India showing the sample districts

**Source.** N. Chowdhury, CIMMYT, New Delhi.

The firm survey was conducted between November 2010 and January 2011 in the selected districts and included face-to-face interviews with poultry firm owners/managers. The interviews were conducted in the local languages with the help of trained enumerators and employing a structured questionnaire, which was developed using insights from a preliminary interview of managers of 15 firms in Karnataka, and after consultation with poultry nutrition experts at the Project Directorate on Poultry (PDP) in Hyderabad. This instrument included questions on (i) general aspects of management structure; (ii) poultry feed composition; (iii) purchasing price of feed ingredients; (iv) feed sources; and (v) output marketing. As there is a significant dearth of economic literature on poultry feed and nutrition in India, we also conducted an expert survey among scientists in the field of poultry nutrition and production to understand the roles of different feed ingredients (in particular maize and its supplements). This has also helped us gain insights on the poultry industry orientation (for example the classification of firms into independent and integrated ones).

*Secondary Data*

To estimate the most economic feed composition, with and without biofortified maize, the market price of ingredients (including that of the synthetic amino acids) from the firm survey, and the recommended minimum and maximum levels of feed components in the Indian poultry production sector were used. The recommended levels were fixed based on the secondary information obtained mainly from PDP, Hyderabad. Literature was reviewed on the role of essential amino acids in poultry production, and the level of amino acids in the major feed ingredients used by poultry firms, to complement the firm-level data. Further, an expert survey was conducted among subject matter specialists at the University of Agricultural Sciences (Bangalore), Karnataka Veterinary, Animal and Fisheries Sciences University (Bidar), private firms dealing with the import of amino acids, and poultry feed manufacturing units. Secondary data were also obtained from government statistics viz., Basic Animal Husbandry Statistics of Government of India (2006, 2010 & 2011), the Livestock Census of India (2003 & 2007) and the Report of Project Directorate on Poultry (PDP 2011).

**Table 2.** Categorization of sample firms with respect to feed sources

| **Firm Type** | **Feed Use** | **% Sample Firms** | | | **Average Size of Firms in '000 Birds** | |
|---|---|---|---|---|---|---|
| | | Broiler (n=113) | Layers (n=72) | Total (n=185) | Broiler | Layer |
| Independent | Completely rely on feed mixing | 7 | 92 | 40 | 23.3 (3.6) | 52.3 (3.4) |
| | Uses both ready-made feed and feed-mixing | 59 | 4 | 38 | 15.0 (2.2) | 80.3 (6.2) |
| | Completely rely on ready-made feed | 0 | 4 | 2 | -- | 70.0 (7.8) |
| Integrated | Contractual arrangement | 34 | 0 | 20 | 9.9 (0.6) | -- |
| Overall | | | | | 13.9 (2.0) | 73.9 (6.9) |

**Note.** Figures in simple brackets show standard errors. Due to oversampling of independent firms for the study, the percentage of different firm-types may not be considered as representative of the poultry sector of South India.
n: Number of observations (firms).
**Source.** Firm survey (2010).

 

*Analytical Frame*

The analytical frame comprises two scenarios – differing with respect to underlying assumptions on a firm's behaviour – to study the potential economic impact of biofortification. The prevalence and impacts of imperfect information on managerial level for the small-scale industries in the developing countries has seldom been studied in the literature. In the farming sector, on the other hand, it is shown that limited information leads farmers to copy adoption decisions of neighbouring producers (Pomp and Burger 1995). The information asymmetry between producers and marketers is also found leading to over-priced inputs and under-priced outputs, and forms an impediment in productivity enhancement (Rota and Sperandini 2010). Such imperfect information also reduces awareness among the potential entrepreneurs of possible market transactions, thereby generating inefficiencies in both allocative and production functions of the markets (Arndt 1988; North 1993). For example, Kristiansen (2003) reported that rural small-scale poultry growers of Indonesia, due to having limited access to information on price fluctuations in the egg markets, were feeling bereaved while competing with the well-connected large scale operators. The study concluded information asymmetry and related information market failures having a huge impact on business opportunities and that a different set of production possibilities would have been present if more information were available. Currently, interaction between various actors in the Indian value chains has been constrained by limited access to information on markets and production technology (Hellin and Erenstein 2009).

We will be using two different analytical scenarios to address the different sectors of poultry production, with varying level of understanding about optimal feed mixtures.

1. The first scenario estimates the least-cost poultry feed rations, with and without biofortified maize, assuming no information constraints for feed costs minimization. In the present context, the integrated large-firms of South India are more likely to enjoy the benefits of feed cost minimization compared to the small-scale poultry producers, given their asset base (e.g. greater access to computer programs and skilled human resources) and integration with contracting firms that supply the feed mix. The first scenario would thus provide plausible results in case of high information availability, especially for the integrated firms.

2. The second scenario acknowledges likely information constraints for optimization – and takes a narrower and simpler approach to estimate the potential cost saving with biofortified maize as a replacement only for synthetic amino acids in the feed. We will subsequently examine the knowledge level of managing staff of small-scale firms on nutrient composition of components of feed mixtures, and show that they are only inadequately informed about the feed composition, so the second scenario would provide, more plausible results for the information constrained small-scale firms.

*Calculation of least-cost poultry feed rations, with and without biofortified maize (Scenario 1):*

A linear programming (LP) model was used to calculate the least-cost feed formulation to meet the minimal feed recommendations for the birds at different growth stages based on market prices and feed composition. The LP model assumes that the poultry firms have perfect information on feed composition and recommended feed needs, and they try to minimize feed cost and maximize their profits, which may be relevant mainly for the large and integrated firms. The rations are so devised that the aggregate nutritional values of different alternative formulations are equal, irrespective of the presence or absence of a biofortified product in them, and the overall nutrient requirements of the industry are met. This method was also employed by De Groote et al. (2010) and Lopez-Pereira (1993). The nutrient composition of different feed ingredients and the recommended dosage of the nutrients are provided in Appendix B. The model estimation is done by:

$$\text{Minimize } Z = \sum_{i=1}^{n} \mathrm{P_i X_i}$$

$$\text{Subject to } \quad A_j \leq \sum_i N_{ij} X_i \leq B_j$$

$$C_i \leq X_i \leq D_i; \quad Z \geq 0$$

where,

- Z is the total cost per kilogram of poultry feed for a given bird growth stage, in Indian Rupees (Rs).
- $P_i$ is the price of ingredient i (Rs/kg).
- $X_i$ is the level of ingredient i in the ration (kg).
- $N_{ij}$ is the content of nutrient j (from 1 to m), in ingredient i, measured in kcal/kg for energy and % for other nutrients
- $A_j$ is the minimum requirement of nutrient j in the feed formulation, in kcal/kg for energy and % for other nutrients.
- $B_j$ is the maximum allowed level of nutrient j in the feed formulation, in kcal/kg for energy and % for other nutrients.
- $C_i$ is the minimum level of ingredient i required (kg), and
- $D_i$ is the maximum level of ingredient i required (kg).

Solving the LP model for the lowest positive value of Z, we estimate the cheapest poultry feed, with and without biofortified maize, separately for starter, grower and finisher and for broiler and layer firms. The list of ingredients and prices are obtained from the firm surveys. An additional variation of the scenario 1 model was estimated, imposing constraints on two feed ingredients (fish meal and groundnut meal), which, irrespective of their nutritional superiority, are used scantly by firms as their availability is limited in the market. The total nutrient levels are calculated by multiplying content matrix with quantity vector; that is, $N_{ij}X_i$. The price of biofortified maize is assumed to be equal to that of normal maize – reflecting the inherent invisibility of the trait and earlier experiences with QPM. Under these specifications, the quantities of different ingredients (maize, soy, synthetic amino acids etc.) required to produce 1 kg of feed at minimal cost for each growth stage, separately for broilers and layers, were estimated.

 

*Calculation of cost saving with biofortified maize as a simple replacement for synthetic amino acids and normal maize in the feed (Scenario 2):*

The above mentioned LP model rests upon the assumption that the poultry firms have perfect information on feed composition and feed requirements to minimize the cost, which may be true in case of large and integrated poultry firms. However, generation of cost-minimizing feed mixtures demand significant managerial skill, as relative prices of the ingredients fluctuates over time. Scenario 2 thus estimates potential cost-savings of biofortified maize as a replacement only for synthetic amino acids and normal maize in the feed. It is more realistic, as most of the firm managers interviewed were of the opinion that the variable of interest would be the quantity of synthetic amino acids saved after the introduction of biofortified maize. No incremental price is assumed for the biofortified maize over the existing normal maize, and cost savings are divided by quantity of maize intake and compared with the market price of normal maize to examine the possibility of evolution of specialized value chains for the quality protein trait.

The surveyed poultry firms used synthetic amino acids in two different forms: (i) commercial mixtures having low amino acid content, which are relatively cheaper; and (ii) unmixed high concentration synthetic amino acids (e.g. synthetic Lysine), which are costlier. In case of (i), biofortified maize may not lead to reduced use of the mixture, unless maize contains the limiting essential amino acid. For example, conventional QPM does not provide additional Methionine, and if Methionine is actually the limiting amino acid in the existing feed composition, firms may not save any commercial mixture at all upon adoption of QPM feed ration. However, the replacement is easier in case of unmixed synthetics. In order to capture both inputs, the potential cost saving from biofortified maize is calculated as the cost of the minimum amount of synthetic input that can be saved due to the use of biofortified maize. Here, we base our calculations on the feed regime of independent poultry firms, except for the synthetic amino acid supplements. The potential cost saving, for (i) commercial mixtures:

$$(1)\ \ \Delta C^s = \Delta Q^s.P^s = \left[ Min\left[ Q_0^s - \left[ \frac{N_j^s - N_j^b}{S_{N_j^s}} \right] \right] \right] P^s \quad \text{if } N_j^s > N_j^b;\ \left[ \frac{N_j^s - N_j^b}{S_{N_j^s}} \right] = 0 \text{ if } N_j^s \le N_j^b$$

for (ii) unmixed synthetic products providing single amino acid:

$$(2)\ \ \Delta C^s = \Delta Q^s.P^s = \left[ Q_0^s - \left[ \frac{N^s - N^b}{S_{N^s}} \right] \right] P^s \quad \text{if } N^s > N^b;\ \left[ \frac{N^s - N^b}{S_{N^s}} \right] = 0 \text{ if } N^s \le N^b$$

where,

- $\Delta C^s$ is the cost saving from replacing only synthetic feed compounds with biofortified maize (Rs/bird)
- $\Delta Q^s$ is the quantity of synthetic feed compound saved (kg/bird)
- $P^s$ is the price of synthetic feed compound (Rs/kg)
- $Q_0^s$ is the quantity of synthetic feed compound provided to poultry before introduction of biofortified maize.
- $N_j^s$ is the quantity of essential amino acid *j* (kg) additionally obtained from synthetic sources.

 

$N_j^b$ is the quantity of essential amino acid *j* (kg) additionally obtained from biofortified maize (QPM or HMM), when conventional maize is replaced with biofortified one.
$S_{N_j^s}$ is the share (0-1) of essential amino acid *j* obtained in synthetic feed compound.

Not many feed trials have been conducted to estimate the comparative impacts of biofortified maize and synthetic substitutes with the total intake of amino acids constant. In previous studies carried out in other countries, the production impact of QPM were calculated relative to normal maize (De Groote et al. 2010), but not against synthetic substitutes. Based on expert opinion, we assume that the yield impact of substituting synthetic sources with biological protein from biofortified maize is negligible, although feed trials are to be conducted in order to substantiate this assumption.

## Results and Discussion

*Current Feed Practices by Poultry Firms*

Before estimating the cost impact of including biofortified maize as a feed component, we examine the existing feeding practices of the sample poultry firms. The structure and cost of poultry production shows significant regional variation; while independent and small-scale producers still account for most of the poultry production in India, large-scale integrated firms contribute to a growing share of output in some regions (Landes et al. 2004). In our feed composition analysis, we exclude the integrated firms, as an already mixed feed is directly supplied to them from the contracting firm, and the managers have limited knowledge of the ingredients of the feed supplied. To facilitate understanding, the feed components used by the independent small-scale firms are divided into two groups: the components of Group A provide the major nutrients, while those of Group B are elements required for better intake of these nutrients by the birds. The feed structure of broiler and layer firms differed substantially (Table 3). Maize is the major source of energy, used by all surveyed firms in the feed mixtures. The main source of protein is soy, used by 71% of broiler and 98% of layer firms. Maize and soybean thereby make up the highest feed cost shares – together accounting for 70% of broiler and 56% of layer average feed cost. Broiler rations, on average, contain 64% maize and 20% soybean cake and 14% mineral mixture. About 95% of the procurement cost of broiler feed is accounted for by these three ingredients.

Maize and soybean cake still form the major feed ingredients in the layer firms, contributing equally (28% each) to the feed cost. They also use maize/soybean-substitutes for energy and protein. For example, broken rice is used for energy and fish meal for protein. Mineral mixture is rarely used (by just 9% of layer firms) as an amino acid supplement. Unmixed amino acids, like synthetic Lysine and synthetic Methionine, are popular and used by 52% and 85% layer firms, respectively. However, these supplements are used in traces and they contribute only marginally to the total feed cost (Table 3). Use of synthetic Tryptophan was not reported.

 

**Table 3.** Composition of poultry feed used by the sample firms

| | Broiler Firms (n =65) | | | Layer Firms (n = 65) | | |
|---|---|---|---|---|---|---|
| | % of Firms Using | Quantity (kg/bird)* | Feed Cost Share (%) | % of Firms Using | Quantity (kg/bird)* | Feed Cost Share (%) |
| **Component group A (major nutrients)** | | | | | | |
| Maize | 100 | 3.45 (0.19) | 37.79 | 100 | 21.96 (0.97) | 28.18 |
| Soy | 71 | 1.51 (0.20) | 32.21 | 98 | 8.62 (1.69) | 28.17 |
| Oil | 29 | 0.24 (0.05) | 1.01 | 8 | 0.05 (0.01) | 0.00 |
| Broken rice | 1 | 0.11 (--) | 0.01 | 49 | 8.08 (0.63) | 4.33 |
| De-oiled rice bran | 1 | 0.18 (--) | 0.02 | 100 | 4.98 (0.36) | 6.07 |
| Sunflower | 1 | 0.18 (--) | 0.03 | 68 | 4.62 (0.27) | 7.23 |
| Fish | 6 | 0.34 (0.04) | 0.46 | 51 | 2.82 (0.26) | 3.27 |
| Di-calcium phosphate | 5 | 0.12 (0.01) | 0.06 | 94 | 0.42 (0.07) | 1.55 |
| Mineral mixture | 91 | 0.80 (0.08) | 25.41 | 9 | 4.53 (0.73) | 1.45 |
| Groundnut | 1 | 1.02 (--) | 0.26 | 20 | 19.03 (0.38) | 7.97 |
| Sorghum | 0 | 0.00 (--) | 0.00 | 38 | 11.35 (0.88) | 2.72 |
| Synthetic Lysine | 1 | 0.01 (--) | 0.02 | 52 | 0.03 (0.00) | 0.28 |
| Synthetic Methionine | 1 | 0.01 (--) | 0.06 | 85 | 0.04 (0.00) | 1.02 |
| **Component group B (nutrient intake enhancing elements)** | | | | | | |
| Toxin binder | 9 | 0.01 (0.00) | 0.12 | 82 | 0.04 (0.00) | 0.32 |
| Phytase enzyme | 1 | 0.00 (--) | 0.01 | 74 | 0.01 (0.00) | 0.22 |
| Liver powder | 3 | 0.01 (0.00) | 0.02 | 60 | 0.03 (0.00) | 0.16 |
| Trace minerals | 1 | 0.01 (--) | 0.01 | 89 | 0.06 (0.00) | 0.36 |
| Antibiotic growth promoter | 3 | 0.00 (--) | 0.04 | 21 | 0.01 (0.00) | 0.07 |
| Vitamin premix | 2 | 0.01 (0.00) | 0.03 | 82 | 0.02 (0.00) | 0.62 |
| Salt | 3 | 0.03 (0.00) | 0.01 | 91 | 0.18 (0.01) | 0.09 |
| Other ingredients | 6 | 0.19 (0.02) | 2.54 | 42 | 5.24 (0.61) | 5.93 |

**Note.** *Shows conditional (on use) mean values, and the figures in brackets show standard error for sample excluding the integrated firms and extreme values.
**Source.** Firm survey (2010).

 

On average, broiler firms spend Rs. 87 and layer firms Rs. 654 to provide nutrients (only Component A) for a bird during its entire life. However, these total costs show a wide variation across individual firms, (from Rs. 25 to 177 in broiler firms; and from Rs. 225 to Rs.1151 in layer firms; Figure 2). The cost differences are primarily associated with significant difference in feed composition, especially in the case of layer firms – and can only be marginally attributed to the differential price of inputs and diverse input-value chains. For example, the layer firms that include fishmeal in the feed could reduce total feed cost by 20%, compared to others. Even more pronounced is the impact of groundnut meal in the layer feed (27% cost reduction). The cumulative distribution of feed cost for layer firms is relative flat for the range of Rs. 500-700, comprising 46% of the firms. These firms are found partly substituting fish meal for soymeal in the feed mixture, especially when the soymeal price is high. Similarly, there may be a cost saving for the few firms that use sorghum as a source of energy in the feed mixture.

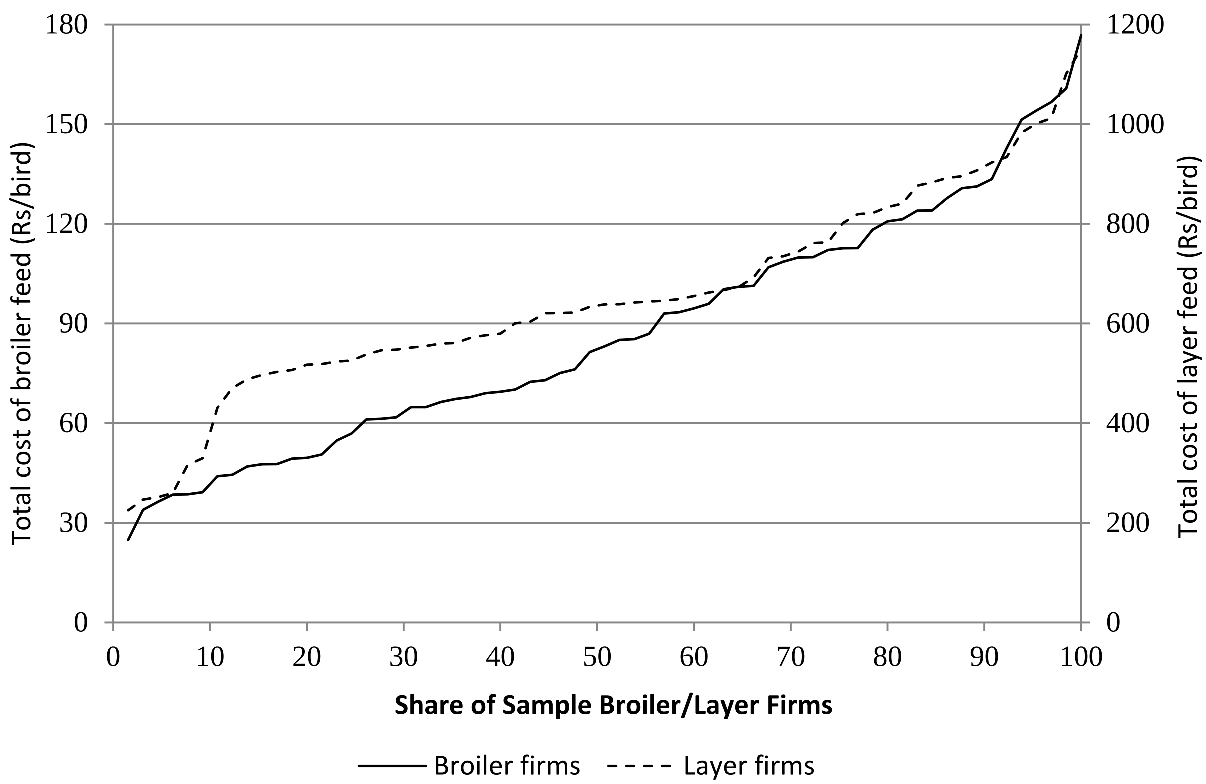


**Figure 2.** Cumulative distribution of sample firms with respect to nutrient feed cost

**Note.** Cost includes that of feed components from Group A only.
1 US$ = Rs. 45.7 (average of 2010).
**Source.** Firm survey (2010).

The survey results allow us to estimate the amount of each of the essential amino acids fed to birds in broiler and layer firms (Appendix C). In the case of layer firms, most firms use about the recommended dosage, each amino acid use showing a relatively flat cumulative distribution, typically around the recommended dosage – although with a relative underutilization of Methionine in the majority of firms. In the case of broiler firms, each amino acid use shows an inclined cumulative distribution, with only a few firms using about the recommended dosage, and with a relative underutilization of Lysine and again Methionine in majority of the firms.

 

A significant share (45%) of broiler firms was found to be using the essential amino acids higher than the dosage recommended by the PDP for profit maximization. One of the reasons could be the excessive use of mineral mixture, which also contains a number of trace minerals and vitamins, necessary for gaining body weight at a faster rate, alongside amino acids. This is less pronounced for layer firms, and the quantity of amino acid used by the layer firms above the recommended dose is not very high. One of the reasons is that over-use of amino acids is associated with the availability of cheaper fish meal in the local market. A comparison of feed composition, feed cost, productivity and gross revenue of these "over-users" (of all the three essential amino acids) with that of the others is made in Table 4.

**Table 4.** Impact of amino acid use on poultry production

| | **Broiler Firms** | | | **Layer Firms** | | |
|---|---|---|---|---|---|---|
| | "Over-users" (n =29) | Others (n =36) | Difference # | "Over-users" (n =39) | Others (n =26) | Difference # |
| Cost share (%) in the feed | | | | | | |
| (i) Maize | 38 | 43 | -5 | 32 | 36 | -4 |
| | (0.4) | (0.5) | (0.6) | (0.2) | (0.6) | (0.5) |
| (ii) Soybean cake | 38 | 19 | 19*** | 29 | 18 | 11*** |
| | (0.4) | (0.7) | (0.8) | (0.3) | (0.4) | (0.5) |
| (iii) Fishmeal | -- | -- | -- | 6 | 2 | 4** |
| | | | | (1.1) | (0.8) | (1.5) |
| (iii) Protein supplements## | 21 | 34 | -13** | 3 | 3 | 0 |
| | (0.4) | (0.7) | (0.8) | (0.1) | (0.4) | (0.4) |
| Feed cost (Rs/bird) | 125.5 | 61.0 | 64.5*** | 763.8 | 646.5 | 117.3*** |
| | (1.1) | (0.5) | (1.1) | (5.1) | (11.8) | (12.6) |
| Other costs (Rs/bird) | 4.1 | 3.6 | 0.5 | 31.1 | 31.8 | -0.7 |
| | (0.3) | (0.3) | (0.4) | (1.6) | (1.4) | (2.2) |
| Total cost (Rs/bird) | 129.6 | 64.6 | 65.0*** | 794.9 | 678.3 | 116.6*** |
| | (6.4) | (3.0) | (6.7) | (32.7) | (70.9) | (70.3) |
| Productivity (kg meat or | 2.3 | 2.2 | 0.1* | 302 | 303 | -1 |
| eggs /bird) | (0.0) | (0.0) | (0.0) | (0.5) | (0.6) | (0.8) |
| Revenue – main product | 95 | 95 | 0.0 | 731 | 717 | 14 |
| (Rs/bird) | (0.6) | (0.3) | (0.6) | (1.4) | (2.0) | (2.4) |
| Revenue – by-product | 5.9 | 4.7 | 1.2*** | 50.3 | 51.8 | -1.4 |
| (Rs/bird) | (0.4) | (0.2) | (0.4) | (2.6) | (3.6) | (4.3) |
| Profit (Rs/bird) | -29.0 | 35.1 | -64.1*** | -13.3 | 90.6 | -103.9** |
| | (7.4) | (3.7) | (7.9) | (31.0) | (68.5) | (67.5) |

**Note.** "Over-users" category is defined as the group of poultry firms that uses feed with a higher dose for each of the three essential amino acids (Lysine, Tryptophan and Methionine). Figures in simple brackets show standard errors.
***, **, * show statistical significance at 0.10, 0.05 and 0.01 levels, estimated with Kruskal-Wallis rank test (Due to the small sample size, we cannot assume with surety that the data is normally distributed, and hence cannot employ the parametric test. The nonparametric Kruskal-Wallis rank test does not assume normality of distribution).
# Difference of over-users over others. ## This group includes unmixed synthetic Lysine/Methionine and mineral mixture.
1 US$ = Rs. 45.7 (average of 2010).
**Source.** Firm survey (2010).

For both broiler and layer firms, the difference arises mainly because of the higher proportion of soybean cake in the feed mixture. No difference was observed with respect to the quantity of maize used, while the "over-users" among broiler firms were actually spending less on synthetic amino acids. There exists a significant difference in the feed cost across the two groups of firms, which is more pronounced for broiler firms (105%) than layer firms (18%). Nevertheless, the "over-use" of amino acids has only marginal impact on the average meat production (by 4%) in case of broilers, and none on the egg production. Impact on gross revenue is insignificant for both types of firms. Feed is a major poultry production cost and improving feed efficiency is important for maximizing profitability (Singh et al. 2002). Our findings suggest that the firms that over-use the amino acids incur an average financial loss on their produce (losses of Rs. 29 per bird for broiler and Rs. 13 for layers), and even larger relative losses relative to those firms that do not over-use (and attain average profits of Rs. 35 per bird for broiler and Rs. 91 for layers). Hence there is substantial scope for increasing efficiency and profitability for these over-users, for which firms need to be provided information on optimal feed composition and nutrition. Lack of adequate information on amino acid use is also likely to affect the potential demand for and adoption of biofortified maize as feed component by poultry firms.

*Impact of Biofortified Maize on the Provision of Least-Cost Feed*

Assuming that the producers are fully aware of the birds' nutrient requirement and the nutrient composition of different feed components, we have calibrated the LP model. Although this assumption may not hold true for many small-scale independent poultry firms, it is reasonable to assume that integrated and large firms use feed mixtures with the least-cost combination of different ingredients. Using these in the LP model, Table 5 (see Appendix A) presents the most economic formulation for different feeds aggregated over the different stages of bird growth in order to find the optimal quantity per bird. The minimum cost of providing the recommended dose of nutrients for a bird is calculated as Rs. 47 (46% lower than the average cost of feed as reported by sample firms) for broilers and Rs. 577 (12% lower than the average feed cost) for layers. There are also significant differences in the structure of the feed ration, mainly due to the availability of fish meal, a cheap protein substitute in the locality. Fish meal is considered to be one of the "best" ingredients for broilers and layers rations, as it enhances the feed consumption and feed efficiency (Solangi et al. 2002). It was found to be priced on a par with soybean cake, but had a higher percentage of all the three essential amino acids than mineral mixture and soybean cake. Hence, in the cost minimizing formulation, it replaces soybean cake and synthetic amino acid supplements completely in both broiler and layer rations. For broiler firms, maize remains the major source of energy. However, for the layer firms, broken rice substantially replaces maize.

This optimal formulation, especially in the absence of soybean cake in the feed mixture, is not the one commonly followed by the firms. This could be due to a number of constraints – both with respect to the physical availability and quality of fish and groundnut meal, as well as the lack of awareness of the poultry managers. In order to estimate a more realistic cost minimizing feed composition, and to understand and incorporate these constraints (see Appendix B), we recalibrated an additional model with more stringent bounds for fish and groundnut meal (Specification 2, Table 6 (see Appendix A)). Upon these additional constraints, the feed cost has increased by 12% for broilers and 8% for layers. These figures are not only closer to the observed practice by sample firms, but the use of soybean meal also increased drastically as a major protein source.

 

Both specifications agree on certain aspects. Metabolizable energy and total protein are the most limiting components in poultry ration. Feed mixtures that meet the required calories and protein have been found to provide the recommended dose of amino acids, without synthetic supplements. In both specifications, when total protein requirement is met, either from low-cost protein sources or from soybean meal, the recommended dose of Lysine, Tryptophan and Methionine are already met, without depending on any synthetic sources. Replacing normal maize with biofortified maize would just add to the levels of Lysine, Tryptophan and Methionine (supplied by low cost protein sources) which are already in excess of the recommended dosage in feed mixtures of firms in the area of this study, especially under Specification 2 (Figure 3). It also implies that for a firm that already follows the optimal feed composition, there would be only marginal cost-saving due to adoption of QPM or HMM grains, and there will be zero demand for the biofortified maize even at the slightest price increment. In other words, the current availability of cheap protein necessitates no additional amino acid through biofortification or synthetic substitutes, at the present price levels. According to experts, fish meal has long been one of the cheapest sources of protein in South India (Solangi et al. 2002, Devegowda and A.K. Panda, *personal communication*). In countries like Kenya where fish meal is relatively expensive, the substitution of normal maize by QPM is found resulting in positive cost savings (De Groote et al. 2010). However, the relative prices depend on seasonal availability and nature of supply chains. These factors, alongside the price variability of major feed components, should be studied further to understand the consistency of these findings.

*Impact of Biofortified Maize as Substitute for Synthetic Amino Acid Supplements*

Generalization of LP results pre-requisites that all firms face the feed supply constraints uniformly, and uniform input price structure prevails. Furthermore, the assumption of perfect information is likely to be violated; as we have already seen that firms often “overuse” amino acids, possibly because of lack of awareness regarding poultry nutrition. The survey also assessed their awareness of various amino acids, with a marked divergence between managers of broiler and layer firms. Most of the broiler firm managers had not heard about the essential amino acids (Figure 4) and the majority (72%) believed that the intake of essential amino acids will have no impact on meat production. The level of awareness was considerably higher among managers of layer firms (particularly for Lysine and Methionine), and 60% associated yield-enhancements with the intake of amino acids. This could be one of the reasons why the amino acids in the feed mix of most layer firms approximate the recommended dosage. However, many of the lower-cost ingredients (e.g. fish meal) may not be available in the market throughout the year, causing difficulties for the poultry firms to follow the least-cost feeding strategy.

 

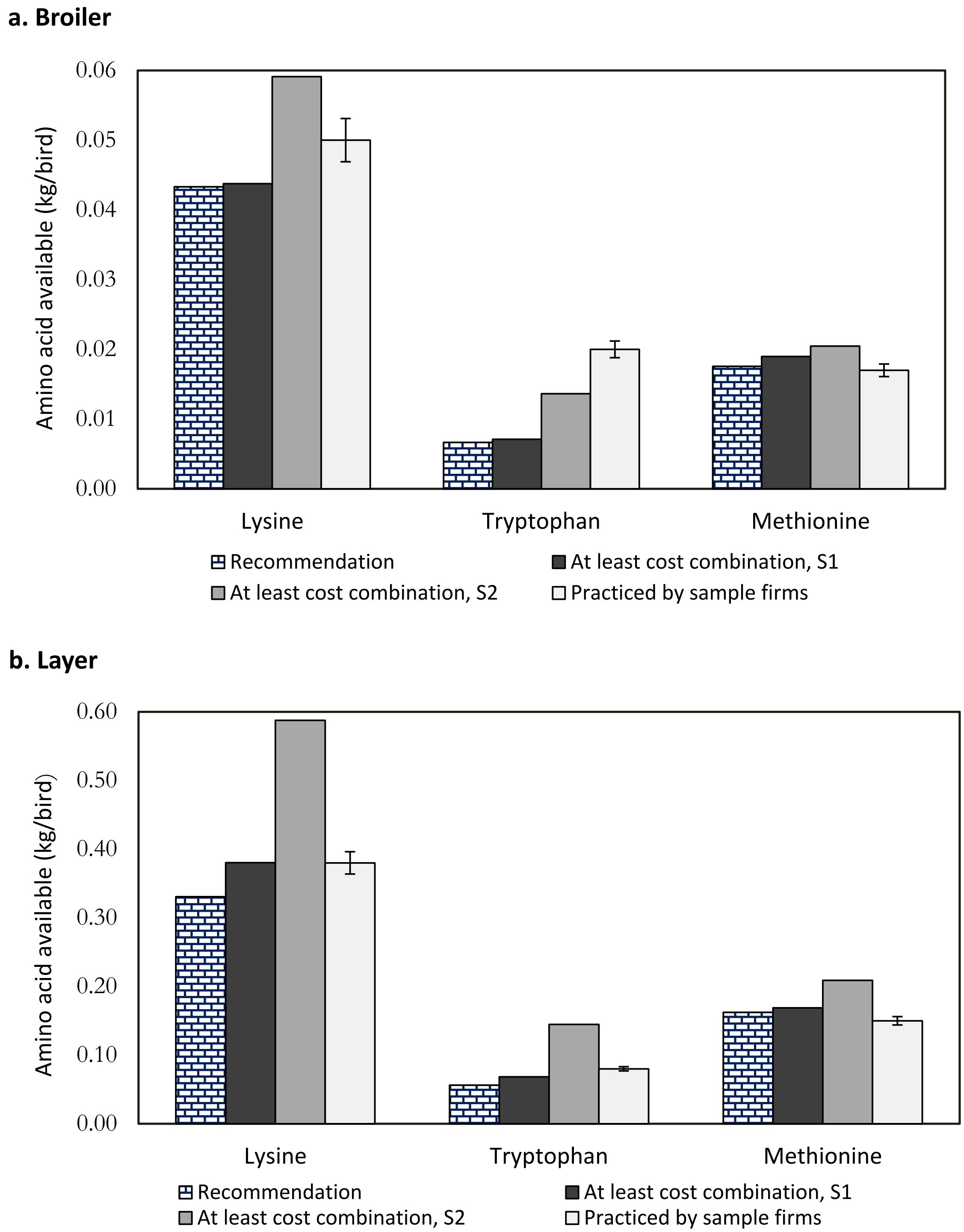


**Figure 3.** Essential amino acids: recommendation  availability at minimized cost, and use by sample firms

**Note.** Error bars show standard errors. S1: Model specification 1; S2: Model specification 2.
**Source.** Mandal et al. (2004 & 2005), Panda et al. (2009), PDP (2011), Ranjhan (1998), estimation from Firm survey (2010).

 

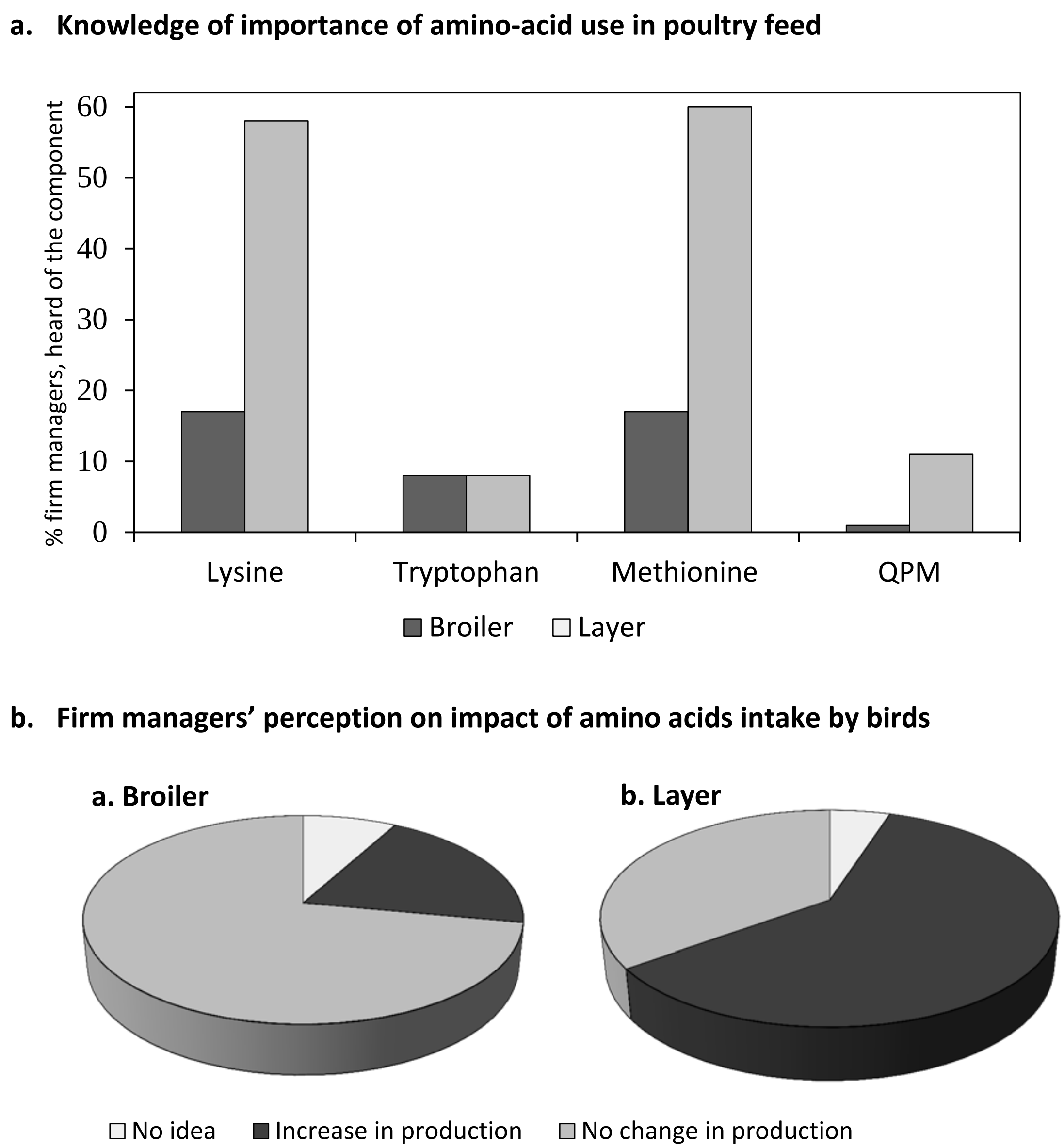


**Figure 4.** Firm managers' awareness and perception on amino acids

**Source.** Firm survey (2010).

Also, only a small proportion of all managers had heard of QPM. This limited awareness poses practical hurdles for the wider adoption of biofortified maize, further exacerbated by the fact that the product is inherently credence good.[3] A distinct supply chain for QPM grain would seem to be the only way of ensuring that the high protein quality of QPM is transmitted down the value

[3] Credence goods are goods for which consumers cannot easily verify the process-attribute claims even after consumption (Roe and Sheldon 2007). Examples include organically produced food, free-range poultry, non-genetically modified foods etc. Although laboratory tests could distinguish biofortified maize from the normal maize, most of the firms do not have the capital, human resource or willingness to incur additional transaction costs to carry out such tests, and hence QPM and HMM falls under the category of credence goods.

 

chain. Concomitant development of value chains and institutions (e.g. contract farming, labelling and certification etc.) is also necessary for the wider adoption of biofortified maize by the poultry and feed industry.

Since a large share of firm managers in the study area, especially those of broiler firms, have only limited information on role of amino acids and its sources, availability of biofortified maize may not result in a drastic change in the feed composition, and it is more realistic to assume that firms might only reduce the use of synthetic sources of protein in response to the increased availability of essential amino acids from biofortified maize (Scenario 2). Based on this assumption, the potential firm-level impact of QPM and HMM were re-estimated. These are considered to be more realistic because the assumption that the firms have perfect information on profit maximizing feed composition is not imposed. Also, maize biofortified with only two essential amino acids (as QPM) may not lead to any savings over composite amino acid supplements, especially when the third amino acid is limiting. The results of impact estimation, based on these more realistic assumptions, are provided in Table 7.

**Table 7.** Impact of biofortified maize under imperfect information on feed composition (Scenario 2)

| | Broiler Firms | | Layer Firms | |
|---|---|---|---|---|
| Quantity of amino acids (g/bird) currently available from synthetic sources | | | | |
| (i) Lysine | 8.8 | | 20.3 | |
| (ii) Tryptophan | 0.4 | | 0.2 | |
| (iii) Methionine | 4.3 | | 36.0 | |
| Cost of amino acids from synthetic sources (Rs/bird) | 19.5 | | 22.0 | |
| Quantity of amino acids (g/bird) additionally provided if normal maize is replaced by biofortified maize | **QPM** | **Prototype HMM** | **QPM** | **Prototype HMM** |
| (i) Lysine | 5.5 | 2.8 | 35.1 | 17.6 |
| (ii) Tryptophan | 1.7 | 1.0 | 11.0 | 6.6 |
| (iii) Methionine | 0.4 | 7.6 | 2.2 | 48.3 |
| Potential cost saving synthetic amino acids (Rs/bird) | 1.6 | 6.1 | 1.2 | 17.0 |
| Potential saving as % of total feed cost | 1.0 | 4.0 | 0.2 | 2.4 |

1 US$ = Rs. 45.7 (average of 2010)
**Source.** Calculated from firm survey (2010); PDP (2011) for the number of broiler/layer birds in year 2009.

On average, broiler firms spend Rs. 19.5 (12% of the total feed cost) and layer firms Rs. 22.0 (3% of the total feed cost) per bird on amino acid supplements. In the case of broilers, synthetic substitutes come mainly as composite supplements and in the case of layers, as unmixed concentrates. Replacing regular maize with QPM for broilers would provide 63% of Lysine that is currently provided through synthetic sources, but Methionine will still be critically limiting. About 92% of the Methionine required would still have to be provided through synthetic sources, which means replacing regular maize entirely with QPM would translate into savings of 1% on the total feed cost. If the normal maize is replaced with the Methionine-enriched HMM prototype, synthetic Tryptophan and Methionine would not be required, but, 69% of the Lysine would still have to come from synthetic sources to meet firms' practice. The cost savings would be slightly greater in this case – at 4% of the feed cost (Rs. 6.1 per bird). However, only 3.45 kg of maize is used for broiler feed on average (Table 3 shows an average spending of Rs. 35 per bird the total cost of maize in the feed mixture). It means that the HMM could imply a potential synthetic amino acid saving of Rs. 1.8/kg maize (Rs. 6.1 per bird per 3.45 kg maize per bird), which corresponds to 17% of the current maize price. This potential saving would be eliminated only if the maize farmers are paid a premium of 17% for HMM over normal maize. In other words, there might be a potential market for HMM as broiler feed component if the price premium is less than 17%. Whether this implies sufficient financial incentive to generate a segregated value chain for biofortified quality protein trait with labelling and certification and/or contract farming requires additional market research.

In the case of layers, most of the firms use unmixed synthetic substitutes at high concentrations. QPM can substitute for all the synthetic Lysine and Tryptophan, and 6% of the synthetic Methionine, but the cost saving is only marginal (0.2%; Rs. 1.2 per bird). With prototype HMM (incorporated into QPM), 87% of Lysine and 100% of Tryptophan and Methionine requirement from synthetic sources can be met through biofortification. Even though most of the synthetic amino acids can be replaced, the magnitude of feed cost change would be just 2.4% (Rs. 16.9 per bird). The maximum price increment economically feasible for maize grains after biofortification (7% or Rs. 0.80 per kilogram) would be lower than in the case of broilers. Although synthetic Methionine is more expensive than synthetic Lysine (around 54% higher), only small quantities are needed to meet the dietary requirement, which is why the estimated feed-cost savings are relatively low. Due to the small potential price increment, it would be more difficult to realize segregated value chains linking biofortified maize production and layer firms.

As HMM is still under development, the amino acid composition of these biofortified varieties at the commercial scale can still only be speculated. A Methionine-enriched QPM variety, with higher Lysine and Tryptophan in addition to Methionine, could produce relatively higher economic benefits than the existing QPM hybrids, but the magnitude of the impact would still be less than 5% of current variable costs for poultry meat and egg production. On the other hand, there is only limited information on the impact of biofortification on the production and quality of poultry meat in comparison with amino acids from synthetic sources. Only a few studies (e.g., Amonelo and Roxas 2009) indicate the possibility of differential productivity impacts of protein from biofortified maize and from the synthetic sources. Feed trials will have to be conducted to ascertain this. One of the recent studies indicated that, although the quantity of meat production was unaffected by QPM uptake by broilers, it helps reduce fat content and increase breast meat (Panda et al. 2013). Even if such differential impacts are proven pervasive and niche market for the chicken so produced can be realized in India, distinct maize-poultry value chains would be necessary for the successful diffusion of the biofortified maize varieties, given its inherent credence good attribute for the poultry firm managers.

 

For now it remains a challenge to construct a marketing scenario in India with positive price premium for biofortified maize, which would imply sufficient incentives for farmers to adopt the speciality maize varieties and poultry firms assure that the maize supplied is biofortified. An important dimension of product differentiation and segregation for speciality traits throughout the value chain is the added handling and transaction costs incurred, and some organizational arrangements may be necessary to reduce these (Miranowsky et al. 2004). One of the possible solutions is poultry firms getting into contracts with the maize farmers. Such institutional arrangements are not widely observed in India, but could be a potential market development for mitigating the information asymmetry in the value chain due to the credence good attribute of biofortified maize.[4] Valuable insights can be derived from a number of studies examining the wide array of cash contracts with varying terms that pose strategic alternatives for buyers, particularly as they seek to use contracting as an element of risk mitigation, for different crops across countries (e.g., Wilson and Dahl 2011, Goldsmith et al. 2008, Darroch et al. 2002). Broadly, the major challenges in successful marketing of speciality crop/variety include the capacity to realize premiums sufficient to cover increased costs, contract price flexible with general market trends, fair and effective distribution of benefits throughout the supply chain, traceability, managing risks of climatic induced quality losses etc. Under these conditions, contractual arrangements are shown co-existing and relatively stable with other conventional market forms (Van Wechel et al. 2007, Janzen and Wilson 2002, Carriquiry and Babcock 2002).

## Conclusion

The development of biofortified maize with enhanced levels of (essential) amino acids has gathered significant research attention, first in relation to human consumption in the developing countries and, more recently, from a business perspective due to the rapid growth of the poultry sector in, for instance, India. However, mainly due to the cheap protein substitutes available in the market, the financial potential of biofortification of maize as poultry feed component appears limited. Beyond this *ex ante* impact assessment, the study also indicates the importance of information at the firm managerial level. In the Indian poultry sector, small-scale firm managers typically lack awareness on the role of amino acids or on new biofortified products, leading to overuse of amino acids, and limiting the economic potential of biofortified maize. Further, the sector appears to incur significant financial losses due to the lack of information diffusion related to the role of nutrients in poultry production and the nutritive value of different feed components. Therefore, in the case of India, it is imperative for the regional governments to develop and strengthen organizational solutions that disseminate appropriate information for the small-scale poultry sector to raise technology adoption and profitability.

The paper also indicates the necessity for carrying out a feasibility study on novel value chains for quality attributes. The inherent credence good status of biofortified maize is a major challenge to realize its market potential. Thus, the potential biofortified maize induced savings, which are already marginal, are based on the assumption that there is perfect substitutability

[4] An example for poultry firms getting into contractual arrangement for ensured supply of maize is shown by Mehta and Nambiar (2008): Suguna Poultry Farm Ltd, a leading poultry firm in South India has tied up with the farmers of Karnataka state for the cultivation of more than 6400 hectares of maize in 2007.

 

between biofortified and synthetic amino acids: that is, there are no other effects, viz. relative poultry yield, meat quality or efficiency. If indeed (and subject to validation with empirical feed data) biofortified maize (compared to synthetic amino acids) improves poultry yield, meat quality or efficiency (as claimed by the preliminary information), the scenario of financial impact estimates would change considerably and could trigger demand for such a product. Furthermore this would provide sufficient impetus to increase research investment in developing new biofortified HMM and QPM varieties or their combinations for the Indian poultry sector. Despite significant information gaps on the potential of biofortified maize, the development of HMM-QPM could be a first step towards further enrichment with high oil content. This is beyond the scope of this study, but given the importance of oil in poultry feed, could be more of a potential game changer. Such a trait pyramiding approach could further increase the potential economic benefits. Further, there is some evidence emerging in the literature (Panda et al. 2013) that feeding poultry with biofortified maize could increase the quality of meat production, which is credence attribute for the poultry consumers. Our paper thereby complements the more qualitative study by Hellin and Erenstein (2009) – but also shows that the economic benefits of current QPM varieties would be marginal if the quality impacts on the end product (poultry meat) are not accounted for, and hence the technology diffusion critically depends on the development of distinct value chains both for maize grains and for poultry products.

## Acknowledgement

The present study was conducted as part of the research project, "Usefulness of High Methionine Maize in Indian poultry sector", at the International Maize and Wheat Improvement Center (CIMMYT), New Delhi, and financially supported by the Indian Council of Agricultural Research (ICAR). The authors are grateful to Lalith Achoth for his valuable guidance in the model development. We also thank the two anonymous reviewers and the editors of this journal for their very useful comments. The usual disclaimer applies.

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# Appendix A

**Table 5.** Cost minimizing poultry feed composition (Scenario 1, Specification 1)

| | Market price (Rs/kg) | Cost-minimizing feed composition (kg/bird for the entire lifespan) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Broiler [lifespan: 42 days] feed with | | | Layer [lifespan: 504 days] | | |
| | | Normal Maize | QPM | HMM | Normal Maize | QPM | HMM |
| Maize | 10.2 | 2.74 | – | -- | 11.54 | -- | – |
| Biofortified maize (QPM/HMM) | 10.2 | -- | 2.74 | 2.74 | – | 11.54 | 11.54 |
| Soybean cake | 19.3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Fish cake | 19.2 | 0.77 | 0.80 | 0.80 | 7.27 | 7.27 | 7.27 |
| Broken rice | 7.5 | 0.40 | 0.40 | 0.40 | 4.68 | 4.68 | 4.68 |
| De-oiled rice bran | 7.0 | 0.03 | 0.03 | 0.03 | 2.29 | 2.29 | 2.29 |
| Sunflower | 13.5 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Groundnut cake | 15.8 | 0.02 | 0.03 | 0.03 | 16.16 | 16.16 | 16.16 |
| Sorghum | 9.1 | 0.05 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 |
| Mineral mixture | 26.8 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Oil | 44.2 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 |
| Di calcium phosphate + other sources of calcium | 24.8 | 0.00 | 0.00 | 0.00 | 4.89 | 4.89 | 4.89 |
| Synthetic lysine | 162.8 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Synthetic methionine | 250.8 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total feed quantity | | 4.02 | 4.02 | 4.02 | 46.83 | 46.83 | 46.83 |
| Feed cost in Rs/bird for the entire lifespan [% change over normal maize] | | 47.2 | 47.2 [-0.1] | 47.2 [-0.1] | 576.8 | 576.8 [0.0] | 576.8 [0.0] |

**Note.** Estimates are obtained from LP model using the feed ingredient price and nutrient composition.
1 US$ = Rs. 45.7 (average of 2010).
**Source.** Optimization results from Appendix B and ingredient prices from firm survey, 2010.

**Table 6.** Cost minimizing poultry feed composition, with limited fish and groundnut meal availability (Scenario 1, Specification 2)

**Table 6.** Cost minimizing poultry feed composition, with limited fish and groundnut meal availability (Scenario 1, Specification 2)

| | Market price (Rs/kg) | Cost-minimizing feed composition (kg/bird for the entire lifespan) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Broiler [average lifespan: 42 days] feed with | | | Layer [average lifespan: 504 days] | | |
| | | normal maize | QPM | HMM | normal maize | QPM | HMM |
| Maize | 10.2 | 2.51 | -- | -- | 17.63 | -- | -- |
| Biofortified maize (QPM/HMM) | 10.2 | -- | 2.51 | 2.51 | -- | 21.54 | 21.54 |
| Soybean cake | 19.3 | 0.58 | 0.58 | 0.58 | 2.98 | 2.63 | 2.63 |
| Fish cake | 19.2 | 0.20 | 0.20 | 0.20 | 2.34 | 2.34 | 2.34 |
| Broken rice | 7.5 | 0.00 | 0.00 | 0.00 | 4.68 | 4.68 | 4.68 |
| De-oiled rice bran | 7.0 | 0.17 | 0.17 | 0.17 | 2.36 | 3.33 | 3.33 |
| Sunflower | 13.5 | 0.00 | 0.00 | 0.00 | 0.11 | 0.11 | 0.11 |
| Groundnut cake | 15.8 | 0.40 | 0.40 | 0.40 | 4.68 | 4.68 | 4.68 |
| Sorghum | 9.1 | 0.00 | 0.00 | 0.00 | 6.14 | 1.62 | 1.62 |
| Mineral mixture | 26.8 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Oil | 44.2 | 0.04 | 0.04 | 0.04 | 0.00 | 0.00 | 0.00 |
| Di calcium phosphate + other sources of calcium | 24.8 | 0.10 | 0.10 | 0.10 | 5.89 | 5.90 | 5.90 |
| Synthetic lysine | 162.8 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Synthetic methionine | 250.8 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total feed quantity | | 4.02 | 4.02 | 4.02 | 46.83 | 46.83 | 46.83 |
| Feed cost in Rs/bird for the entire lifespan [% change over normal maize] | | 52.8 | 52.8 [0.0] | 52.8 [0.0] | 625.0 | 610.15 [-2.4] | 610.2 [-2.4] |

*Note.* Estimates are obtained from LP model using the feed ingredient price and nutrient composition.
1 US$ = Rs. 45.7 (average of 2010)
*Source.* Optimization results from Appendix B and ingredient prices from firm survey, 2010.

# Appendix B

Nutrient composition of different ingredients and their recommended dose for broilers and layers

Nutrient composition of different ingredients and their recommended dose for broilers and layers

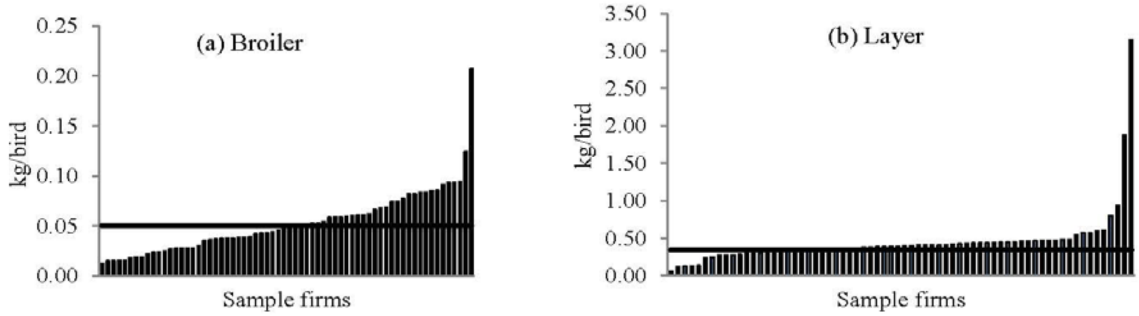
| | Energy (Kcal/kg) | Crude protein (%) | Lysine (%) | Tryptophan (%) | Methionine (%) | Crude fat (%) | Crude fibre (%) | Calcium (%) | Available Phosphorous (%) | Constraint imposed in optimization | Recommended feed requirement (gram/day/ bird) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Feed ingredients** | | | | | | | | | | | |
| Maize | 3350 | 10.00 | 0.26 | 0.04 | 0.18 | 3.80 | 3.00 | 0.02 | 0.13 | = 70% | |
| QPM | 3350 | 10.00 | 0.42 | 0.09 | 0.19 | 3.80 | 3.00 | 0.02 | 0.13 | = 70% | |
| HMM | 3350 | 10.00 | 0.34 | 0.07 | 0.40 | 3.80 | 3.00 | 0.02 | 0.13 | = 70% | |
| Soybean cake | 3300 | 36.49 | 2.18 | 0.47 | 0.54 | 18.00 | 5.50 | 0.25 | 0.24 | = 35% | |
| Broken rice | 2800 | 7.00 | 0.14 | 0.09 | 0.11 | 3.00 | 5.00 | 0.02 | 0.04 | = 10% | |
| De-oiled rice bran | 1700 | 14.00 | 0.83 | 0.21 | 0.31 | 1.00 | 14.00 | 0.10 | 0.19 | = 20% | |
| Sunflower | 1800 | 19.20 | 0.68 | 0.23 | 0.44 | 1.00 | 26.00 | 0.37 | 0.30 | = 10% | |
| Fish cake | 2500 | 60.00 | 4.20 | 0.60 | 1.62 | 9.00 | 3.00 | 5.00 | 2.00 | = 5%** | |
| Groundnut cake | 2400 | 45.00 | 7.47 | 2.07 | 2.25 | 1.00 | 10.00 | 0.20 | 0.19 | = 10%** | |
| Sorghum | 3000 | 8.80 | 0.18 | 0.09 | 0.14 | 3.00 | 4.00 | 0.03 | 0.13 | = 35% | |
| Mineral mixture | 0 | 0.00 | 1.20 | 0.05 | 0.58 | 0.00 | 0.00 | 0.00 | 0.00 | = 5% | |
| Oil | 10000 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | = 5% | |
| Di calcium phosphate + other sources of calcium | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 23.00 | 18.00 | = 20% | |
| Synthetic lysine | 0 | 0.00 | 98.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | = 5% | |
| Synthetic methionine | 0 | 0.00 | 0.00 | 0.00 | 99.00 | 0.00 | 0.00 | 0.00 | 0.00 | = 5% | |
| **Recommended dose in poultry feed** | | | | | | | | | | | |
| Broiler | | | | | | | | | | | |
| Pre-starter (1st week) | 2950 | 23.50 | 1.25 | 0.20 | 0.55 | 6.00* | 7.00* | 0.95 | 0.47 | | 20 |
| Starter (2nd & 3rd weeks) | 3050 | 21.50 | 1.15 | 0.18 | 0.48 | 6.00* | 7.00* | 0.95 | 0.45 | | 61 |
| Finisher (4th to 6th week) | 3150 | 19.00 | 1.05 | 0.16 | 0.42 | 6.00* | 7.00* | 0.90 | 0.40 | | 144 |
| Layer | | | | | | | | | | | |
| Chick (1st to 6th week) | 2750 | 20.50 | 1.05 | 0.17 | 0.45 | 6.00* | 7.00* | 1.00 | 0.45 | | 24 |
| Grower (7th to 18th week) | 2500 | 17.00 | 0.80 | 0.13 | 0.35 | 6.00* | 7.00* | 1.00 | 0.40 | | 55 |
| Layer (19th to 72nd weeks) | 2600 | 16.00 | 0.70 | 0.12 | 0.35 | 6.00* | 7.00* | 3.50 | 0.30 | | 109 |

**Note.** *: Indicates the upper limit values (in case of other nutrients, lower limit values are given); **: Constraints used in *Specification 2* (fish meal was taken as unbounded and groundnut meal = 35% in Specification 1).

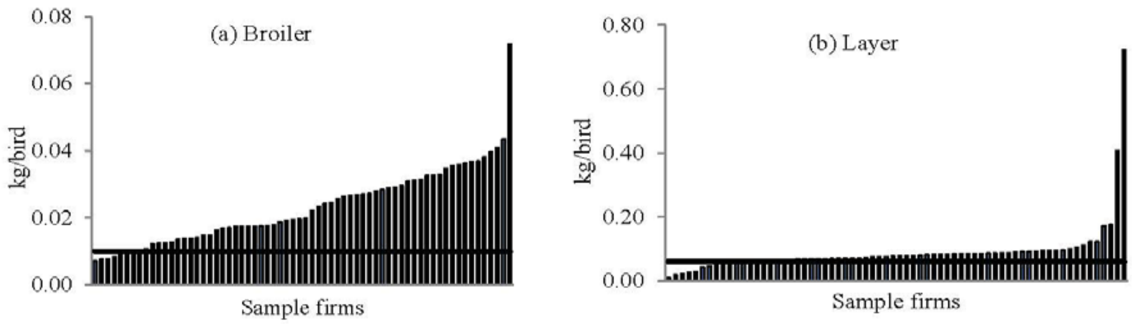
**Source.** PDP 2011, Panda et al. 2009, Mandal et al. 2005, Mandal et al. 2004, Ranjhan 1998

## **Appendix C** Amino acid consumption by sample firms

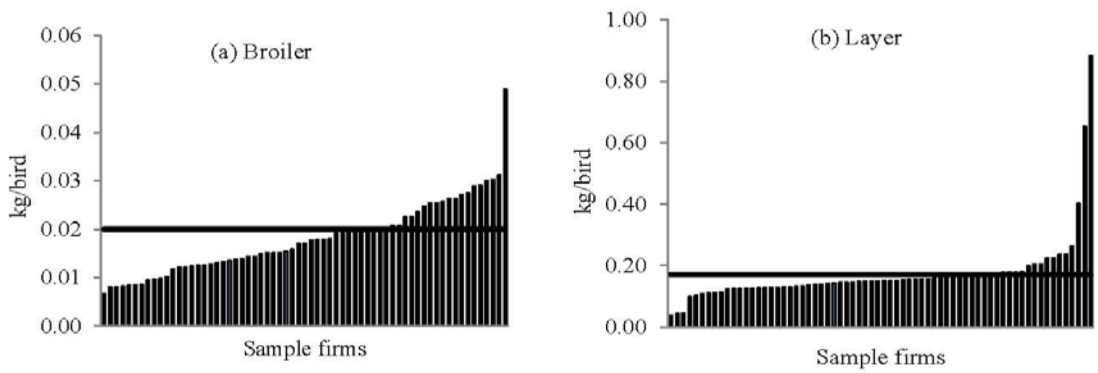
1. Lysine




2. Tryptophan




3. Methionine




**Note.** In these graphs, bar represent the actual use of amino acid by the sample firms and line the recommended dosage.
**Source.** Firm survey 2010.