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Bioscience Study on Analysis of Biochemical Compositions and Nutritional Energy by Linear Method on Poultry Feed

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Abstract: Poultry feed accounts for over 80% of the cost of poultry production. The rising feed cost is driving many poultry farmers out of business. The feed's cost and nutritional quality must be considered when formulating an effective feed to cover the essential needs of poultry—the present paper aimed to brand an optimum poultry feed in terms of price and quality. The samples were collected from different countries that export raw materials, including Morocco. In total, about 200 samples were collected. The nutritional energy and biochemical compositions of the principal trades will be analyzed to determine a method for the production of poultry feeds. This method is done by a linear programming system that allows the optimization of the percentages of each primary trade in order to produce feeds for "3 categories" of poultry (starters: 0 to 4 weeks, growers: 4 to 18 weeks, and layer: 18 weeks to slaughter). An alternative to chemical analysis is the practice of near-infrared spectrometry, denoted as (NIRS). The result is a large database that allows us to evaluate the optimal raw for the production of poultry feeds.

Keywords: formulation; poultry feed; near-infrared spectrometry; biochemical composition.

1. Introduction

The poultry industry requires significant resources and is widely regarded as a premium food product in numerous countries and societies [1, 2]. However, with rising labor costs and a burgeoning world population, the worldwide appetite for animal protein is rising, posing numerous obstacles to meeting the demand for poultry products [3-6].

Poultry feeds are specially designed to feed different poultry species, such as chickens, turkeys, ducks, and geese [7, 8]. These feeds are formulated to meet the specific nutritional needs of poultry at different stages of growth and development, from the starter phase to the egg or meat production phase [9, 10]. Poultry feeds generally comprise a mixture of grains, vegetable proteins, minerals, vitamins, and feed additives to ensure a balanced nutritional intake [10]. The ingredients used to make these feeds are carefully selected to ensure healthy growth, bright feathers, and optimal egg or meat production.

There are also poultry feeds that are specially formulated to meet the nutritional needs of the animals according to the way they are raised. For example, organic poultry feeds are formulated without the use of genetically modified ingredients or chemicals, while free-range feeds are formulated for animals that have access to the outdoors and can feed on a wider variety of foods [11]. Over the last 50 years, significant advancements have been made in the poultry industry's production system, achieved through enhancements in genetic engineering, efficient management practices, and breakthroughs in nutritional science [12, 13].

In conclusion, poultry feeds are a key component of the poultry industry, providing a healthy and affordable source of protein for consumers around the world. Poultry feeds are carefully formulated to meet the specific nutritional needs of different poultry species at each stage of growth and development to ensure healthy growth, optimal egg or meat production, and good animal health with optimal cost and quality.

Poultry feed costing is an important aspect of the poultry industry [14]. Poultry farmers need to be able to determine the cost of feed for their animals so they can plan their budget and set competitive prices for their production [15]. Several factors must be considered to calculate the cost of poultry feed, such as feed composition, quantities needed for each animal, and ingredient prices. Farmers can automate the process of calculating feed costs using feed management software or programming techniques, allowing them to manage their business effectively and maximize profitability [16]. The development of high-quality feed formulations hinges on a thorough understanding of the physicochemical characteristics of raw materials [17] and the impact of replacing some raw materials with others on broiler chicken production efficiency and meat quality [18-20]. The primary aim of this study is to investigate the optimal formulation for poultry feed by analyzing the biochemical compositions and nutritional energy of key ingredients.

2. Materials and Methods

The formulation of poultry feeds involves the process of designing and developing a balanced diet for poultry birds, which will meet their nutritional requirements for optimal growth, development, and production [21, 10]. Poultry feeds are formulated based on the bird's specific needs at different stages of life. The nutrient requirements of the bird vary based on their age, breed, and the purpose for which they are being raised, whether for meat production or egg laying.

The formulation of poultry feeds takes into account the bird's requirements for protein, energy, minerals, vitamins, and other essential nutrients. These nutrients are typically derived from various sources, including grains, legumes, oilseeds, and animal by-products [22]. The process of feed formulation involves determining the nutrient requirements of the bird and the nutrient composition of various feed ingredients. Feed formulators use mathematical models to balance the nutrient content of the diet and ensure that the bird's requirements are met [23, 24, 10].

The aim of feed formulation is to provide a nutritionally complete diet that meets the bird's requirements for optimal growth, health, and productivity while minimizing feed costs and maximizing profitability for the farmer. Overall, the formulation of poultry feeds is a complex process that requires a sound understanding of the bird's nutrient requirements, the nutrient content of various feed ingredients, and the principles of animal nutrition.

2.1. Calculation of nutritional requirements.

Determining the nutritional requirements of poultry involves a number of steps and factors. Here are some of the key considerations that are taken into account when determining the nutritional requirements of poultry:

- Age and stage of growth: The nutritional requirements of poultry vary based on their age and stage of growth. Young birds require more protein and energy than adult birds, while birds in the laying phase require additional nutrients such as calcium and phosphorus to support egg production [25, 26].
- Breed: Different breeds of poultry may have different nutritional requirements based on their size, weight, and genetic makeup [27, 28].
- Gender: Males and females may have different nutritional requirements, particularly in terms of protein and energy needs [29, 30].
- Production purpose: Poultry raised for meat production have different nutritional requirements than those raised for egg production since they have different growth rates and body composition [31, 32].
- Environmental conditions: The nutritional requirements of poultry may be affected by environmental factors such as temperature, humidity, and stress [33, 34].

Feed formulators typically use a combination of empirical data and mathematical models to determine a particular poultry group's specific nutritional requirements. This involves conducting feeding trials in which birds are fed diets with varying nutrient levels to determine the optimal balance of nutrients for their growth, health, and productivity. Once the nutrient requirements have been established, feed formulators can develop diets that meet these requirements, using a range of feed ingredients and supplements to ensure optimal nutrition at a cost-effective price.

Currently, there are nutritional requirements for poultry, as defined by two main organizations: the French National Institute for Agricultural Research (INRA) and the National Research Council (NRC) in the United States [35, 36]. Both organizations publish regular updates of their guidelines, which provide detailed information on the nutrient requirements of different types of poultry at different stages of growth and production. Feed formulators and farmers widely use these guidelines to ensure that their birds receive optimal protein, energy, vitamins, minerals, and other nutrients.

2.2. The nutritional value of the raw materials.

Determining the nutritional values of available ingredients is a critical step in formulating poultry feed. This involves measuring the nutrient content of various feed ingredients, including grains, oilseeds, and animal by-products, to determine their suitability and potential contribution to the overall nutrient profile of the diet. The raw materials used for feed formulation depend on the country or region and on the potential of the ingredients [37].

Several methods for determining the nutritional values of feed ingredients include chemical analysis, near-infrared spectroscopy (NIRS), and in vitro digestion assays. Here are some of the key steps involved in this process:

- Sample collection and preparation: A representative sample of the feed ingredient is collected and prepared for analysis using standardized procedures to ensure accuracy and reproducibility.
- Chemical analysis: Chemical analysis involves measuring the nutrient content of the feed ingredient using a range of laboratory techniques, including proximate analysis, amino acid analysis, and fatty acid analysis. These methods can provide information on the protein, fat, carbohydrate, fiber, mineral, amino acids, and vitamin content of the ingredient [37-39].
- Near-infrared spectroscopy (NIRS): NIRS is a non-destructive technique that uses infrared light to measure the nutrient content of feed ingredients. This method is often faster and more cost-effective than chemical analysis and can be used to analyze large numbers of samples quickly and accurately [10, 40].
- In vitro digestion assays: In vitro digestion assays involve simulating the digestive process in the laboratory, using enzymes and other chemicals to break down the feed ingredient and measure the nutrient content. This method can provide information on the digestibility and bioavailability of different nutrients in the feed ingredient [41].

Once the nutrient content of various feed ingredients has been determined, feed formulators can use this information to develop balanced diets that meet the specific nutritional requirements of their poultry flocks. This involves selecting a combination of feed ingredients that provide optimal levels of protein, energy, vitamins, minerals, and other nutrients while also considering factors such as cost, availability, and palatability.

When formulating poultry feed, it is crucial to consider various factors that may affect the mixture, especially the presence of anti-nutritional factors. These factors can negatively impact the absorption and digestibility of nutrients, inhibit enzymes, cause damage to the liver and intestines, and even result in stunted growth in children or growth retardation in chickens [37, 42, 43].

2.3. Formulation methods.

Poultry feed formulation is a crucial aspect of poultry production that combines various ingredients to provide balanced and nutritious diets for poultry birds. Feed formulation for poultry is a complex process that requires knowledge of the nutritional requirements of different bird species, the availability of feed ingredients, and the cost of the ingredients. Formulating the correct feed for poultry is essential to achieve optimal production performance, including growth, reproduction, and health. Several formulation methods exist for poultry feeds, including Pearson's square, trial and error, and mathematical optimization methods. Each method has its advantages and disadvantages, and the choice of method depends on the resources available, the level of precision required, and the goals of the poultry production system.

2.3.1. Linear programming.

Linear programming is a mathematical optimization technique used in feed formulation for poultry and other livestock species. It involves formulating a linear objective function that represents the nutritional requirements of the poultry and a set of linear constraints that represent the limitations imposed by the availability and cost of the feed ingredients. The objective function is then optimized subject to the constraints to determine the optimum combination of feed ingredients that meet the poultry's nutritional requirements while minimizing the feed's cost. Linear programming is a powerful tool that can consider many variables and constraints simultaneously, making it possible to formulate balanced and cost-effective diets for poultry.

Linear programming is a technique that can be used to minimize the cost of poultry feed by formulating a mathematical equation system that balances the percentage, nutritional value, and constraints of the feed ingredients used in the mathematical equation system [44]. By optimizing the objective function subject to the constraints, the technique can determine the optimum combination of feed ingredients that will meet the nutritional requirements of the poultry while minimizing the cost of the feed [45]. This enables poultry farmers to formulate balanced and cost-effective diets tailored to their birds' specific needs, leading to improved production performance and profitability. However, it requires specialized software and technical expertise to use effectively.

Their principles equations are:

$$Z = \sum_{i=1}^{n} C_i X_i \ \text{(for minimum costs)} \quad (1)$$

$$\sum_{i=1}^{n} a_i X_i \ \geq \ B_i \text{ that } X_i \geq \ 0 \text{ (for constraints)} \quad (2)$$

Z represents the overall cost of the food, Ci refers to the reported unit cost per kilogram of a specific ingredient, Xi represents the quantity of ingredient i per kilogram of food, a_i corresponds to the nutrient values of the ingredient, and B_i denotes the required levels that must be met for each ingredient [44-47].

2.4. Influencing the formulation of a poultry feed.

The optimization of poultry feed involves using mathematical techniques such as linear programming to formulate diets that meet the birds' nutritional requirements while minimizing the feed's cost. The following steps can be followed to optimize poultry feed:

- Define the nutritional requirements of the poultry: The first step in optimizing poultry feed is to determine the nutritional requirements of the birds in terms of the energy, protein, and other essential nutrients that they need to grow, reproduce, and maintain good health.
- Identify available feed ingredients: The next step is to identify the available feed ingredients that can be used to formulate the poultry feed. This might include grains, soybean meal, fishmeal, and other protein and energy sources (Cereals, Protein crops, By-products of the cereal industry, Oil cakes, Vegetable oils and fats, Animal meal, Mineral concentrates, amino acids and vitamins of biosynthesis)
- Determine the nutrient composition of the feed ingredients: It is important to determine the nutrient composition of the feed ingredients to ensure that the poultry feed meets the nutritional requirements of the birds. This can be done using laboratory analysis or using published nutrient composition data.
- Formulate the feed: Using the nutrient composition of the feed ingredients and the nutritional requirements of the birds, a feed formulation can be created using mathematical techniques such as linear programming. The objective is to create a feed that meets the birds' nutritional requirements while minimizing the feed's cost. The threshold of incorporation of raw materials is defined as a percentage for each raw material used in the

feed formulation. The lower and upper limits are established to guarantee the quality of the finished product is constant. In this case, the percentage incorporation thresholds for raw materials in accordance with the recommendations of INRA and DSM [35] are as follows:

-Corn grain: from 20% to 40%.
-Wheat grain: from 0% to 40%.
-Peas: from 0% to 10%.
-Soya: from 0% to 8%.
-Rapeseed: from 0% to 8%.
-Sunflower oil: from 0% to 4%.
-Rapeseed oil: from 0% to 4%.
-Sodium chloride salt: from 0.1% to 1%.

- Test the feed: Once the feed has been formulated, it is important to ensure that it meets the nutritional requirements of the birds and that it is palatable and digestible.
- Adjust the feed: Based on the testing results, adjustments may need to be made to the feed formulation to improve its nutritional value, palatability, or digestibility.
- Monitor the birds: Finally, it is important to monitor the performance of the birds on the feed to ensure that they are growing well, reproducing, and maintaining good health. Any issues with the feed can be addressed through further adjustments to the feed formulation.

2.5. Origin and methods for determination of biochemical composition.

2.5.1. Origin of the samples.

The samples for this study were collected from suppliers delivering ingredients to farmers and at a food processing unit (Morocco). The collection was organized to cover as much variability as possible related to seasons, suppliers, origins, and primary product exporting countries (Brazil, Ukraine, and Argentina) in 2022 and 2023. 150 samples were collected, covering the following categories: cereals, cereal by-products, oil cakes, oils, and miscellaneous. The samples were packaged in dark-colored polyethylene plastic packages to prevent water absorption and lipid oxidation in the presence of light. Afterward, they were transported to the laboratory for chemical analysis.

2.5.2. Methods for determination of biochemical composition.

2.5.2.1. The protein content of the samples.

The Kjeldahl method is a common method for determining the protein content of food samples, including those intended for poultry [48]. Here are the basic steps to perform a Kjeldahl analysis:

- Sample preparation: The sample should be ground and dried to obtain a fine powder. It is important to consider the sample's moisture content, which should be measured and taken into account for the final calculation.
- Digestion of the sample: The sample is then digested with concentrated sulfuric acid and hydrogen peroxide. This step converts the proteins into ammonia.
- Titration of the ammonia: The ammonia produced during digestion is then titrated with a sulfuric acid solution to determine the amount of nitrogen present in the sample.
- Calculation of the protein content: The measured amount of nitrogen is then used to calculate the protein content of the sample by applying a conversion factor. The conversion

factor is typically 6.25 for animal-origin foods, as proteins contain approximately 16% nitrogen.

It is important to note that the Kjeldahl method does not directly measure protein content but rather measures nitrogen content, which is then converted into protein content. This method is considered a reference method for determining the protein content of foods and is widely used in the food industry.

2.5.2.2. Fat determination.

The Soxhlet extraction method is common for determining the fat content in the samples, including those intended for poultry [49, 50]. Here are the basic steps to perform a Soxhlet extraction:

- Sample preparation: The sample should be ground and dried to obtain a fine powder.
- Weighing of the sample: A precise amount of the sample is weighed and placed in a filter paper cartridge.
- Extraction: The sample cartridge is placed in the Soxhlet, an apparatus consisting of a flask, a condenser, and a collection flask. The organic solvent, such as petroleum ether or carbon tetrachloride, is added to the flask and heated to produce vapors that rise and condense on the condenser. The solvent droplets that form on the condenser then fall back into the flask, extracting the fat from the sample.
- Evaporation: The extraction is repeated several times until the fat is completely extracted. The solvent is then evaporated, leaving behind the fat.
- Weighing of the extract: The collection flask containing the fat is dried and weighed to determine the mass of the extract.
- Calculation of the fat content: The fat content is then calculated by measuring the mass of the extract and comparing it to the mass of the initial sample.

It is important to note that the Soxhlet extraction method is relatively time-consuming and requires the use of potentially hazardous chemicals.

2.5.2.3. The ash content.

The ash content was determined using the AOAC 923.03 method [48]. This method is a standard method for determining the ash content of foods. Here are the basic steps of the method:

- Sample preparation: The sample must be dried at an appropriate temperature to remove moisture.
- Weighing of the sample: A precise amount of the sample is weighed into a previously ignited crucible.
- Ashing: The crucible containing the sample is placed in a preheated furnace at a temperature of 550-600°C for about 4 to 6 hours until all organic matter is burned away, leaving only the ash.
- Cooling: The crucible is removed from the furnace and cooled to room temperature.
- Weighing of the ash: The crucible is weighed with the ash to determine its mass.
- Calculation of the ash content: The ash content is calculated by measuring the mass of the ash and comparing it to the mass of the initial sample.

This method provides a measure of the total amount of minerals present in a food and is useful for evaluating the nutritional quality of poultry feed.

2.5.2.4. Cellulose content.

The determination of cellulose content can be done using the Weende method. Here is a general overview of this method:

- Sample preparation: The sample is first dried at an appropriate temperature to remove moisture. It is then ground to obtain a fine powder.
- Starch extraction: The sample is then treated with hot water and ethanol to extract the starch.
- Cellulose extraction: The sample is then treated with sulfuric acid to extract the cellulose.
- Ash removal: The ash is removed by calcination.
- Weighing of cellulose: The cellulose is weighed to determine the amount present in the sample.
- Calculation of cellulose content: The cellulose content is calculated by measuring the mass of cellulose and comparing it to the mass of the initial sample.

Cellulose content is important for evaluating the nutritional quality of poultry feed, as it is related to the digestibility of nutrients in the gastrointestinal tract.

2.5.2.5. Moisture content.

The moisture content of foods can be determined by various methods, including the gravimetric method and the conductivity method [51]. We use the gravimetric method, which involves the following steps:

- Sample preparation: The sample is first dried at an appropriate temperature to remove all moisture.
- Sample weight: The initial weight of the sample is accurately measured.
- Drying: The sample is placed in a desiccator at a controlled temperature and humidity until its weight is constant.
- Dry sample weight: The weight of the dry sample is then accurately measured.
- Calculation of moisture content: The moisture content is calculated by subtracting the dry sample's weight from the sample's initial weight, dividing the result by the initial weight of the sample, and then multiplying by 100 to obtain a percentage.

Determining the moisture content is important because moisture can significantly impact the quality and shelf life of poultry feed. Foods with high moisture content may be more susceptible to bacterial growth and degradation, which can reduce their quality and nutritional value.

2.5.2.6. Starch.

The value of starch can be determined by polarimetry. This method is based on the measurement of the rotation of polarized light by optically active substances such as starch.

The steps of the polarimetry method for determining starch value are as follows:

- Sample preparation: The sample is ground and sieved to obtain a fine and homogeneous powder.
- Starch dissolution: Starch is dissolved in distilled water to obtain a clear solution.
- Measurement of specific rotation: The starch solution is placed in a polarimeter, and the specific rotation is measured. Specific rotation is defined as the observed rotation by an optically active substance of 1 g/mL placed in a tube of 1 dm length.

- Calculation of starch content: The starch content is calculated using a calibration curve established by measuring the specific rotation of solutions of known starch concentrations.

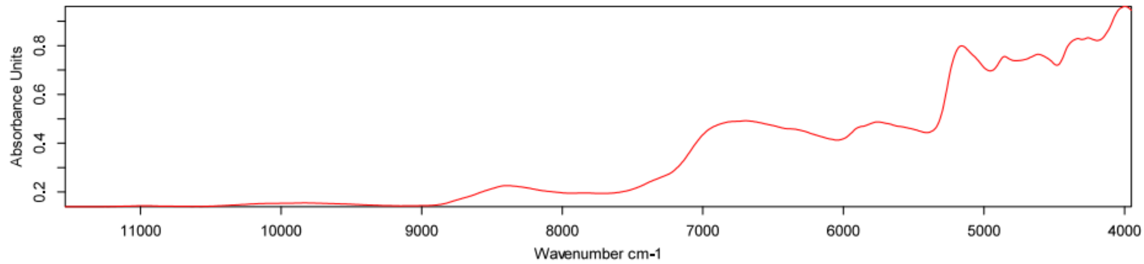
The determination of starch value by polarimetry is important because starch is an important source of carbohydrates for poultry feed. Insufficient starch content in feed can affect poultry feed's quality and nutritive value.

2.5.2.7. Energy value of the samples.

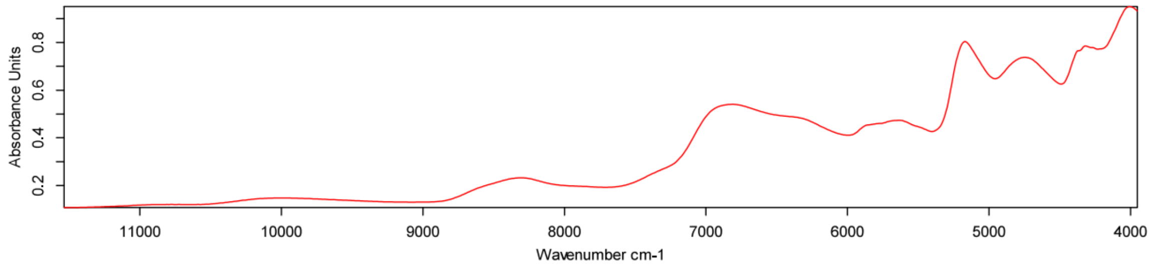
The theoretical energy value of the samples was calculated using Atwater coefficients [52, 53]. These coefficients are conversion values that estimate the amount of energy available in the macronutrients present in food. The standard Atwater coefficients are 4 kcal/g for proteins and carbohydrates and 9 kcal/g for lipids. The theoretical energy value was calculated by applying these coefficients to the samples' protein, carbohydrate, and lipid contents.

2.5.2.8. Near-infrared spectrometry (NIRS).

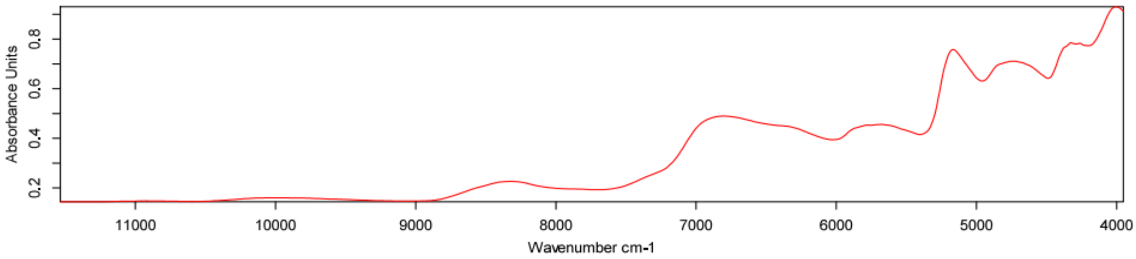
NIRS was used in this study to determine the chemical composition of the samples using a BRUKER MPII spectrometer in quartz cups between 350 and 2300 nm. NIRS is a non-destructive analytical technique that uses the near-infrared region of the electromagnetic spectrum to provide information on the chemical composition of a sample. It is a rapid, reliable, and cost-effective method that can be used to analyze multiple components in a single analysis. The samples were scanned using a NIRS instrument, and the resulting spectra were analyzed using multivariate analysis techniques to determine the chemical composition of the samples, including protein, fat, moisture, fiber, and ash content. NIRS is a valuable tool in food analysis and has the potential to significantly reduce the time and cost associated with traditional chemical analysis methods. Figure 1 illustrates the spectra obtained from raw materials and the corresponding products using NIRS.



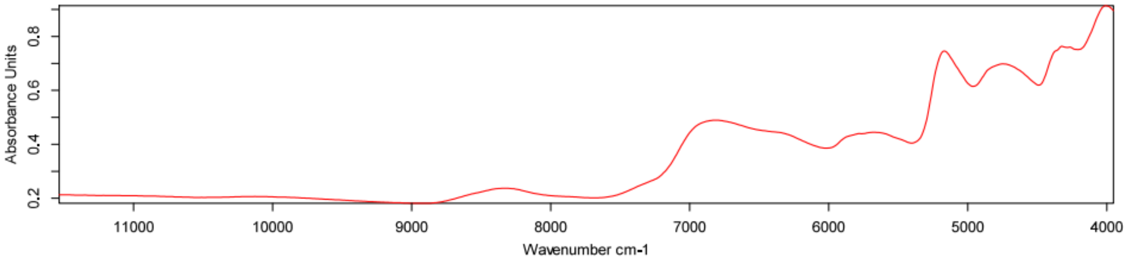
(a)



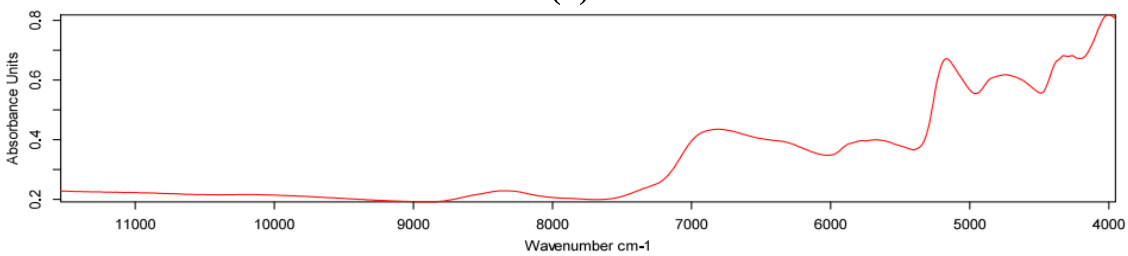
(b)



(c)



(d)



(e)

Figure 1. Spectra of some samples of raw materials and elaborated feeds for poultry. **(a)** soybean; **(b)** corn; **(c)** starter chickens; **(d)** grower chickens; **(e)** layer chickens.

3. Results and Discussion

We selected 9 raw materials that build the variables of the formulation without mentioning the additives; biochemical analyses are made for the raw materials and the formulas obtained, taking into consideration that the analyzed samples are dried; these results are presented and detailed in Figures 2, 3 and 4, and to confirm these results we use NIRS (Figure 1).

The following list contains 9 variables and their corresponding values:

X_1: Soybean
X_2: Wheat middlings
X_3: Alfalfa 17-18%
X_4: Rice bran
X_5: Canola oil
X_6: Corn
X_7: Soft wheat
X_8: Soybean cake
X_9: Wheat bran

These variables represent different types of raw materials. Before manufacturing poultry feed, the chemical, biological, and energetic composition of each raw material used in the manufacture of poultry feed must be determined. This result is presented in Figure 2, and all results are consistent with the worldwide recommended values [54-56].

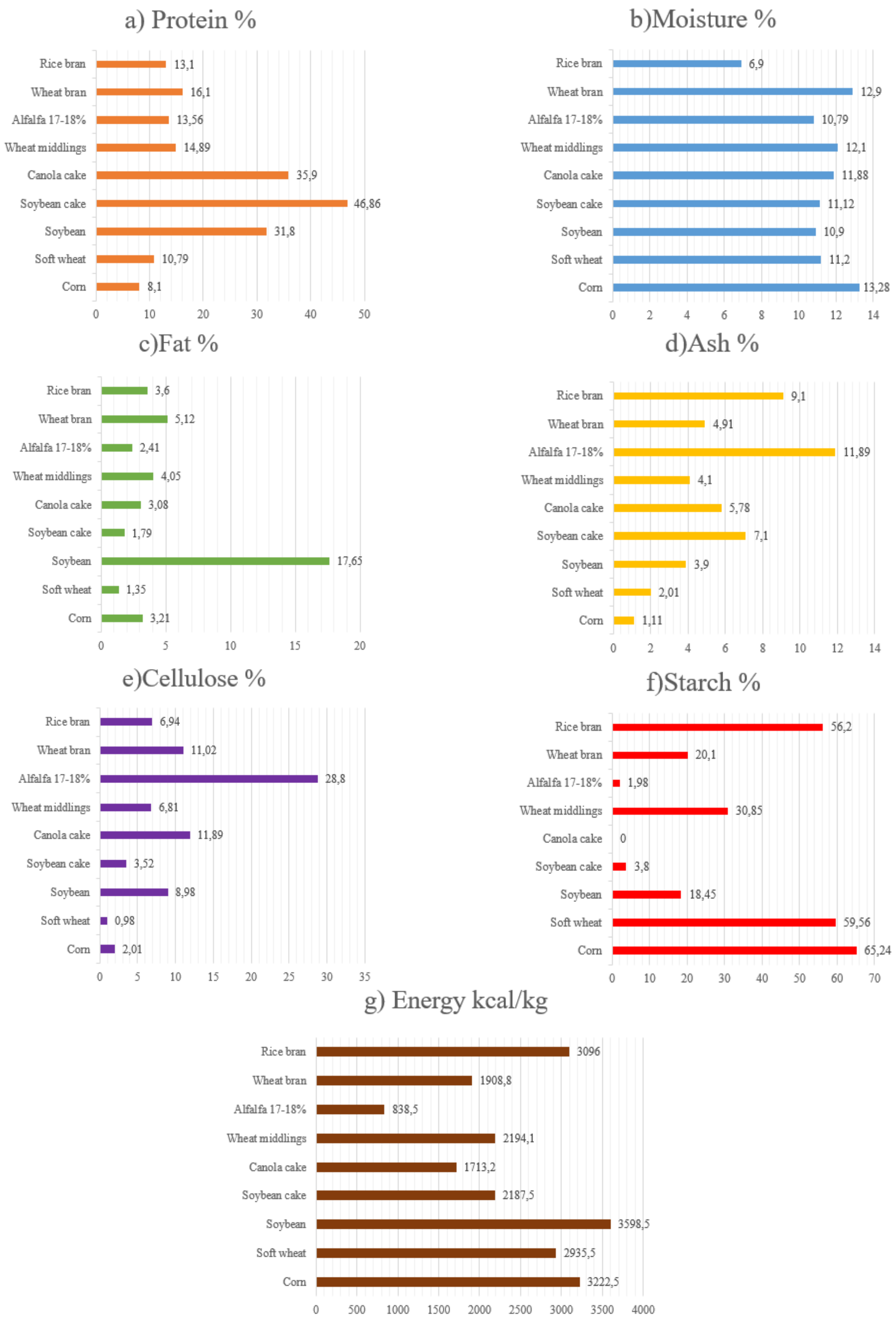


Figure 2. The biochemical composition and energy value of each raw material.

From Figure 2(a), we can observe that the material with the lowest protein content is corn, with a value of 8.1%. The material with the highest protein content is soybean cake, with a value of 46.3%, followed by canola cake (35.9%), this value is higher and also compatible with FAO [56], which means that these materials are a good source of amino acids for poultry [57].

Then, the moisture contents (Figure 2(b)) range from 6.9 to 13.28%. This value is compatible with FAO [56]. Moisture is an important element in poultry feed materials as it can impact feed quality and shelf life. Poultry feeds must contain appropriate moisture to ensure microbiological stability and digestibility.

Figure 2(c) shows that the lowest fat content is soybean meal and soft wheat, with 1.79 and 1.35%, respectively, and the highest fat content is soybean, with a value of 17.65%. This value is compatible with FAO [56]. Fat is a highly concentrated source of energy in poultry feed. It also provides essential fatty acids necessary for the growth and development of poultry [58, 59].

It is important to note that the material with the lowest ash content is corn, with a value of 1.1%, and the material with the highest protein content is alfalfa, with a value of 11.89% (Figure 2(d)). This value is compatible with FAO [56]. Ash contents are important in supplying essential minerals such as calcium, phosphorus, magnesium, sodium, and potassium. These minerals are necessary for the growth, development, and maintenance of the health of the birds [60, 32].

It can be observed that the material with the lowest cellulose content is soft wheat, with a value of 0.98%, and the material with the highest cellulose content is alfalfa, with a value of 28.8% (Figure 2(**e**)). This value is compatible with FAO [56]. Cellulose is a component of plant cell walls, an important fiber source in poultry feed.

From Figure 2(f), we can observe that the material with the lowest starch content is canola cake, with a value of 0%, and the material with the highest starch content is corn, with a value of 65.24% followed by soft wheat (59.56%). This value is compatible with FAO [56]. Starch is an important source of carbohydrates in poultry diets. It provides energy for poultry's metabolic and physical activities, d they need a starch-rich diet to maintain their growth, reproduction, and overall health [61].

Finally, the value of the energy of raw materials (Figure 2(g)) ranged from 838 to 3598 kcal/kg. The energy value of the raw materials used in poultry feeds is important because it indicates how much energy the feed can provide to the bird. This energy is needed to maintain the bird's body functions, growth, and production. Energy values are expressed in kilocalories (kcal) of dry matter.

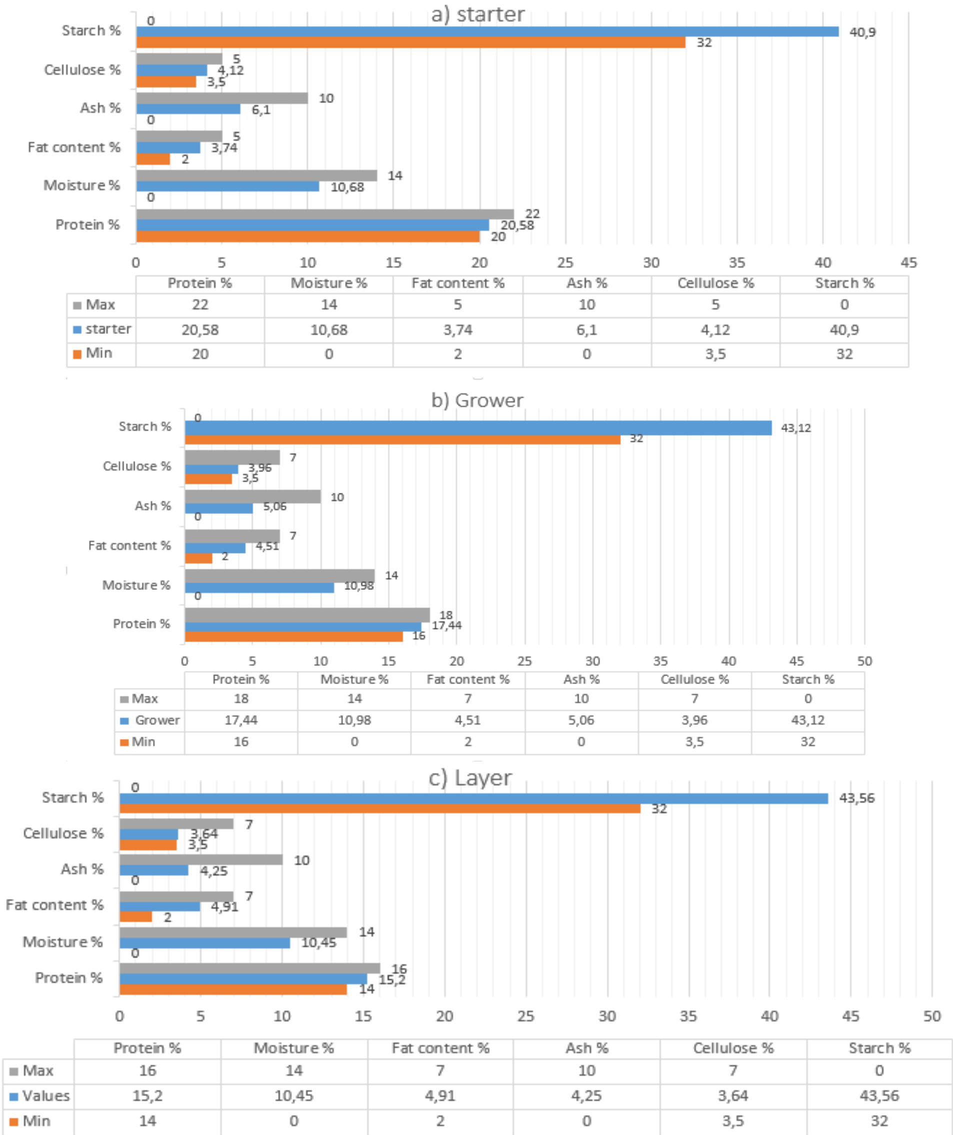
3.1. Results obtained from the formulation of poultry feed.

Each nutrient has recommended intake levels expressed as a minimum and/or maximum concentration in food. These levels are calculated based on the food's energy concentration and daily consumption to meet daily requirements. Essential nutrients such as essential amino acids and vitamins have minimum levels set to achieve production objectives. However, for vitamins, where uncertainties are high, recommendations are set higher than theoretical needs to avoid deficiencies. The selection of nutrients and units used allows for precise adjustment of intakes to requirements. For instance, digestible amino acids, which are usable by the animal, are used to express amino acid intake instead of total amino acids found in the feed.

A mathematical formula was used by linear programming with the Excel solver to formulate the feeds for three categories of poultry:

-Starter chickens (0 -4 weeks)
-growing chickens (4 - 18 weeks)
-laying chickens (from 18 weeks)

Figures 3 and 4 contain the values found for the feeds and the minimum and maximum recommended thresholds according to each poultry category, which are compared with international standards [62]. It can be seen from Figures 3 and 4 that all the results found are within the recommended ranges [35, 62, 55, 54], which indicates that the linear formula used is valid and applicable.



a) starter	Protein %	Moisture %	Fat content %	Ash %	Cellulose %	Starch %
Max	22	14	5	10	5	0
starter	20,58	10,68	3,74	6,1	4,12	40,9
Min	20	0	2	0	3,5	32

b) Grower	Protein %	Moisture %	Fat content %	Ash %	Cellulose %	Starch %
Max	18	14	7	10	7	0
Grower	17,44	10,98	4,51	5,06	3,96	43,12
Min	16	0	2	0	3,5	32

c) Layer	Protein %	Moisture %	Fat content %	Ash %	Cellulose %	Starch %
Max	16	14	7	10	7	0
Values	15,2	10,45	4,91	4,25	3,64	43,56
Min	14	0	2	0	3,5	32

Figure 3. The biochemical composition of each feed poultry.

The protein value was 20.58% for starter chicken, 17.44% for grower chicken, and 15.2% for layer chicken, and these results are compatible and within the recommended ranges (Figure 3). Protein is essential in poultry diets because it is needed for the growth and repair of body tissues, including muscles and feathers, so starter chickens require a higher amount of protein [63, 64]. The poultry needs high-quality protein for egg production and chick growth. Poultry feeds must contain sufficient protein to meet the nutritional requirements of the birds, and the protein sources used must be easily digestible and well-balanced in amino acids for optimal growth.

The value of fat was 3.74% for starter chicken, 4.51% for grower chicken, and 4.91% for layer chicken, and these results are compatible and within the recommended ranges (Figure 3). Fat is a highly concentrated source of energy in poultry feed. It also provides essential fatty acids necessary for the growth and development of the birds. Fatty acids are important in forming cell membranes, transporting fat-soluble vitamins, regulating body temperature, and producing hormones [65-67]. Fat also helps improve the texture and palatability of poultry feed. However, it is important to maintain an adequate balance of protein, fat, and carbohydrates in a poultry diet to maintain optimal health and growth [61]. The use of animal fats, therefore rich in saturated fatty acids, can lead to the formation of soaps that are poorly absorbed by chicks and cause a poor use of calcium and, consequently, an increase in the incidence of tibial dyschondroplasia [76]. It is, therefore, better to use fat from a vegetable source.

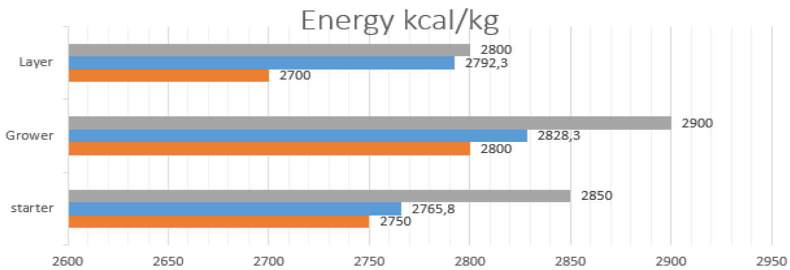
The starch value was 40.9% for starter chicken, 43.12% for grower chicken, and 43.56 % for layer chicken, and these results are compatible and within the recommended ranges (Figure 3). Starch is an important source of carbohydrates in poultry feed [68]. It provides energy for poultry's metabolic activities, nervous system function, and physical activity [17]. Starch is important for the quality of poultry meat because it can influence the texture and flavor of the meat [69, 70]. In addition, starch is used as a binder in the manufacture of poultry feed to maintain the consistency of the feed.

The value of ash was 6.1% for starter chicken, 5.06% for grower chicken, and 4.25 % for layer chicken, and these results are compatible and within the recommended ranges (Figure 3). As a result, the minerals play different functions, like keeping osmotic pressure, maintaining ionic balance, and building the skeleton and/or eggshell [71, 32]. These minerals are necessary to grow, develop, and maintain birds' health. The onset of egg-laying results in a high calcium requirement used for eggshell formation. Ash can also be used to adjust the acid-base balance in poultry feeds, as feeding too acidic or too basic a diet can lead to health problems in birds. Therefore, ash is an important source of nutrients for poultry and should be considered when formulating feeds to ensure proper nutritional balance. Ash is important for poultry because it provides essential minerals needed to grow and maintain healthy bones and muscles [72]. Poultry also requires certain minerals for body functions such as blood clotting, maintenance of osmotic pressure, and oxygen transport. However, excessive ash in the diet can be detrimental to poultry. High ash levels can lead to increased urine production, exacerbating health problems in poultry, especially older or sicker birds. Therefore, poultry feeds must contain an appropriate amount of ash to meet the nutritional needs of the birds without causing health problems.

The value of cellulose was 4.12% for starter chicken, 3.96% for grower chicken, and 3.64 % for layer chicken; these results are compatible and within the recommended ranges (Figure 3). Cellulose is a compound found in plants that cannot be digested by poultry due to their inability to produce the enzyme cellulose [73, 74]. However, cellulose has an important role in poultry diets as a source of dietary fiber, which helps maintain digestive health and prevent digestive disorders such as constipation [75, 76]. Dietary fiber, including cellulose, is also important for weight control in poultry, as it can help reduce feed intake and increase satiety. In addition, dietary fiber can influence the bioavailability of nutrients, slowing the rate of nutrient absorption and releasing them more slowly into the digestive system, which can improve nutrient utilization by poultry [77-79]. Dietary fiber also has a beneficial effect on intestinal health by stimulating the growth of beneficial bacteria in the intestinal tract and improving the consistency of droppings.

The moisture value was 10.68% for starter chicken, 10.98% for grower chicken, and 10.45 % for layer chicken; these results are compatible and within the recommended ranges (Figure 3). Poultry feeds must contain appropriate moisture to ensure microbiological stability and digestibility. If the feed contains too little moisture, it can become too dry and hard, which can cause digestion problems in poultry. On the other hand, too much moisture in feed can cause it to spoil more quickly, promote the growth of bacteria and molds, and cause health problems in poultry [80, 81]. The optimum moisture content of poultry feed depends on the type of feed, storage conditions, and desired shelf life.

The value of energy was 2765.8 kcal/kg for the starter chicken, 2828.3 kcal/kg for the grower chicken, and 2792.3 kcal/kg for the layer chicken, and these results are compatible and within the recommended ranges (Figure 4). The energy values found are consistent with the recommended values, in which the energy source is cereals and vegetable proteins. Cereals have a high energy value due to their complex carbohydrate content, while vegetable proteins have a lower energy value. The addition of fat to poultry diets can also increase the energy value of the feed due to its fat content. However, it is important to note that fat should be used in moderation because feeding too much fat can lead to obesity and health problems in poultry. In summary, the energy value is an important factor to consider when formulating poultry feeds to ensure that poultry receives adequate energy to support growth and production.



	starter	Grower	Layer
Max	2850	2900	2800
value	2765,8	2828,3	2792,3
min	2750	2800	2700

Figure 4. The energy value (expressed in kcal/kg) of various types of poultry feed.

These results obtained from a mathematical formula can be influenced by several factors that cannot be controlled at all times and can influence poultry feed manufacturing. Here are some examples:

- Ingredients in Poultry feed are usually a mix of cereals, proteins, vitamins, minerals, and additives. These ingredients can vary largely due to the variability of raw materials used and inconsistencies we might expect from region or year over the quality, which has an impact on possibly how digestible the feed is.
- Government regulations and industry standards influence the composition of poultry diets. These can take the form of strict regulatory controls on antibiotics and other feed additives.
- Market demand for poultry products is elastic because it can oscillate due to economic conditions, seasonal trends, and the influence of health and dietary implications, which are incepted by various market supply exceptions. To remain competitive, poultry feed manufacturers should be able to respond to these changes in demand.
- Raw material expenses like grain and protein are the raw materials, so these prices will fluctuate according to global and local economic conditions. This would impact poultry feed manufacturing costs.
- Technological innovations, such as the way feed is manufactured for poultry, may also be affected by the technological advances in the production of feeds. For example, novel manufacturing and formulation methods can be implemented to enhance the quality, safety, and shelf life of poultry feed.

4. Conclusions

The characterization of these raw materials has made it possible to highlight their nutritional potential in poultry feed. These data can be used to establish composition figures for local raw materials that can be used in poultry feed. Their dissemination to poultry farmers will allow them to better orient themselves in the choice of ingredients with high nutritional values and reduce the formulation cost. The feed's cost and nutritional quality must be considered when formulating an effective feed to cover the essential needs of poultry. This paper aims to define an optimal poultry feed in terms of price and quality. Samples were collected from different raw material exporting countries and from Morocco. In total, about 200 samples were collected. The analysis of the main trades' nutritional energy and biochemical compositions is to be carried out to determine a method for producing poultry feed. This method is realized by a linear programming system that allows the optimization of the percentages of each main trade in order to produce feeds for "3 categories" of poultry (starters: 0 to 4 weeks, growers: 4 to 18 weeks, and layer: 18 weeks until slaughter). An alternative to chemical analysis is the practice of NIRS, which can be used to estimate the properties of a sample quickly and inexpensively. A large database allows us to evaluate the optimal raw material for poultry feed production.

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Conflicts of Interest

The authors declare no conflict of interest.

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