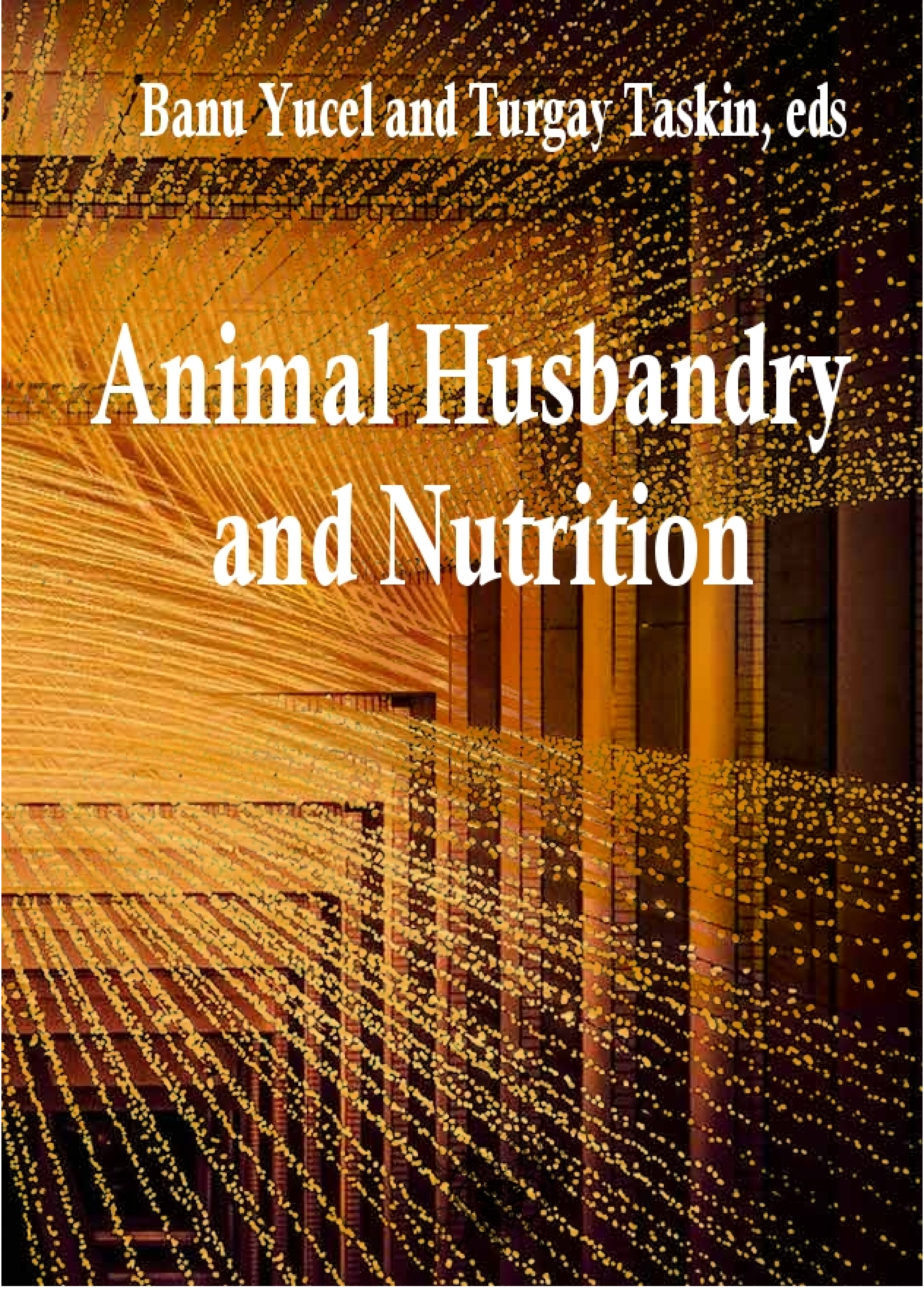

Banu Yucel and Turgay Taskin, eds

Animal Husbandry and Nutrition

Chapter 1

The Innovative Techniques in Animal Husbandry

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Abstract

Technology is developing rapidly. In this development, the transfer of computer systems and software to the application has made an important contribution. Technologic instruments made farmers can work more comfortable and increased animal production efficiency and profitability. Therefore, technologic developments are the main research area for animal productivity and sustainability. Many technologic equipment and tools made animal husbandry easier and comfortable. Especially management decisions and applications are effected highly ratio with this rapid development. In animal husbandry management decisions that need to be done daily are configured according to the correctness of the decisions to be made. At this point, smart systems give many opportunities to farmers. Milking, feeding, environmental control, reproductive performance constitute everyday jobs most affected by correct management decisions. Human errors in this works and decisions made big effect on last product quality and profitability are not able to be risked. This chapter deal with valuable information on the latest challenges and key innovations affecting the animal husbandry. Also, innovative approaches and applications for animal husbandry are tried to be summarized with detail latest research results.

Keywords: animal husbandry, futuristic techniques, innovative applications

1. Introduction

The increased world population is demanding more reliable quality livestock products the number of farms is decreasing but the number of animals for per farm and animal production are increasing In addition to this trend livestock production problems also increasing [1]. The solution of these problems comes from multidisciplinary studies from very different fields such as technology. In large enterprises it is not possible to obtain the expected performance without using technology and automation systems from animals with very high genetic values. Daily work on livestock farming is simple in and standard application routinely Data monitoring in the modern dairy farm enables the ongoing control of production, animal health, and welfare [2]. However, as the number of animals increases, error burden and work load increase. Successful livestock farmers will be capable of rapidly adapting their infrastructures to exploit changes in technology for better production. Mechanism and automation systems offer options in front of the user in intense competition for convenience. Currently, most data is extracted manually, yet manual observation is gradually being replaced by many milking systems by automated recording (milk yield, milk conductivity, activity recording and body weight measurements) leading to better data, both in quantity and quality. The number of farms automation systems has increased rapidly since 1980. Almost any medium- to large-sized farmers can benefit from enhanced automation [1, 2]. There are many opportunities for facilities in automation technologies and systems. Today livestock farmers increasingly use robots on production or algorithms to optimize their farm management decisions. Technological developments are creating a new automation system in which smarter and more flexible work possibilities in livestock production [3]. The automation of animal husbandry and integration of on-farm systems and processes have a key role to play in facilitating the process of meeting each of important challenges for competitive market [4]. The main technology are electronic recording, milking, heat detection auto-weighing, auto-drafting, genetic improvement, feeding, barn optimization, and health monitoring, livestock housing and equipment designs. These technologies provide to dairyman many opportunities to make easier and more convenient their decisions about dairy future plans. This chapter deal with valuable information on the latest challenges and key innovations affecting the animal husbandry aspect of milk, meat production and reproductive performances of the herds. Also, innovative approaches to dairy cattle, beef cattle breeding, and reproductive performance characteristics are tried to be summarized with detail research results. This chapter provides an introduction to systematic reviews and discuss the result of innovative research results in animal husbandry, animal welfare, animal health. The aim of this chapter is to present a review of the current scientific viewpoints about the concept and definition of animal husbandry innovations. The use of systematic reviews to address questions about intervention effects, usage, economy, positive and negative points of technology and innovations are discussed. The need of interaction among different disciplines is stressed, as well as the need to scientifically assess innovation using validated indicators. This chapter starts with examining technology requirements in animal production for getting better and good quality animal products and the role of innovation. Also, current innovative technologies and equipment's possibilities usage results were reviewed using most detailed research results. After these section chapter then examines the different technologies that use to obtain more convenient production knowledge and technologies usage level at farm level. Lastly, the chapter uses worldwide research results to assess the overall level of innovation of animal production. In addition to benefits of the innovation, some suggestions and implications about unintended side effects in its production and application will be summarized.

2. Current technology applications

The benefits of new technology are plentiful and include increased cost efficiency, improved animal welfare, improved working conditions, better production monitoring (e.g. remote monitoring, access to real-time data) and improved provision of important production data. The new technology means producers can work easier and improve cattle welfare, production efficiency, and profitability. Technologic developments provide more efficient, profitable and fast solutions for farmers to get on time process using management and direct manipulation possibilities. Continuous monitoring of disease, and its careful management is essential for the well-being of an animal management [5, 6]. This can be achieved through the detection of early stages and, subsequently, the detection and treatment of the infection [7, 8]. Automation today is super-sophisticated technology and software as well as complicated machinery. A number of computer-assisted image analysis applications are being developed for more convenient animal husbandry. The latest computer programs can identify and classify sounds of animal for specific situations. Many research concluded that these applications could be used to monitor the welfare of animals and provide early identification of disease, physiologic status, and abnormality [9, 10].

The main technology that livestock farmers requirements met is electronic records, milking, heat detection walk-over-weighing, auto-drafting, genetic improvement, feeding, barn environment optimization, and health recording etc. Some sensors are currently available for this purpose, but they do not fulfill all demands. Also, with advances in proteomics and genomics, new biomarkers are being discovered, allowing the disease to be detected at earlier stages. This will lead to assays with higher sensitivity, which can provide additional quantitative information on the level of inflammation 'on-site' and 'on-line' and which is also faster and less expensive. These technologies provide to dairyman many opportunities to make easier and more convenient their decisions about dairy future plans.

3. Breeding and genetics

In dairy farms which very high genetic value of breeding animals cannot get the expected performance without the use of latest technology. Dairy cattle herd management programs if can be used as effectively, dairy farming will have many advantages for consumer, farmer and also animals. Genetic information and type evaluation of herd members and bulls are particularly suitable for expanded electronic updating. However, to obtain these advantages from this system required to have knowledge of the functions and effective use of the functions. The large amount of data in the obtained on many issues related to animals, herd management, and an individual unless used in decisions about animals, ensuring the heavy data flow, record keeping or assessment will not give the expected results. Breeds in animal husbandry has changed a lot with the use of breeding and gene technology. Till 1980s livestock products demands have been met by breed substitution, cross-breeding, and within-breed selection. But these demand in future is to be met using new techniques such as such as artificial insemination and more specific selection techniques. Genomic selection provides more possibilities for the more high rate of genetic gain in the livestock sector. After all genomic breeding values will be calculated from the genetic marker, rather than from pedigree and phenotypic information in near future. The genome maps for poultry and cattle is completed and these developments provide new opportunities for animal breeding and animal models [11]. Leakey [12] reported that DNA-based tests for genes or markers affecting traits that are difficult to measure currently, such as meat quality and disease resistance, will be particularly useful. But genetic resources still important for helping livestock adapt to changing the climate [13]. Native breeds are to genetic insurance against future challenges. In combination with modem reproductive technologies, there is potential to use frozen and stored germplasm (genetic resource banks) to support conservation measures for the maintenance of genetic diversity in threatened species. Besides the direct application of technologically advanced reproductive procedures, modern approaches to non-invasive endocrine monitoring play an important role in optimizing the success of natural breeding programs [14]. A separate progeny-test category may be developed for farms that collect all data electronically and have those data monitored closely. Automated data collection along with parentage verification offers substantial opportunities for genetic improvement of overall economic merit. Nowadays biological samples are sent laboratory for genetic analysis to identify the relevant genes responsible for productive parameters. Also, selective breeding can reduce the need for alternative methods.

4. Computer and internet usage

New technology in computers, biotechnology and scientific discoveries regarding ruminant nutrition and genetics provide the basis for accelerated progress in milk production for those dairy farmers that adopt these technologies. 10 years ago most dairy farmers focused their attention solely on animal husbandry practices. The use of computers for farm management in dairy sector started in as early in 1990s in many developing countries. As personal computer was developed and the price has dramatically declined, more and more farmers began to use computers by themselves in the last decade. But generally, computers have been used by producers with larger farms. Small-scale farmers bypassed the technology because of its cost and their lack of knowledge about computer use in farming. Many computer programs were described, by which data on data in dairy herds may be processed. The some computer software is designed for timely and direct convenience to farmers. Thus, the breeder can evaluate the monthly lots of data using many formulas with high accuracy using these software. It can also be programmed for annual report for detail evaluation of herd evaluation. In addition to all these, daily milk yields feed consumption, pregnancy check, inseminated cow list can be programmed for daily work routine. In recent years there is a form of high interest to cattle breeding and this is leading to the establishment of intensive farms. The only criteria for the life cycle continuity of these intensive farms would be on maximum profitability and competitiveness ability on market. This concept mainly related to forceful usage of knowledge, technology and management at intensive farms and small enterprises and cattle breeding organizations. Whenever the farmers meet any problem in order to refer to an organization for learning to new solutions and the absolute result most probably they prefer to share with farmers who are more experienced for them [15]. But developed countries heavily use computer and internet that is the main way to reach information [16, 17]. Meanwhile in undeveloped or developing countries, several reasons limit using computer and internet these are listed as high financial cost, difficulties to use technology, loss of knowledge to economic benefits, hesitate to use new technologies, lack of education, strict personality, poor infrastructure, lack of personal experience and not enough time to spent [18]. On the other hand, the country wide effect of the communication instruments extends to 80% and this is enough to eliminate most of the reasons which are mentioned above. If the farmer evaluates the benefits of using computer and internet they will replace this technology in farm management.

5. Electronic identification

The Electronic identification system is started 1970s. However, current laws deal with the visual, readable markings that are placed on the animal (EU Directives 92:102:EEC and EU Directives 820:97:EC) [19]. There are numerous animal ID technologies available to livestock producers. Radio frequency identification (RFID) will likely be used to identify cattle. These devices have an electronic number that will be unique for an individual animal and link that animal to the database [20]. Electronic ear tags, injectable transponders and boluses with a transponder, inside in the reticulum are the latest technology for animal identification technology [18]. Many types of RFID tags (boluses, ear tags, injectable glass tags) are used subcutaneous placement for animal identification. These systems work using radio frequency for sending data. Boluses retain in the first two stomachs of the ruminants and accepted as safe for animal health [21]. They can be administered even to lambs after weaning at the fifth week and the retention rate can reach 100% [22]. The injectable transponders, on the other hand, can be applied easily after birth [23], while the preferable locations differ in each animal species [24–26]. These technologies (implants, ear tags, and rumen boluses) are available on the market for cattle farmers. All these devices has special chip system for sending data for the base computer for evaluation. These devices has some specific components on their system regarding storing and evaluating data used for evaluating herd data. Some electronic tags has reader which can be receive and store the required many data for evaluation. Some of tag works transferring the number to another storage system for another evaluation stage. Data sends using antenna for transfer data on the system [27]. From a technological point of view, RFID tags can be grouped in two categories according to the carrier frequency band: LF (low frequency) tags function at 125–134.2 kHz, whereas HF (high frequency) tags function at 13.56 MHz. Electronic scales may be justified as a way to determine body condition score automatically. Another technology which is very useful for farmers is electronic weighing system. An easy and powerful electronic weighing system that accurately measures cattle weight. So farmers can monitor cattle performance easily and continuously. These system established on the road the waterer or cattle squeeze. Stored information send to the main computer for evaluation. Complimenting this is auto-drafting, where cattle going through a race are automatically separated on the basis on age, sex, or weight, or any other criteria the producer preferences.

6. Milking automation

Milking automation system is also involve the dairy sector at 1990s [28]. Suitable objective measuring systems are needed in animal husbandry to quickly and safely recognize illness, normal estrus cycle, quiet heat or stress in animals [29, 30]. An automatic milking system requires a completely different management system for milking, feeding, cow traffic, cow behavior and grazing, but also for safeguarding milk quality and animal health [31]. Electronic devices or sensors are the tools that need to take over the human visual inspection for abnormality. In order to develop sensors to detect abnormal milk a definition of abnormal milk is still basic requirements [32–36].

Sensors have been in the market for a long time, but their use in milking systems is quite new. Because milks were being evaluated by milkers during milking. However, with the development of intelligent milking systems, the use of sensors in the milking systems has become widespread [37].

The milking robots equipped with sensors to detect signs of mastitis which measures the many characters of the abnormal milk pH, Somatic cell count, milk acidity, milk conductivity etc. systems also can be regarded milking specifications of the system such as parlor performances, milking efficiency etc. [5]. Simple automatic cup removal devices monitor the milk flow rate from individual cows and at a threshold, the milking vacuum is shut off and the system is activated to withdraw the cups from the cow. Post-milking teat disinfection is an established component of many mastitis control strategies. This is normally performed manually in many farmers using either a pressure operated spray lance or more a dip cup. Behavior meter also installed to the milking systems for animal monitoring. The behavior meter continuously records the lying time, lying bouts and the activity of the individual animals. The cow-behavior observations enable animal welfare assessment in different environmental conditions and stressful situations, as well as reproductive and health status [38]. Another options to separation gate usage at automatic management systems.

The cattle separation is a risky and challenging activity that needs to be done frequently. If milkers also make an animal separation, the milking efficiency and parlor performances decrease. Reducing the need and risk of this workforce for separation is an important advantage. The grouping and separation of cattle in the big herd constitutes an enormous workload for the farmers. Electronic separation gates are not common in many cattle farms [19, 20].

Removing the labor required to separate animals can have a significant impact on the performance of the handling and management operations. To a lesser extent, diseased cows need to be brought to the attention of the dairy farmer. Some sensors are currently available for this purpose, but they do not fulfill all demands. When an operator is involved with animal separation, other tasks are not being done and performance suffers. With larger herds, identification and drafting of individuals are major tasks. Automatic drafting is not routinely installed on many dairy farms. Electronic tongue technology gives more advantage for farmers for many aspects [39]. Electronic tongue used potentiometric chemical sensors. An array comprised sensors with plasticized PVC membranes with cross-sensitivity to inorganic and organic cations and anions, chalcogenide glass sensors, chloride-, potassium- and sodium-selective electrodes, and glass pH electrode. Automatic milking systems using newly developed sensors (NIR, SCC and LDH etc.) provide much faster and more effective results. Many biosensor search studies for mastitis diagnosis continue [40].

Tsenkova et al. [41]	Near infrared (NIR)	SCC in raw milk
Pemberton et al. [42]	Electrobiochemical sensor using a screen-printed carbon electrode (SPCE)	Detect NAGase via its ability to convert the substrate 1-naphthyl N-acetyl-b-D-glucosaminidinase to 1-naphthol
Eriksson et al. [43]	A gas-sensor array system, or 'electronic nose'	Interact with volatile substances, including sulfides, ketones, amines and acid
Whyte et al. [44]	To automatically determine the SCC based on measuring the DNA content of somatic cells	The DNA and histone levels can then be measured and correlated to the SCC
Wu et al. [45]	PicoGreen	The DNA from somatic cells was incubated with PicoGreen, and the resulting fluorescence was measured using an optical sensor
Akerstedt et al. [46]	Competitive biosensor assay	Surface plasmon resonance to monitor the interaction between Hp, which was immobilized onto the chip surface, and hemoglobin (Hb)
Choi et al. [47]	Fluorescence was measured using an optical sensor	A chip for simultaneously monitoring pathogens, somatic cells and pH in raw milk samples
Mottram et al. [48]	Chemical-array-based sensor "electronic tongue'	To detect chloride, potassium and sodium ions released during mastitis in addition to inorganic and organic cations and anions
Moon et al. [49].	Disposable microchips	The milk sample is mixed with a lysis solution to burst the somatic cells, and a fluorescent dye is added to stain the DNA
Rodriguez and Galanaugh [50]	Disposable device	On counting milk leukocytes
Hettinga et al. [51]	Detection of the patterns of volatile metabolites produced	To identify different pathogens, such as *S. aureus*, coagulase negative staphylococci, streptococci and *E. coli*, and to determine infection-free udder quarters
Davis et al. [52]	A lactate screen printed sensor	Elevated levels of lactate
Garcia-Cordero and Ricco [53]	Biochips	Sensor-based platforms with the development of novel biomarkers could thus allow the diagnosis of the pre-clinical stage of mastitis
Garcia-Cordero and Ricco [54]	Microfluidic CD-based assay device	After centrifugation on a conventional CD-player, the SCC can be measured based on the height of the cell pellet formed
Lee et al. [55]	A biochip	Incorporated DNA amplification of genes that are specific for seven known mastitis-causing pathogens
Dimov et al. [56]	Microfluidic device	Integrates solid-phase extraction and NASBA has recently been reported for the identification of low numbers of *E. coli*

Table 1. Research results of sensors technology used for mastitis detection.

Viguier et al. [40] reported that the current SCC and alternative methods for detection of mastitis. There are a lot of sensors which are used for good quality milk productions. Faster results have been achieved with the use of microchip technologies. In addition, with these technologies, you are ready to diagnose more successful mastitis with more effective tests and results with wider angle, more accurate results. All these each tests provide rapid mastitis detection. Milk conductivity and appearance of milk is used commonly on the farms. But other methods give another early mastitis detection for the fast and accurate decision for cure disease.

A number of other methods using visible and other light spectra have shown promise in detecting milk abnormalities and measuring various components of milk [39]. **Table 1** summarized the technology of main sensors used for mastitis detection.

But De Mol and Ouweltjes [57] reported that the single and combined measures of 29,033 milkings to detect clinical mastitis and concluded that early warning is not reliable with sensors and software currently on the market. Lind et al. [58] reported that as of 2000 there were not yet sufficiently effective methods available to monitor characteristics of milk automatically so as to divert milk from unhealthy cows. Binda et al. [59] reported that many farmers were still reluctant to rely on electronic devices to monitor cow health status.

Automatic milking systems give many information about milk production, milking speed, milk acidity, milk conductivity etc. new sensor added some other new component such as milk progesterone level, milk temperature etc. But radio-frequency identification provide more possibilities for improving the reliability of collecting data.

7. Feeding automation

Computer programmer designed many software for make best option for farmer to ration preparation. Optimal feeding programs can be done for advanced options such as live weight, racing, lactation period and animal feed stock information. These programs use data from the National Research Council in animal feed and feed content.

Various systems for automated animal feeding will be used in many big dairy farms to get better production. They will comprise complete systems include each stage of feeding, feed preparation, mixing equipment and the installations for distributing feed. Feed components such as grass and maize/corn silage as well as mineral feed and feed concentrate will be loaded, mixed and delivered to the feed table built up there by the systems. The Automation systems as simple consists of a control panel, a programmable command manager, a scale, a communication interface and finally all the needed equipment to organize the feeding process and feed provision to the animal of each age groups. Computer-controlled calf feeders have many advantages over traditional calf feeding methods. Calves carry a transponder, and it is possible to follow the daily intake of individual calves [39]. Calves learn to use the computer-controlled milk feeding system fairly easily and this the technology offers a significant reduction in labor cost (73%). These systems can be combined with automatic weighing and health observation system for calf welfare. Calves reared in a group-pen had fewer days of medication than calves in hutches [60] fed milk-replacer from buckets twice a day. Electronic Concentrate Feeding system ensures that each cow is supplied with the exact ration of feed at the exact right time. The Belt Feeder feed distributor is the ideal introduction to the concept of automatic feed supply systems. Small, flexible, economical – the combination of a conveyor belt and sliding scraper. Grothmann et al. [61] reported that the various technical approaches to automation. These are reported that the stationary systems such as conveyor belts and mobile systems such as self-propelled or rail guided feeder wagons. In addition to feeding system automation approaches, rumen activity sensors are very popular innovative techniques for cattle farmers to reduce metabolic disorders. When the sensitive cows exhibit increasing acidosis, this allows a farmer to adjust feeding to prevent major problems [62].

Many electronic sensors can be used for rumen pH and rumen temperature of cattle. Especially rumen bolus can work 100 days continuously and data stored every 15 minutes for future evaluation [63].

The rumination activity is a good indicator of cattle health condition. A certain level of well being is a prerequisite for rumination [64] excitement and stress [65], states of anxiety [66] and various diseases [67, 68] inhibit rumination [69]. Another sensor used for collecting data for cow jaw movement to estimate chewing activity. This sensor works on the principle that the changing pressure of the animal is not detected during opening and closing of the mouth.

8. Health observation

The big hazard for animal production is to disease outbreak. The disease can spread quickly in the confined conditions. Many diseases has specific signals for detection, animals to look for signs of stress, disease, and damage caused by many agents. They alert staff or, potentially, other systems to find the affected animals and identify them report to manger before the problem spreads. An animal disease has serious economic implications on farm productivity. Public institutions and private groups are working collectively to assist individuals in addressing society’s stake in disease prevention and control [69]. The right time detects disease three to 5 days’ sooner, reduce treatment costs, reduce mortality rates, improve production efficiency. The production, product quality, product composition, body condition, and behavior provide a good indication for the health status of animals. By closely monitoring normal pattern changes, the farmers ensure animal health status. Many firms provided programs developed and provided by data collection and analysis products for monitoring animal behavior for the best early detection system. To monitor the health conditions of each cow the sensors are mounted on the cow. Sensor networks consist of several tiny, low price devices and are logically self-organizing ad hoc systems. The role of the sensor network is monitoring the health parameters of animals, gather and convey the information to other sink nodes. Sensors that collect data such as temperature, pH, etc., receive a lot of data, so it is possible to transmit data at intervals. Many new sensor technologies that will be useful in animal health and behavior are developed [70, 71].

Another sensor usage results of an experiment in which a temperature sensor built into a bolus were placed in the rumen of a cow [68, 72, 73]. On-farm scoring of behavioral indicators of animal welfare is challenging but the increasing availability of low cost technology now makes automated monitoring of animal behavior feasible. Furthermore, behavioral measures, such as the occurrence of aggression or stereotypic behavior, are important indicators of welfare problems. Including behavioral-based welfare criteria is, therefore, essential for an overall welfare assessment.

9. Reproductive performances

Estrus detection technology; Average calving interval in cattle farm is the best criteria for comparisons for reproductive performances of the farms which is varying between 13 and 18 months [60, 74], heat detection efficiency vary between 30 and 50% in most dairy herds [69, 75]. Research results showed that the 5–30% of the cows were not in or near oestrus when inseminated [76, 77]. Results of oestrus detection varied depending on the many factor such as threshold value, cow number, barn style, and the statistical method for data analysis. The detection error rates between 17 and 55% and indicate a large number of false warnings [78]. As a result of satisfying oestrus detection and conception rates, purchase and maintenance costs of the oestrus detection system should charge off. A number of both inexpensive to expensive aids and technologies are available to meet some but not all of these criteria [79]. Traditionally, oestrus detection is performed by visual observation of the dairy herd in many countries but this procedure particularly difficult on large dairy farms [80] because of short observation periods during feeding and milking. Galiç et al. [81] reported that the effect of herd size on milk yield, calving age, lactation number, and calving interval is significantly important ($P < 0.01$) and small farms are generally more successful than large farms. Mean duration of oestrus was calculated by Schofield et al. [82] as 13.5 h with a standard deviation of 2.3 h. [83, 84]. As a result of technical progress in monitoring cows using computers, automatic oestrus detection has become possible. In many studies, different traits have been analyzed for utilization in automatic oestrus detection. The electronic systems are an electronic device that detects cows that stand to be mounted by a herd mate and provides a continuous monitoring of activity [85], radiotelemetry is a computerized estrus detection devices. Also patches give another possibilities using mounting activity of cows. I a cow mount another cow then he transmitter is depressed and a signal sent to a receiver. During this time, date, time and duration of the mount stored and send to the main computer. On computer all these data evaluated and prepared for final decision.

Although costs associated with computerized estrous detection are higher than other methods, the benefits may pay off with increased estrous detection accuracy. Estrus detection errors can result huge economic loses for dairy farms. The economic loses vary \$2–\$6/day for dairy farms. But missing 1 cycle cost \$42 to \$126 for a cow. Using detection aids provide advantages because of the prevention of these losses [85]. Pedometers are used to detect the estrus by storing past physical activity the current physical activity and comparing it previous activity data. After analyzing data programs prepare report for cow which is activity accepted as estrus. Beeper or flashing light is also use for alerts the farmer for control this cows [79].

Pedometers also used for estrus detection attached to the leg of the cow to measure the amount of her activity over a unit time span.

Many pedometric systems are commercially available in the market. Also standing activity systems is commercially available in the markets. Standing activity activated by the mounting cow. Radio signal picked up by receiver and relayed to a buffer and a personal computer to analyzing of data. This system record cows number, standing time, date and duration to evaluation on time [79].

Chung et al. [86] reported that voice identification processing can be used to detect estrus both economically (simple microphone) and accurately (over 94% accuracy), either as a stand alone solution. The Mount Count manual version of the Heat Watch system is also available in the markets at more low price which is not required a computer or software to process and display the data. One aid is a pressure sensitive device mounted on the back of each cow, which can be triggered when the cow stands for mounting. Pressure sensitive device is programmed when a certain number of valid mounts have been recorded a light give signals. The second one is effective aids for detecting standing estrus is a marker or teaser animal. Marker animals are worn marking device. When an animal in standing estrus is mounted by the marker animal, the chin-ball marker will rub against the animal in standing estrus, leaving marks on her back and rump. Mounting and standing activity are effective methods for estrus detection. There are many other methods available on the system such as cervical mucus, vaginal characteristics, temperature, blood flow, and hormone changes in blood and milk. But these methods not applicable on the farm level. Milk progesterone level is o good criteria for stage of the cycle or pregnancy. So it can be used for diagnose problem cows in herd [87].

The behavior meter continuously records the animal behavior for many purposes (lying time, lying bouts and the activity of the individual cows). The cow-behavior enables animal welfare assessment in different environmental conditions and stress situations, as well as reproductive and health status [28].

Pregnancy check: Pregnancy diagnosis is one of the most important factors to get ideal calving interval. The most common methods are rectal and transrectal ultrasonography of the reproductive tract. Both procedures are required training and time. An experienced practitioner using ultrasound can reliably diagnose pregnancy from 30 days gestation whilst an experienced veterinary is able to diagnose pregnancy from 35 days. Enzyme-linked immunosorbent assay (ELISA), radioimmunoassay (RIA) or latex agglutination (LA) tests use either blood or milk to detect a marker of pregnancy. Estrone sulfate, progesterone and glycoproteins are used for indicators of pregnancy in cattle [8, 88, 90]. Estrone sulfate is a conjugated steroid product of estrone, is produced by the fetus and as such offer high specificity. The negative part of this test is to high rate of false negatives and the inability of the test to reliably diagnose pregnancies before 100 days of gestation [88], progesterone [89]. Wireless system was designed to measure many characteristics of cows is also developed to detect early stage of pregnancy in multiple cows.

10. Barn environment control

Animal production starts at environment which is cow lived in. Many factors affect the sensitivity of cows to their surrounding environmental conditions. Latest technologies involve the use of sensors to collect data, followed by data analyses with the objective of enhancing the understanding of the system interactions, and developing control systems [91]. Latest technologies aim to provide adequate data for producers and farmers to optimize the efficiency of their agricultural system, thus increasing the overall performance of the animals. There are many sensors for use at dairy barn environment control automation. Temperature and relative humidity sensors; airspeed sensors, carbon dioxide sensors, ammonia sensors and light sensors etc. When ambient temperature gets warmer than 25°C cow begins use their energies to cool themselves down rather than to produce milk. The effects of heat stress on dairy cattle physiology and productivity have been well established. Milk yield can decrease by about 10 percent. At the same time, if the environmental factors for example air quality are poor, milk production and quality can be affected adversely. However high producing dairy cows need an optimal indoor climate throughout the year, to maintain high production levels. Barn environment is also important for the farm worker. While the thermoneutral zone for cattle ranges from −5 to 25°C [91]; the thermoneutral zone for people is shifted to higher air temperature ranges. Modern technology also helps to control barn environment which is many sensor installations to measure factors such as temperature, humidity, solar radiation, and luminosity over a large cultivated surface. These sensor and automation systems planned as a capable of recording and adapting to environmental conditions inside the barn. The variety of sensors monitors a wide-ranging range of parameters of interest. Automation systems not only can automate for temperature, but also have wind and rain sensors. The wind sensors feed wind speed data into the controller, which then adjusts curtain height to compensate for higher air transfer rates. The rain sensor can be programmed to close the curtain to a predetermined height when it rains to keep moisture off cows and stalls. Cows likes bright environments. For this reason, equal illumination in barn improves milk yield. This is especially important during short winter days. For this reason the right kind of illumination planning, dimensioned to the size of barn, orientation of barn and roof material is very important for good illumination in barn.

Lighting is the most obvious change with the shift to automatize barn. Digitally controlled LEDs can extend the day, supplementing sun in autumn and winter. LEDs use less energy than traditional lamps, making artificial lighting economical. The availability of specialist barn luminaires makes it possible to tune the color. New technology provided is a self-regulating, micro-climate controlled environment for optimal animal growth and production. New technologic tools can monitor nearly every aspect of animal barn indoor environment. Incorporating the environment-sensing capability of wireless sensor networks into mobile monitoring systems can provide convenient control of the barn microclimate anywhere, anytime for more productive animal production. Environmental sensors and other control facilities of the barn is first component of the barn automation. Secondly computerize system for monitoring and controlling for barn environment. And thirdly supports the communication between this two component.

11. Conclusions

The industrial revolution has made a radical change in the production method and systems throughout the world. The net result has been the more comfortable animal, higher production, and decreased labor. The rapid penetration of these new age technologies will provide a further layer of sophistication of farm work and new strategies in animal production. Some of the technologies are already available on the market for framers but most are at the research stage in labs for new applications. Each new technology can enable productivity, growth and other benefits at farm level for animal and farmers as well as at the level of the country where productivity acceleration is sorely needed. Within countries, technology potential will be affected by their sector, and these activities will be affected within sectors. Although some of these technologies are already available, most are at the research stage in labs. Taking all of the factors into account, someone estimate it will take times for technology effect on current farm activities. Animal farming is to big market for technologic applications for more convenient production. While most of the farmers are reliant on new technologic applications to improve their productivity and competitiveness, technology plays a major role in achieving many critical tasks in many animal farms. In today's dynamic competitive market, it does not matter where they operate and where they operate for farmers that the use of technology is not an option is a solution for their problems.

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Chapter 2

Effective Temperature for Poultry and Pigs in Hot Climate

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Abstract

Existing knowledge on the relative significance of air temperature, humidity, and velocity in a hot environment for housed pigs and poultry is reviewed and synthesized in an effective temperature (ET) equation. The suggested unit has an easily perceivable scale where ET is equal to air temperature if the relative humidity is 50% and the air velocity is 0.2 ms^{-1}. The included method to determine the relative significance of air temperature and humidity is similar to the way it is done in the Temperature Humidity Index. Several authors have suggested different Thermal Humidity Indices for different categories of animals, but this chapter found no evidence that the relative importance of temperature and humidity is different for pigs than for poultry or for large than small ones. The suggested ET equation includes a separate velocity term, which assumes that the chill effect is proportional to the **air** velocity or to the square root of the **air** velocity and that the chill effect declines linearly with increased **air** temperature until it becomes insignificant as the **air** temperature approaches the animal body temperature.

Keywords: effective temperature, heat stress, thermal humidity index, air velocity, poultry and pig production

1. Introduction

Hot climate has a direct negative effect on productivity and animal welfare in livestock production. Addressing these negative consequences requires access to a variety of technical solutions that can influence one or more of the air physical parameters in the animal zone. The technical solutions involve approaches such as increased ventilation, air conditioning, air recirculation and insulation and may influence climate parameters such as air temperature, velocity, humidity, and conditions for radiation heat exchange. Optimal use of the available approaches presumes knowledge on how the animals respond to changed thermal environment and how the different air physical parameters contribute to protect animals from heat stress.

Fifty years ago, Beckett [1] suggested an effective temperature (ET) for swine to express the combined influence of air temperature and humidity and defined the effective temperature to be equal to room temperature if the relative humidity was 50%. An air velocity of 0.2 m/s is often used as a reference level for draught-free condition, and therefore, we assess that it will be relatively easy to relate to an effective temperature (ET) that is equal to air temperature if the air velocity is equal to 0.2 m/s.

A long tradition exists for using a combination of dry-bulb and wet-bulb temperature to calculate indices expressing the combined effect of air temperature and air humidity [2]. These indices are given different names but can generally be written in the form of Eq. (1). The Temperature Humidity Index, THI (°C), is the most frequently used name for these indices when they are applied to farm animals, and numerous authors [3–9] have suggested the use of THI to express the relative significance of air temperature and humidity on heat stress among confined pigs and poultry

$$THI = at_{db} + (1 - a)t_{wb} \tag{1}$$

where a is the weighting of dry-bulb temperature; t_{db} is the dry-bulb temperature (°C); t_{wb} is the wet-bulb temperature (°C).

The sole difference between THI and the effective temperature [1] is that THI is equal to the air temperature if the relative humidity in air is equal to 100%, where the effective temperature is equal to air temperature if the relative humidity is 50%. For certain value of a (in Eq. (1)), the effective temperature at the air velocity of 0.2 m/s $\left(ET_{v=0.2}\left(^{\circ}\mathrm{C}\right)\right)$ with approximation can be calculated as THI plus a linear function of air temperature as it appears in Eq. (2)

$$ET_{v=0.2} = THI + bt_{db} + f \tag{2}$$

where b and f are constants depending on a in Eq. (1).

The general procedure used to determine the a-value in Eq. (1) is to expose animals to different combinations of air temperature and humidity and determine which a-value results in the best correlation between THI and measured response variables, which can be physiological parameters [3–9] or production parameters [10]. The resulting a-values differ from study to study, and if more response variables are included in the same study, the a-value may be different for the different response variables [4–6, 8]. Most frequently, reported a-values lie in the interval between 0.6 and 0.9, and normally it appears that the a-values have to differ considerably from the value that resulted in the best correlation before it significantly degrades the correlation between the parameters used and THI. From a practical point of view, it is naturally most convenient to use the same a-value for all of the categories of animals included, and therefore in this study we investigate to which extent the use of a common a-value agrees with reported studies. An initial review of reported studies led us to the assumption that 0.75 would be an appropriate level for a common a-value. In this study, we inquire the validity of using a common a-value of 0.75 by comparing the correlation coefficient at the a-value that best reflects data with the correlation coefficient at $a = 0.75$.

At $a = 0.75$, the constants b and f in Eq. (2) was calculated to be 0.042 and 0.70, respectively, and Eq. (2) can then be rewritten as

$$ET_{v=0.2} = THI + 0.042t_{db} + 0.70 \tag{3}$$

After the insertion of Eq. (1) in Eq. (2), $ET_{(v\ =\ 0.2)}$ can be calculated as

$$ET_{v=0.2} = 0.794t_{db} + 0.25t_{wb} + 0.70 \tag{4}$$

Tao and Xin [9] developed a Temperature-Humidity-Velocity-Index (THVI) for market-size broilers based on measured body temperature increase for 90 min of exposure to 18 different heat-stress conditions. The conditions include three levels of air temperatures (35, 38, and 41°C), two levels of dew-point temperatures (19.4 and 26.1°C), and three levels of air velocities (0.2, 0.7, and 1.2 m/s).

The authors defined THVI as shown in Eq. (5)

$$THVI = (0.85t_{db} + 0.15t_{wb})v^{-0.058}(0.2 \le v \ge 1.2) \tag{5}$$

where v is the air velocity, m/s.

The equation predicts the effect of an increased air velocity at an increased air temperature without considering the animal body temperature, and therefore it does not reflect that the convective chill effect of an increased air velocity must decline as air temperature approaches the animal body temperature.

Our preliminary examination of the data reported by Tao and Xin [9] indicated that it would be more adequate to assume a decreased influence of the air velocity when the air temperature approaches the animal body core temperature. This relationship prompted us to suggest an equation structure that treats the influence of the air velocity as an additional term to Eq. (2) as it appears in Eq. (6)

$$ET = ET_{v=0.2} - c(d - t_{db})(v^{e} - 0.2^{e}) \tag{6}$$

where c is a constant that may depend on animal species, sizes, and animal density; d is the temperature where ET no longer can be reduced by increased air velocity (°C); e is a constant that controls the influence of velocity.

In the study, the data presented by Simmons et al. [11] and Dozier et al. [12] indicate a linear influence of velocity corresponding to $e = 1$ in Eq. (6). An alternative assumption of a square-root relationship of velocity is supported by results reported by Uwagawa et al. [13] and by heat transfer theory where the Nusselts number is frequently assumed to be proportional to the square root of the Reynolds number [14]. The aim of this chapter is to review literature to identify data that can be used for parameter estimation and for validation of Eq. (6) and to uncover the limitations for the equations and the need for using **different** parameters for **different** species, animal density, or body weights.

2. Methods and results

The suggested effective temperature equation was developed from a review of published studies on how pigs and poultry react when exposed to various combinations of air temperature, humidity, and air velocity.

2.1. Combined effect of air temperature and air humidity

2.1.1. Pigs

Beckett [1] based the "swine-effective temperature" on a partitional heat loss diagram for a 67-kg growing pig and presented a graph to illustrate the combined influences of air temperature and humidity. From the mentioned graph, we read the swine-effective temperature for nine combinations of air temperature (29.4, 32.2, and 35.0°C) and relative humidities (25, 50, and 75%) and tested which a-value in Eq. (1) resulted in the best correlation between the effective temperature and Eq. (1). The best correlation was found for $a = 0.88$, and the correlation coefficient was as high as 0.995. Unfortunately, the author did not indicate how well heat loss data were reflected in the presented graphs.

Ingram [3] exposed four pigs aged 10–12 weeks to each of six different combinations of dry- and wet-bulb temperatures (t_{db}, °C/t_{wb}, °C: 32/22, 32/27, 36/23, 36/32, 40/26, and 40/36) and measured the rectal temperature every 5 min for up to 70 min after the exposure began. The author plotted the results against an effective temperature equivalent to THI in Eq. (1) for $a = 0.15$, 0.35, and 0.65. The visual results were that the correlation was best in the graph where $a = 0.65$, but no correlation coefficients were mentioned. A comparison of the included three graphs indicates that an increase in the a-value from 0.65 to 0.75 would have only a limited influence on the correlation between the rectal temperature increase and THI.

Roller and Goldman [4] exposed 26 barrows weighing 76–119 kg to heat exposure for 3 h. Two pigs were tested at one of 13 combinations of dry-bulb temperatures (34.4–42.8°C) and dew-point temperatures (17.7–31.1°C), and rectal temperature, **respiration rate, pulse rate,** and ambient temperatures (dry-bulb and wet-bulb) were measured. Data were examined to determine which relative influence of wet-bulb temperature ($1-a$) in Eq. (1) resulted in the best correlation with results. According to a graph presented by the authors, the best correlation coefficient ($r = 0.88$) was found when the rectal temperature increase after 3 h of heat exposure was used as the response variable, and this correlation coefficient was found at a-value of 0.68. Including the effect of respiration rate increase and the results after 2 h of exposure, the authors concluded that THI using $a = 0.75$ would be the most precise for a single indicator of thermal environment imposed.

2.1.2. Broilers

As mentioned in Section 1, Tao and Xin [9] develop a Temperature-Humidity-Velocity-Index (THVI) based on body temperature increase at broilers exposed to warm conditions at different dew points and air velocities. The authors used Eq. (1) to state the relative significance of air temperature and humidity and found that $a = 0.85$ best represented their data. However, a graph presented in their article indicates a very limited influence of "*a*" in the interval from 0.7 to 1.0. Purswell et al. [10] presented similar relationships. Their study concerned live performance of broilers maintained at three different dry-bulb temperatures (15, 21, and 27°C) and three different relative humidities (50, 65, and 80% RH) **from days 49 to 63 of age.** The authors used regression analysis to demonstrate a quadratic relationship between THI and live performance parameters, where THI was based on $a = 0.85$. Successively, we used their reported data to determine the significance of varying the *a*-value in these analyses. The result was a very limited influence of *a* in the interval from $a = 0.6$ to 1.0.

2.1.3. Laying hens

Egbunike [5] conducted a study using 68 Harco birds that were 10 months old at natural humid tropical environmental conditions. The daily dry and wet temperatures during the study period ranged from 25.4 to 33.3°C and from 20.6 to 22.2°C, respectively. The respiratory rates and rectal temperatures were measured at 2-h levels from 08:00 to 16:00. The correlation coefficients between measurements and Eq. (1) were calculated for each of eleven 0.1 interval of "*a*" between 0.0 and 1.0 in Eq. (1). The best agreement (correlation coefficient = 0.71) was found for respiratory rate at $a = 0.6$. The correlation coefficient would be reduced from 0.71 to 0.69 if "*a*" was increased from 0.6 to 0.75. For rectal temperature, the best agreement (correlation coefficient = 0.69) was found for $a = 0.5$, and using $a = 0.75$, the correlation coefficient was reduced to 0.66.

Zulowich [6] measured 10 different physiological parameters (mainly related to respiration rate and rectal temperature) for laying hens individually exposed for 5 h to five different air temperatures (30, 32, 34, 36, and 38°C) at two different relative air humidities (50 and 90% RH). The author used the measurement to calculate the correlation coefficient for the linear relationship between the physical parameters and THI at *a*-values between 0.1 and 0.9. The result showed that the highest correlation coefficient was at very different *a*-values for the included physiological parameters; however, the *a*-value had a limited influence on the correlation coefficient.

2.1.4. Turkeys

Xin et al. [7] subjected 15–16-week-old turkeys to acute heat exposures of three different dry-bulb temperatures (32, 36, and 40°C) and two different wet-bulb temperatures at each of the dry-bulb temperatures. The authors found a significant increase in the total heat production with heat load which correlated best ($r = 0.98$) with THI at $a = 0.74$.

Brown-Brandl et al. [8] determined the *a*-value in Eq. (1) for tom turkeys at 6, 10, 15, and 20 weeks of ages based on the measurement of four different physiological responses (body temperature, CO_2 production, moisture production, and heart rate). Thirteen birds in each age group were individually exposed to temperatures between 23 and 40°C in combination with relative humidities between 40 and 90%, and response surface methodology was applied to use fewer birds than a conventional design would demand. The resulting weighting of dry-bulb temperature (a) was between 0.10 and 0.99 and the belonging R^2-values ranged from 0.004 to 0.81. **In addition,** the result did not indicate any systematic influence of bird ages, and the large difference between the values indicates that the results have a limited utility in the assessment of using a common a-value in Eq. (1).

2.1.5. *Overview over* a*-values and correlation coefficients*

Table 1 shows an overview of cases where it was possible to state a-values that best reflected the used data and the correlation coefficient for how well the data were reflected at that a-value and at a = 0.75. The table is organized, so the investigations that resulted in the highest correlation coefficient are mentioned first, and the investigations where the correlation coefficient was below 0.6 are not included. It appears that the a-value that best reflected data was between 0.50 and 0.90 and that the correlation coefficient at a = 0.75 was nearly as high as for the a-value that reflected the data best.

[Ref]	Species	Response variable	a-Value	Correlation coefficient
[9]	Broiler	Body temperature increase after 1.5 h of heat exposure	0.85	0.99 (0.99)
[7]	Turkeys	Total heat production after 3.5 h of heat exp.	0.74	0.98 (0.98)
[10]	Broilers	Feed intake	0.90	0.98 (0.98)
		Body weight gain	0.80	0.97 (0.97)
		Feed conversion	0.75	0.90 (0.90)
[4]	Pigs	Rectal temp. increase after 3 h heat exposure	0.68	0.88 (0.86)
[6]	Hens	Maximum rectal temp. after 5 h heat exp.	0.55	0.83 (0.83)
		Respiratory rate after 5 h heat exposure	0.85	0.79 (0.79)
		Time with heat exposure before rectal temperature reaches 44.5°C	0.70	0.73(0.73)
[4]	Pigs	Rectal temp. increase after 2 h of heat exp.	0.80	0.72 (0.71)
[6]	Hens	Respiration rate increase at exposure to natural warm condition	0.60	0.71 (0.69)
		Body temperature increase at exposure to natural warm condition	0.50	0.69 (0.66)
[4]	Pigs	Respiration rate increase after 3 h heat exp.	0.70	0.63 (0.63)
[6]	Hens	Number of times the resp. rate crossed 100 m^{-1} at 5 h heat exp.	0.90	0.63 (0.63)
		Time for hen to reach her maximum respiratory rate at heat exp.	0.62	0.62 (0.61)

The figures in brackets show the correlation coefficient at a = 0.75.

Table 1. Overview of studies where it is possible to state the a-value (in Eq. (1)) that best reflects the used data and the correlation coefficient for how well the data are reflected at that a-value and at a = 0.75.

2.2. Combined effect of air temperature, humidity and velocity

2.2.1. *Broilers*

Tao and Xin [9] provided data on the average body temperature rise for the four broilers included in each of the 18 temperature treatments mentioned in Section 1. We used these 18 observations to determine which values for the parameters c and d in Eq. (7) resulted in the best agreement between predicted values and data assuming either a linear or a square-root dependency with velocity ($e = 1$ or 0.5). The best quadratic correlation (r-square value of 0.97) was obtained at $c = 0.7$, $d = 43°C$, and $e = 0.5$

$$ET = 0.794t_{db} + 0.25t_{wb} + 0.70 - c(d - t_{db})(v^e - 0.2^e) \quad (7)$$

Figure 1 compares the measured body temperature rise with prediction by the equation presented by Tao and Xin [9] (Eq. (5)) or by Eq. (7), at $c = 0.7$, $d = 43°C$, and $e = 0.5$. It shows that Eq. (7) significantly improves the agreement compared to Eq. (5), especially at high heat load.

As it appears from **Figure 1**, the body temperature for broilers exposed to the warmest conditions was elevated by approximately 4°C during the experiment which may explain why the parameter d (in Eq. (7)) is found to be a few degrees above the normal body temperature for broilers.

In order to determine the maximum body temperature increase, Tao and Xin [9] continued the 18 treatments for at least 3 h or until at least one of the four broilers included in each treatment died. Circles in **Figure 1** indicate treatments where at least one of the four birds died. Using Eq. (7), no animals died unless they were exposed to an ET above 35°C, and at least one of the four birds used in each treatment died if they were exposed to ET above 35°C.

If the assumed dependence of velocity is changed from a square-root relationship ($e = 0.5$) to a linear relationship ($e = 1$), then the best reflection of the data presented by Tao and Xin [9] will be at $c = 0.31$ and $d = 44°C$, and the R-square value is reduced from 0.97 to 0.96. This small reduction indicates that an assumed linear relationship with velocity reflects the data almost as well as an assumed square-root relationship.

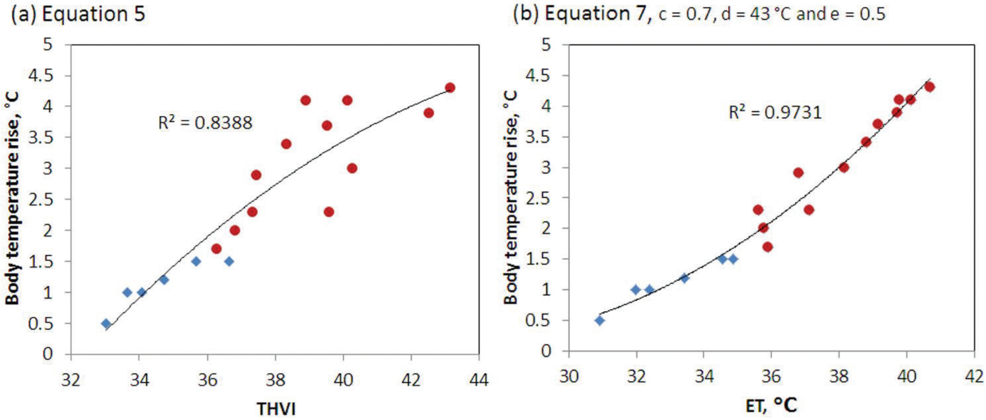

Figure 1. Comparison of measured and predicted body temperature rise for broilers exposed to 18 different combinations of dry-bulb temperature, dew-point temperature, and air velocity as a function of (a) THVI (Eq. (5)) and (b) ET (Eq. (7)).

Simmons et al. [11] measured heat loss from groups of broiler chickens subjected to various air speeds (1, 1.5, 2, 2.5, and 3 m/s) and ambient temperatures (29, 32, and 35°C). The measurements were conducted in a wind tunnel where groups of either 500 five weeks old birds or 400 six weeks old birds, were exposed to each of the 15 treatments for 60 min including a 30-min period permitting the broilers to react to the air speed setting and a 30-min measurement period. **The air velocity was measured** in an unobstructed section at the exit of the wind tunnel. The sensible heat loss was measured as the heat increase across the bird section, and similarly, the latent heat estimation was based on the measured increase of air humidity across the bird section. The authors modeled the measured heat losses as a second-order polynomial of the air velocity for each ambient temperature level, each heat loss type (sensible and latent), and each bird age, and found R^2-values of 0.73–0.96 for the agreements between data and the models. The estimated values generated by the models show a negative sensible heat loss at an ambient temperature of 35°C at air velocities up to 2.5 m/s. This is an unlikely result because it would require that the surface temperature should have been below the ambient temperature and that disagree with Uwagawe et al. [13], that for laying hens and the same ambient temperature measured skin temperatures between 37.4 and 40.2°C. The negative sensible heat loss at 35°C found by Simmons et al. [11] may be due to evaporation of water from litter in the wind tunnel and consequently the underestimation of sensible heat loss and corresponding overestimation of latent heat loss. The estimated negative sensible heat loss at relatively low temperatures makes values predicted by the models unsuitable for estimations of the parameters in Eq. (7).

The two studies of Yahav et al. [15, 16] report the growth performance for fast-growing male Cobb chickens raised for 4 weeks in battery brooders in a temperature-controlled room at 26°C. From 5–7 weeks, the birds were housed in individual cages and subjected to air temperature of 35°C and 60% relative humidity. Each trial included four groups of 60 birds exposed to different air velocities. The authors mentioned that the air velocities were maintained at ±0.25 m/s, but did not provide further information on how the velocities were measured. Reported results show that both the body weight and feed intake increased with the air velocity until the air velocity reached 1.5 or 2 m/s; however, above 2 m/s both parameters decreased with the air velocity. Yahav et al. [16] also measured body temperature and found a significantly higher body temperature among the birds exposed to the air velocity of 3 m/s than among those exposed to 2 m/s. The authors suggested that the body water balance is the main reason for the deterioration in the bird performance at an increased air velocity and that broilers might be unable to drink sufficient amount of water under extreme hot conditions.

For individually kept chickens, these results indicate that the assumption of the influence of the air velocity used in Eq. (7) fails for the air velocity larger than 1.5 or 2.0 m/s. Yahav et al. [15] mentions that the bird density may play a role for the found influence of an increasing air velocity from 2 to 3 m/s. For animals kept in pens at higher density, "radiation and conductance among the birds may increase heat load, and the high density may prevent ventilation of unfeathered areas such as the shanks, which are major structures for sensible heat loss, and thus efficient convection may be prevented" [15].

Simmons et al. [11] and Dozier et al. [12, 17] measured the growth performance of male broiler chickens kept in flocks of 53 birds at a diurnal temperature cycle. Simmons et al. [11] exposed the birds to air temperatures of 25–30–25°C over 24 h (sine curve) with dew point maintained at a constant temperature of 23°C at different air velocities. The reported results for the birds from the 5th to the 7th week of life are reproduced in **Figure 2**.

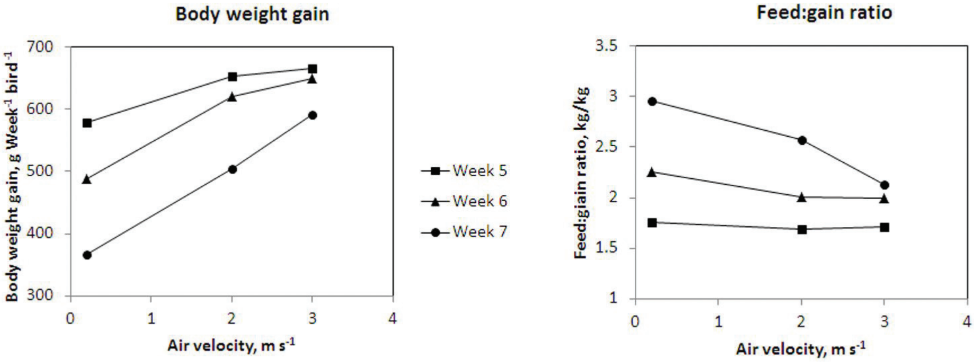

Figure 2. Body weight gain and feed conversion ratio during weeks 5–7 for broilers maintained at different air velocities at air temperatures controlled between 25 and 30°C in a 24-h sine curve and at a constant **dew point** of 23°C (based on the data by Simmons et al. [11]).

For both body weight gain and feed conversion ratio, **Figure 2** indicates a tendency to a reduced influence of the air velocity at an increased air velocity for birds at 5 and 6 weeks of age, but this tendency is not seen for birds at 7 weeks. A possible explanation can be that the younger birds already are close to their optimal production condition at an air velocity of 2 m/s and therefore they will experience a minor benefit due to further increase in the air velocity.

Dozier et al. [17] used a more extreme diurnal cyclic air temperature of 25–35–25°C (dew-point temperature still at 23°C) and reported measured body weight gain and feed conversion rate during weeks 5–7 as shown in **Figure 3**.

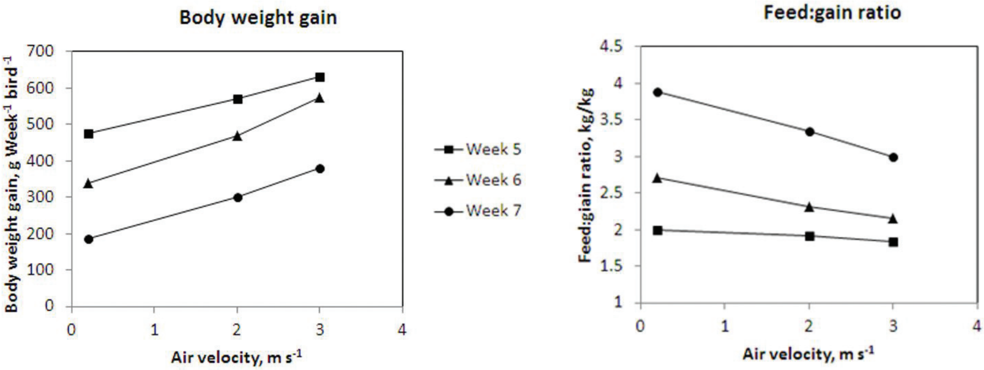

Figure 3. Body weight gain and feed conversion ratio during weeks 5–7 for broilers maintained at different air velocities at air temperatures controlled between 25 and 35°C in a 24-h cycle and at a constant dew point of 23°C [17].

The results consistently show that a linear influence of the air velocity may be valid for flocks of broilers at least up to an air velocity of 3 m/s.

In the absence of further data sets suitable for validation of Eq. (7), we tried to model the relative body weight gain reduction as a function of ET using data from different studies. This includes measurements in groups maintained at different air velocities and the same air temperature or maintained at different temperatures and the same air velocity. In that effort, we defined the relative body weight gain reduction (RBWR, % $°C^{-1}$) at a certain ET (°C) as

$$RBWR = \frac{\left(BWG_{Low\ \ ET} - BWG_{High\ \ ET}\right) \times 100}{0.5\left(BWG_{Low\,ET} + BWG_{High\ \ ET}\right)0.5(Low\ \ ET + High\ \ ET)} \tag{8}$$

where *Low ET* is the ET at the condition for measurement with low heat load (°C); *High ET* is the ET at the condition for measurement with high heat load (°C); BWG_{Low} *ET* is the body weight gain at low ET (g day^{-1} $bird^{-1}$); BWG_{High} *ET* is the body weight gain at high ET (g day^{-1} $bird^{-1}$).

In addition, we assumed that the calculated RBWR was valid for ET = 0.5 (*Low ET* + *High ET*) and calculated relations between ET and RBWR for different values of *c* and *d* in Eq. (7) assuming either a linear or a square-root relationship with velocity. The best agreement with a quadratic model was found for a linear relationship with velocity (*e* = 1) and *c* = 0.15, *d* = 41, see **Figure 4**.

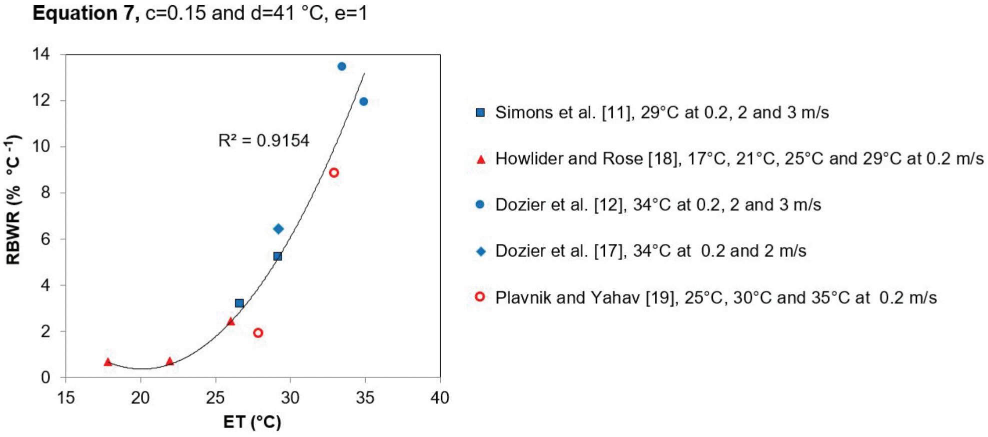

Figure 4. Relative body weight gain reduction (RBWR) for flocks of 22–56-day-old broilers maintained at different ETs calculated by Eq. (7).

The figure includes data from two studies [18, 19] comparing the body weight gain for flocks of broilers exposed to different air temperature treatments at the same air velocity and three studies [11, 12, 17] comparing the body weight gain for flocks of broilers exposed to different air velocities at the same air temperature treatment.

The study conducted by Howlider and Rose [18] included broiler chickens kept in 12 pens of 40 birds at each of four constant temperature levels (17, 21, 25, and 29°C) in the period from 22 to 49 days of age. Unfortunately, the authors did not report air velocity and air humidity during the study period. To identify a possible assumption for humidity to calculate ET, we investigated how the parameters *c* and *d* depended on two widely different assumptions—either a relative humidity of 50% or a dew point of 10°C. The two assumptions resulted in nearly identical values for the two parameters, and therefore, we assessed that both assumptions would be acceptable and decided to use the relative humidity of 50%, for the data presented by Howlider and Rose [18]. The authors provided separate weight gain data for male and female chickens, and it shows that males grew 20% faster than females, but a temperature increase from 17 to 29°C reduced the weight gain by 15% for both genders. This similar effect of increased temperature justifies that **Figure 4** includes studies with both genders as well as studies with males only.

The study by Plavnik and Yahav [19] included four groups of six male Cobb chickens exposed to each of four different temperature treatments during 6–8 weeks of age. The temperature treatment included three constant temperature levels (25, 30, and 35°C) and one treatment where the chickens were exposed to a diurnal cyclic temperature of **12 h at 25°C and 12 h at 35°C**. Compared with the cyclic temperature treatment, the body weight gain was increased to 63% at the constant 25°C treatment and decreased to 6% at the constant 35°C treatment. This indicates that the cyclic temperature treatment is comparable with a constant temperature that is only marginally lower than the temperature in the warmest part of the cycle. We utilized this relationship to assume that other studies involving cyclic temperatures [11, 12, 17] could be treated as studies where temperature was 1°C below the temperature in the warmest part of the cycle.

Dozier et al. [12] measured the growth of male broilers exposed to either still air or air velocity of 2 m/s from 28 to 49 days of age at a 25:30°C diurnal cyclic temperature conditions corresponding to those used by Simmons et al. [11] and Dozier et al. [17]. To investigate the significance of the abovementioned temperature assumption, we conducted additional calculations assuming temperatures either 0 or 2°C below the temperature in the warmest part of the cycle. This calculation did not change the parameters that resulted in the best agreement, but using the same temperature as in the warmest period resulted in slightly better agreement.

The articles that included different air velocities [11, 12, 17] do not provide detailed information on how the stated air velocities were measured, but apparently they are all conducted in the same wind tunnel facility and there is no indications of differences in velocity measurement procedures between the three studies.

The same articles report weekly weight gain data showing that the influence of velocity increases with age. Therefore, it is a source of uncertainty that has been necessary to incorporate studies that include different age intervals as shown in **Figure 4**, but **no measurements indicate** that the relative influence of temperature and velocity is affected by age.

If the assumed dependency of velocity is changed from a linear relationship ($e = 1$) to a square-root relationship ($e = 0.5$), then the R-square value for the best agreement between RBWR and ET is reduced from 0.92 to 0.72.

2.2.2. Laying hens

Uwagawa et al. [13] measured the effect of the air velocity and temperature on skin temperatures (at comb, shank, and wattle) for 78-week-old laying hens exposed to different air temperatures (10, 15, 20, 25, 30, and 35°C) and different air velocities (0, 1, 2, and 4 m/s), but no information about the air humidity was provided. The birds were individually exposed to the environment for 1.5 h before a 30-min measure period. We used the average of reported skin temperatures measured at comp, shank, and wattle to determine the values of c and d in Eq. (7)

that resulted in the best quadratic relationship with ET assuming either a linear or a square-root relationship with velocity. To investigate the significance of the lack of information on the air humidity, we made the calculation with two widely different assumptions, either that all measurements were conducted at 50% RH or that they all were conducted at dew-point temperature of 8°C. The latter causes a decrease in relative humidity from 87 to 18% for the temperature increase from 10 to 35°C. For both assumptions, the best correlation was found for a square-root relationship with velocity (*r*-square values of 0.99) at $c = 0.15$ and $d = 44$ (**Figure 5**).

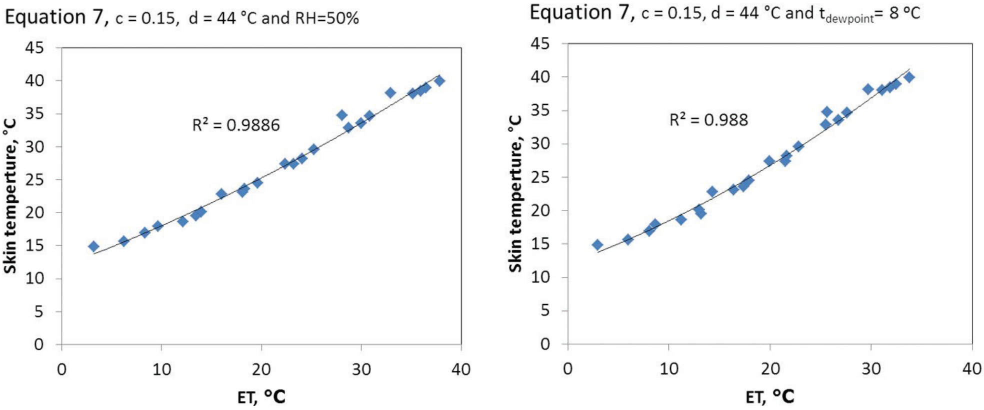

Figure 5. Skin temperature at different ETs calculated by Eq. (7) assuming $c = 0.15$, $d = 44$°C, and $e = 0.5$. Data originate from the study by Uwagawa et al. [13] and include exposure to different ambient temperatures (10, 15, 20, 25, 30, and 35°C) and different air velocities (0, 1, 2, and 4 m/s). The left-hand graph assumes a constant air humidity of 50% RH and the right-hand graph assumes a constant dew-point temperature of 8°C.

If the assumed dependency of velocity is changed from a square-root relationship ($e = 0.5$) to a linear relationship ($e = 1$), then the *R*-square value for best reflection of the data presented by Uwagawe et al. [13] is reduced from 0.99 to 0.97.

2.2.3. Pigs

Mount and Ingram [20] measured the effect of ambient temperature and air velocity on sensible heat loss from two pigs in each of three different weight ranges (3.4–5.8, 20–25, and 60–70 kg). The measurements were conducted with a heat flow disc [21] strapped to the dorsal thorax of the pigs, while they were individually kept in a cage with closed sides. Above the cage, a variable speed fan directed a stream of air vertically into the cage and the air speed was measured at 5–10 cm above the heat flow disc. Body temperatures, environmental temperatures, and heat loss were measured every 5 min, until four readings had indicated that a steady state had been reached. The measurements were conducted at air speed close to 0.08, 0.35, 0.60, and 1.00 m/s for each of five ambient temperatures (35, 30, 25, 20, and 15°C). Unfortunately, the authors did not provide information about air humidity and, therefore, we also in this case investigated the significance of different humidity assumptions. As in the former case, the parameters *c* and *d* in Eq. (7) that best reflected the measurements were unaffected of whether the relative humidity or the dew point was assumed to be constant. For all three weight ranges, the best correlations were found for a square-root relationship with velocity (R^2 between 0.91 and 0.98) at $c = 1.0$ and $d = 42$) (**Figure 6**). A linear relationship with velocity resulted in the best agreement with measurements at $c = 0.8$ and $d = 42$ and the r-square value was between 0.89 and 0.96 for the three weight ranges.

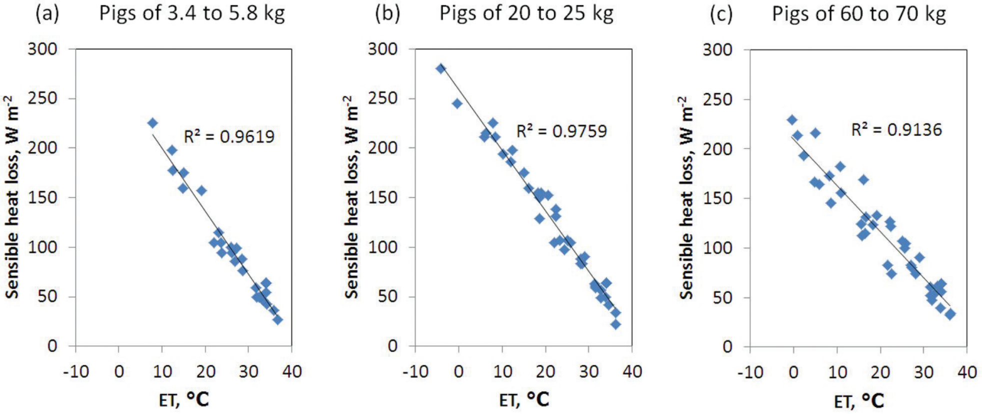

Figure 6. Sensible heat loss for pigs at different ETs calculated by Eq. (7) assuming $c = 1$, $d = 42°C$, 50% RH, and a square-root relationship with measurement. Data originate from mount and Ingram [20] and include exposure to different ambient temperatures (15, 20, 25, 30, and 35°C) at different air speeds (close to 0.08, 0.35, 0.60, and 1.00 m/s). The three graphs represent different weight ranges.

Massabie and Granier [22] measured production performance for finishing pigs kept in groups of six animals (0.67 m^2/animal) at air temperatures of 20, 24, and 28°C, with and without ceiling fans located above the partitions between each second pen generating downward air streams to increase the air velocity. The authors inform that the air velocity was increased from 0.56 to 1.3 ms^{-1} during the growth period, but provides no information on how the air velocity was measured. A time-weighted average velocity of 1.07 ms^{-1} can be calculated from a step curve reported by the authors. Reported results illustrated in **Figure 7** show that the ceiling fan increased the daily weight gain, but simultaneously it increased the feed conversion ratio.

The results presented in **Figure 7** indicate that the negative influence of increased temperature on daily gain begins at approximately 20°C without the air velocity and at a higher temperature if the pigs are exposed to the air velocity. At 28°C, the effect of the air velocity (an increase from 0.2 to 1.07 ms^{-1}) is equivalent to an approximately 5°C lower temperature without the air velocity. For the feed conversion ratio, the effect of velocity is equivalent to an approximately 3° lower temperature without the air velocity. These figures can be compared with the estimated influence of the air velocity on ET. Using Eq. (7) and assuming $t_{db} = 28°C$ and $t_{wb} = 23°C$, we calculated that an increase of an air velocity from 0.2 to 1.07 ms^{-1} can reduce the ET by approximately 4°C if $c = 0.42$ and $d = 39°C$. This calculation was based on an assumed linear relationship with velocity, but since data included only two levels of velocity it is equally

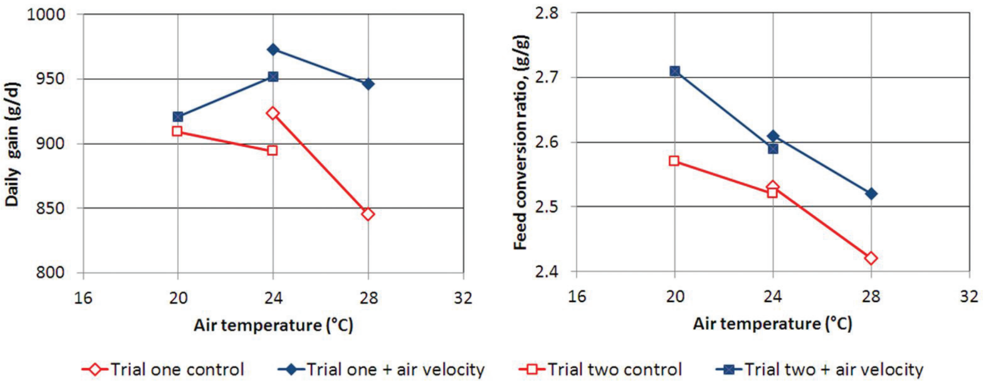

Figure 7. Daily weight gain (left-hand graph) and feed conversion ratio (right-hand graph) for finishing pigs maintained at different air temperatures with and without a ceiling fan to increase the air velocity from 0.56 to 1.3 ms^{-1} during the growth period (results reported by Massabie and Granier [22]).

relevant to assume a square-root relationship with velocity and that the assumption would change the parameter *c* to 0.62.

3. Discussion

Data from several studies [4, 6, 7, 9, 10] confirm that the THI calculated as Eq. (1) is an operational way to express the relative significance of air temperature and air humidity. The relative significance of the two parameters has been determined by analyzing which value of "*a*" provides the best agreement between a response parameter and the THI. **Table 1** includes 15 cases where a response variable was correlated to THI, and it appears that *a*-values between 0.55 and 0.90 best agreed with the used data. The cases include growing pigs, broilers, hens, and turkeys, and response variables included respiratory rate, body temperature, heat production, and performance results. As it appears from **Table 1**, the correlation coefficient in all 15 cases was nearly equally large at $a = 0.75$ as it was at the *a*-value that best reflected the data. Generally, the chapter shows that an *a*-value needs to differ relatively much from the value that best reflects the data before the correlation significantly degrades.

The work by Brown-Brandl et al. [8] regarding tom turkeys is the sole study that includes data systematically divided into animals at different ages, but the results are ambiguous and, therefore, not suitable to indicate how practical *a*-values should depend on the age of the animals. It is notable that Egbunike [5] found an *a*-value of equal magnitude in natural humid tropical environmental condition at relatively low heat load (t_{db} range from 25 to 33°C) as Roller and Goldman [4], Ingram [3], Tao and Xin [9], and Xin et al. [7] found at acute exposure to severe heat load (t_{db} range from 32 to 43°C). **Based on this, our assessment** is that the works we have reviewed do not include results that require or justify the use of different *a*-values for pigs or poultry, for large or for small animals, for different animal density, or for mild or severe heat load. We assess that an *a*-value of 0.75 is valid as a common applicable value.

The study by Tao and Xin [1] was the sole work found in this chapter that systematically investigated the combined influence of air temperature, air humidity, and air velocity. They proposed a THVI equation (Eq. 5) by extending the THI model with a correction factor ($v^{-0.058}$) to include the influence of the air velocity. Analyses in this chapter show that THVI overpredicts the influence of the air velocity if the air temperature approaches the animal body temperature. The data provided by Tao and Xin [1], however, support the assumption that the effect of increased velocity declines if the air temperature approaches the animal body temperature, which is the case in Eq. (7), and analyses in this study showed that the data provided by Tao and Xin [1] correlated remarkably well with Eq. (7).

Unfortunately, the article on skin temperature in laying hens [13] and the article on sensible heat loss from pigs [20] provide no information on air humidity. However, analyses in this study showed that data from both Uwagawa et al. [13] and Mount and Ingram [20] correlated very well with Eq. (7) at widely different assumptions for the air humidity.

For all three [9, 13, 20] a square-root relationship with velocity ($e = 0.5$) correlated slightly better with Eq. (7) than a linear relationship with velocity ($e = 1$). These studies all concern short-term exposure of individual animals to different thermal environments.

For broilers in flocks, other studies [11, 12, 18] indicate that it might be valid to assume a linear influence of the air velocity up to at least 3.0 m/s. The difference might be because the animals give shelter to each other and, therefore, reduce the effect of the air velocity. This hypothesis also explains why we found smaller influence of velocity ($c = 0.15$ instead of $c = 0.31$ at $e = 1$) in the analyses of body weight gain reduction for flocks of broilers. Provided that the velocity represents the velocity above the animals, the increase in animal density will increase the sheltering and consequently decrease the velocity among the animals, and an adjustment of the *c*-values appears to be an appropriate way to compensate for this relationship.

The study by Uwagawa et al. [13] on skin temperatures in laying hens indicated that Eq. (7) might be valid in a range of temperature of 10–35°C and air velocity of 0.2–4 m/s. As it was the case for the data presented by Tao and Xin [9] and by Mount and Ingram [20], a square-root relationship with velocity reflected the data slightly better than a linear dependency, which supports the choice of the square-root dependency in the estimation of ET for individually kept animals.

Tao and Xin [9] exposed the animals to thermal condition that increased their body temperature with up to about 4°C and that may explain why calculated parameter *d* was above the normal temperature for broilers. Correspondingly, the data by Uwagawa et al. [13] and by Mount and Ingram [20] included treatments with high temperatures and low air velocities that may have increased the animal body temperature and therefore explains why the parameter *d* also calculated from these data was above the normal temperature for the included animals. The data used for broilers in flock resulted in a *d*-value similar to the normal body temperature for broilers (40.6–43.0°C [23]) which matches the milder thermal load the animals in the included studies were exposed to.

As for broilers, the studies on pigs [20, 22] indicated a larger influence of velocity for individually kept animals than those kept in groups, which as mentioned for broilers can be explained by those group-housed animals that give shelter to each other.

The estimated influence of velocity (parameter *c* in Eq. (7)) was generally larger for pigs than for broilers, but these results may possibly be explained by the difference in used test facilities and methods to determine the air velocity.

The studies on individually kept animals [9, 13, 20] confirm the validity of the velocity term in Eq. (7), but, unfortunately, the used experimental conditions were widely different from animal production. Determinations of the parameters *c*, *d*, and *e* for practical use require data obtained from conditions corresponding to animal production. The included studies on broilers in flocks [11, 12, 17] are all conducted in an experimental wind tunnel, which, to some extent, are similar to commercial tunnel-ventilated broiler houses, although there are large differences in the tunnel scale and in the number of animals. The experimental condition used in the study on group-housed pigs [22] could possibly be implemented in pig production, but the uncertainty on how the air velocity was determined in this study limits the possibilities of exploiting the results.

Unfortunately, we did not find other studies to validate Eq. (7) or to estimate the parameters *c*, *d*, and *e* for other categories of pigs and poultry than broilers and finishing pigs kept in groups. But nevertheless, we assess that Eq. (7) is a valid way to express knowledge on the relative significance of air temperature, humidity, and velocity at high heat load for pigs and poultry. However, it is acknowledged that the influence of the air velocity is determined based on a very limited amount of data. Therefore, it is likely that future studies will generate more knowledge that improves estimations of the parameter in—and possibly also the structure of—the model for ET estimation and furthermore establishes parameters adapted to different species, different age groups, or different production levels.

4. Conclusions

Existing knowledge on the relative significance of air temperature, humidity, and velocity in the thermal environment for housed pigs and poultry is reviewed and synthesized in an ET equation (Eq. (7)) with an easily understandable scale, where ET is equal to air temperature if the relative humidity is 50% and the air velocity is 0.2 ms^{-1}. The suggested ET equation treats the relative significance of air temperature and humidity in the same way as the frequently used THI equation (Eq. (1)). Analyses of reported data suitable to determine the relative weighting of the dry-bulb temperature (*a* in Eq. (1)) in poultry and pigs show that the weighting with the best correlation with data differs a great deal, but the correlations are in all cases nearly equally good if a weighting corresponding to $a = 0.75$ is used. Consequently, a common *a*-value of 0.75 is used in the further development of the ET equation for broilers and pigs.

The dependence of velocity is treated as an additional term in the suggested ET equation. This term is assumed to be proportional to the difference between the animal body temperature and the room air temperature, and reported data were analyzed to determine whether a linear or a square-root relationship with velocity best reflected the data. Data from studies on body temperature increase of broilers [9], on skin temperature of laying hens [13], and on sensible heat loss of pigs [20] individually exposed to different thermal environment agreed well with the ET equation, and the agreement was slightly better with a square-root dependence of velocity than with a linear dependence.

The data from studies of animal groups are less clear, but indicated that the wind shading among the animals reduces the effect of the air velocity (the parameter *c* in Eq. (7)). For broilers in flocks, a linear dependency of velocity reflected data better than a square-root dependency.

Future studies on the influence of the air velocity may generate results that enable improvements of the ET equation and possibly generate different versions of the equation to deal with different species, age groups, and production levels. However, presently the proposed model and parameters might be useful in the assessment of the relative influence of air temperature, air humidity, and air velocity for groups of broilers or finishing pigs.

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Chapter 3

Nitrogen Emissions and Mitigation Strategies in Chicken Production

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Abstract

Air emissions from feeding operations and manure management in chicken production are among the major sources of environmental concerns globally. Nitrogen emissions in chicken production occur in several forms but mainly ammonia can contribute directly or indirectly to several environmental and public health hazards. Chicken production also contributes to some extent to climate change through the emissions of nitrous oxide, fine particulate matters, and methane. Emissions and nutrient losses take place in different systems and at every stage of chicken production operations. To effectively reduce the environmental impact of chicken production, appropriate measures should be taken across the chicken supply and manure management chain. Nutritional and manure management strategies for mitigating nitrogen emissions in chicken production are discussed. Challenges associated with the adoption of some of the mitigation strategies are identified and measures to address them are suggested. Co-benefits of mitigating nitrogen emissions in chicken production to the planet, the people and the producers are numerous.

Keywords: nitrogen, emissions, chicken, manure, feeding strategies

1. Introduction

Chicken production is an important source of nutrition and livelihood all over the world. Over the years, significant improvement has been achieved in chicken production, and it is one of the fastest growing sub-sectors of the livestock industry. Chicken production therefore holds great potentials in meeting the increasing demand for animal protein, such as meat and egg, arising from population growth and changing consumer preferences. However, in addition to the production objectives of ensuring profitability and quality, environmental sustainability must be given paramount consideration so as to ensure that production practices benefit the people, the planet, and the business without jeopardizing future utilization of resources.

Air emissions and manure handling in chicken production are among the major sources of environmental concerns globally. Ammonia, nitrous oxide (N_2O), and other oxides of nitrogen (NO_x) are nitrogenous emissions of concern in broiler and layer production systems, while methane, particulate matters, and black carbon emissions also occur. The potential sources of environmental footprint (particularly relating to carbon, nitrogen, phosphorous, particulate matters and micro-organisms) in the animal feeding operations include the animal, type of feed, manure, and housing accessories including bedding and heating materials [1]. Although poultry supply chain is not the main source of greenhouse gases (GHGs) emissions, emissions intensity or emissions per unit of output is significant and needs to be mitigated through adequate measures. This is because the growth forecast in global demand for chicken meat and egg between 2005 and 2030 is 61 and 31%, respectively [2]. This means if appropriate measures are not taken to reduce the emission intensities of these products, production increases required to meet the risen demand will be proportionate to GHGs emissions growth, and this kind of trend is not desirable.

Improved feeding practices, utilization of specific agents, long-term management practices, and animal breeding strategies are some categories of measures that could be employed to mitigate emissions from animal production operations, including chickens [3]. Feed management practices including those that reduce the oversupply of protein and amino acids in the diets are perhaps the most important measure to mitigate nitrogen emissions in chicken production. Reduction of dietary supply of protein and amino acids to chicken is possible because birds have been selected and bred for improved feed conversion efficiency and growth over the years. Also, feeding feed supplements that could enhance the utilization of the diets thereby reducing nutrient excretions by the chicken is also an effective emission mitigation strategy. Enzymes can also contribute to nutrient excretion reduction in chickens. Enzymes reduced the variability in the nutritive values between feedstuffs and improved the accuracy of feed formulation, thereby aiding management and profitability of poultry feeding operation [4]. Specific agents could also be used for manure amendments in order to reduce the volatilization of already excreted nutrients, particularly nitrogen in from of NH_3 and N_2O. This chapter discusses nitrogenous emissions, associated hazards, and some emissions mitigation strategies, particularly feeding and manure management approaches, in chicken production. Some reported undesirable effects of feeding low-protein diets, and measures taken to correct them are also presented.

2. Emissions in poultry supply chain

Emissions of different types and magnitude take place throughout the entire chicken supply chain. Therefore, for emission mitigation strategies to be effective, the important sources across the chicken value chain must be taken into account. Nutrient losses from chicken supply chains can be air emissions such as CH_4, N_2O, and NH_3 or to water sources by leaching of e.g. NO_3^- and P_2O_5 through the soil and by run-off (including intended discharge) [5], and some of these important emissions are briefly discussed (**Table 1**).

Agricultural sector ammonia emission is mainly from livestock operations manure management and chemical fertilizers. Globally, chickens are among the most important contributors to ammonia emissions. Significant portions of nitrogen excreted in chicken production are emitted into the atmosphere in the form of ammonia, which is formed as a result of microbial activities, although limited losses in form of N_2O and NO_3 also occur [6]. Poultry excretions contain high concentration of uric acid which is transformed into urea through aerobic decomposition. When mixed with urease present in the fecal material, urea N can quickly be transformed into highly volatile ammonia and easily diffused into the surrounding air. High temperatures, pH, wind velocity, and urease activity, as well as large surface area for emissions, enhance the volatilization of ammonia in chicken manure [7]. Without taking measures to modify nutrient excretion, as much as 18–41% of fecal N could be lost into the atmosphere in the form of NH_3 and other nitrogenous compounds [8].

Concentrations of ammonia are usually considerably high near the animal facilities due to increased deposition. However, ammonia concentration in the atmosphere reduces as the distance away from the animal facilities increases. Reduction in atmospheric ammonia concentration can be up to 50–70% at a distance of 0.4–4 km away from the animal facility [9]. Accordingly, the mass of ammonia nitrogen expected to be deposited in the soil around sources such as chicken and manure storage facility decreases as the distance increases.

Greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are also emitted in chicken production, although the contributions are significantly lower than

Emissions	**Remarks**
Methane (CH_4)	This is a combustible greenhouse gas, and it is 28 times more powerful than CO_2. It is produced from the decaying organic matter in manure stored under oxygen-free conditions
Nitrous oxide (N_2O)	This is a greenhouse gas, and it is 265 times more powerful than CO_2. It is an intermediate product during the nitrification of NH_4^+ into NO_3^-; and during the denitrification of NO_3^- in manure applied to soils low in oxygen (e.g. waterlogged areas)
Ammonia (NH_3)	An aggressive and acidifying gas, which is a product from urea degradation in manure (and urine). It causes respiratory problems in humans and animals and acidification of soils when deposited
Nitrate (NO_3^-)	It is formed in the soil by nitrification of NH_4^+/NH_3 after manure application. It is a water-soluble ion which is prone to leaching. Concentration in high quantity in potable water may lead to nitrite poisoning (NO_2^-) causing an oxygen deficit in the blood of humans and animals
Phosphate (P_2O_5)	It is from superficial run-off of manure and/or from leaching of the water-soluble form. It causes eutrophication of open waters (dense growth of algae and death of fish from subsequent lack of oxygen)

Source: [5].

Table 1. Some important gaseous emissions in chicken supply chain.

those of ruminants. The Global Life Cycle Assessment of emissions from chicken supply chain revealed some important information that could contribute to the effective mitigation of emissions and reduction of emissions intensities (**Table 2**). The chicken supply chain is responsible for about 606 million tonnes CO_2-eq of GHG emissions, representing about 8% of the total emissions from livestock sector [10]. Thus, chicken supply chains account for a quantity of GHGs emissions that warrant giving attention to its mitigation. Therefore, to be effective, mitigation strategies should target major emission sources along the chicken meat and eggs value chains. By emission category in the chicken supply chains, major sources of proportion are CO_2 (meat, 59.4%; eggs, 48.9%) and N_2O (meat, 36.5%; eggs, 40.1%) (**Table 3**).

Emission of N_2O from chicken manure management depends on the composition of the feces, microbes, and enzymes involved and the conditions of the feces after excretion. Mostly, N_2O are emitted as an intermediate product during nitrification and denitrification reactions, leading to nitrate reduction in some litter system. However, it is possible to store manure in a way that minimizes nitrogenous emissions. There is a trade-off between methane and nitrous oxide emissions because while handling of chicken manure under anaerobic conditions leads to the production of methane, management under aerobic conditions with pockets of anaerobic conditions encourages N_2O volatilization.

The composition of diets and the efficiency of its conversions to meat and/or egg affect the quantity, physical, and chemical properties of chicken manure and in turn the potential

System	Production (million tonnes)		Emissions (million tonnes CO_2-eq)		Emission intensity (kg CO_2-eq/kg product)	
	Eggs	Meat	Eggs	Meat	Eggs	Meat
Backyard	8.3 (14.3%)	2.7 (3.7%)	35.0 (16.1%)	17.5 (4.5%)	4.2	6.6
Layers	49.7 (85.7%)	4.1 (3.8%)	182.1 (83.9%)	28.2 (7.2%)	3.7	6.9
Broilers		64.8 (90.5%)		343.3 (88.3%)		5.3
Total	58.0 (100%)	71.6 (100%)	217.0 (100%)	389.0 (100%)	3.7	5.4

Source: [10].

Table 2. Global production, GHG emissions, and emission intensity for chickens.

Class of emission	Meat	Eggs	Sources
CO_2 emissions	59.4	48.9	Feeds, LUC soy bean, direct energy, postfarm
CH_4 emissions	1.6	9.0	Manure management
N_2O emissions	36.5	41.0	Applied and deposited manure, fertilizer and crops residue, manure management
Others	1.4	1.1	Feeds, rice CH_4 and indirect energy CO_2

Source: Based on [10].

Table 3. Global emissions from chicken meat and egg supply chain by category of emissions (%).

emissions [1]. Similarly, manure handling and environmental conditions would affect chemical and physical properties of the manure, that is, its chemical composition, biodegradability, microbial populations, oxygen content, moisture content, and pH [11].

3. Nitrogen excretions in chicken production

Annual manure excretions by species show that chicken production ranks in terms of manure turnout. It is evident that when compared with other categories of livestock, either on an individual basis or as a group, each chicken type animal unit is a major contributor to manure excretions (**Table 4**). The quantity of manure excreted by the animal also has far-reaching implications for the overall nutrients excreted into the environment. Depending on the efficiency of nutrient utilization, 50–80% of the nitrogen supplied in animal diets may be excreted [12] and more than 70% of the total nitrogen excreted in poultry is uric acid, which is rapidly converted to ammonia through the process of hydrolysis [13]. Therefore, chicken feces with higher proportion of total ammoniacal nitrogen will tend to emit ammonia more quickly and in higher quantities.

Nitrogen excretion in chicken production is largely influenced by over supply of protein and/or amino acids in the diets, although there may be other factors, and it is a major contributor to other nitrogenous emissions emanating from manure handling and production. Oversupply of dietary protein and some amino acids is a common practice which stems from the attempts to meet the requirements of the birds at various stages of growth, that is, starter, grower, and finisher phase [15]. A typical 23% crude protein diet contains significant quantity of amino acids in excess of requirement [8]. The requirement for protein in chicken is essentially the requirements for amino acids. Protein fed to chickens is absorbed for various metabolic functions in

Species of animal	Number of animals per animal unit (AU) (an AU 1000 lbs)	Annual manure production in tons per animal unit	Rank in terms of manure production per animal unit
Beef cattle	1.00	11.50	4th
Dairy cattle	0.74	15.24	1st
Swine (breeders)	2.67	6.11	9th
Swine (others)	9.09	14.69	3rd
Hen (laying)	250.00	11.45	5th
Pullets (over 3 months)	250.00	8.32	6th
Pullets (under 3 months)	455.00	8.32	6th
Broilers	455.00	14.97	2nd
Turkey (slaughter)	67.00	8.18	8th

Based on [14].

Table 4. Annual manure production estimates from livestock species per animal unit.

the body in the form of amino acids. Excess protein consumed is stored in the form of glucose or fat. In the event that amino acid is converted to glucose or fat, nitrogen is first removed in the liver and converted to urea. The urea is transported to kidney for elimination from the body in the form uric acid in the case of chickens. Such oversupply of nutrients is not necessary as it amounts to increased production costs, constitutes a drain on profitability, wastage of scarce and expensive resources, and reduced production efficiency, and contributes to environmental challenges associated with chicken production. A significant amount of protein fed to chicken is excreted in diverse forms of nitrogen, and this could be volatilized into the atmosphere through some biological processes (**Table 5**). It is possible to exceed the threshold concentration of both oxidized and reduced forms of nitrogen and these have consequences for the planet, the people and the chickens (which translates to negative effect on the profitability of the chicken enterprise). Some of such consequences include respiratory diseases caused by exposure to high concentrations of fine particulate matters, contamination of drinking water by nitrates, eutrophication of surface water bodies leading to harmful algal blooms and decreased water quality, changes in vegetation or ecosystems as a result of higher concentration of nitrogen, climatic change associated with increases in nitrous oxide in the atmosphere, nitrogen saturation in forest soils, and soil acidification through nitrification and leaching.

On fresh basis, chicken raised under the extensive system excretes an estimated 4.5% of its body weight and 0.02–0.15 kg/bird/day [5]. Diets, housing system, manure handling method, and season of the year are among the factors affecting nitrogenous emissions in animal production [17]. In addition, available fecal nitrogen can determine the extent of ammonification, nitrification, and denitrification. Thus, the proportion of nitrogen volatilized into the atmosphere differs with manure type, manure management practices, and increases with the length of storage (**Tables 5** and **6**).

Manure type	**DM content (%)**	**Typical loss % total N**	**Range % total N**	**N form lost**[*]
Type of poultry housing				
Poultry, high rise	—	50	40–70	NH_3
Poultry, deep litter	—	40	20–70	NH_3, N_2O, N_2
Poultry, cage and belt	—	10	4–25	NH_3
Poultry, aviary	—	30	15–35	NH_3, N_2O
Long term storage system				
Solid heap, poultry	50	10	5–15	NH_3, NO_3, N_2O
Solid compost	40	40	20–50	NH_3, NO_3, N_2O
Slurry tank, top loaded	10	30	20–35	NH_3
Slurry tank, bottom loaded	10	8	5–10	NH_3
Slurry tank, enclosed	10	4	2–8	NH_3
Anaerobic lagoon	5	70	50–99	NH_3, N_2, N_2O

Source: [16]*N forms are listed in order of the expected quantity lost, with most of the loss being in the form of NH_3.

Table 5. Typical losses of long-term manure storage used in animal production expressed as a percentage of total nitrogen entering storage.

Application method	Semisolid manure	Liquid slurry	Lagoon liquid	Dry litter
Injection		5	5	
Broadcast with immediate incorporation	25	25	10	10
Incorporated after 2 days	35	35	20	20
Incorporated after 4 days	60	60	40	35
Incorporated after 7 days or never incorporated	75	75	55	50
Irrigation without incorporation		80	50	

Source: [5, 18].

Table 6. Relative NH_4^+-N losses of some field practices as percentage of the total NH_4^+-N.

4. Challenges associated with nitrogen emissions in chicken production

Several challenges are associated with nitrogen excretions and/or emissions in chicken production. Air emissions and fecal minerals emanating from intensive chicken operations could have serious environmental consequences when poorly managed. Frequent complaints against animal-based industries are mainly associated with dust, odors, and bio-aerosols. For example, microbes, endotoxins, and mycotoxins are suspended in air, which are generated in production and manure storage facilities, as well as during land spreading of poultry litter [19]. An efficient handling of nutrients at all the stages of production is critical to reducing the release of nitrogenous and other emissions into the environment.

4.1. Some potential hazards associated with nitrogen excretions

Several hazards to personal safety are known to be associated with liquid manure storage facilities. Depending on the gas concentration and length of exposure, symptoms ranging from headaches and eye irritation to death can be caused by gases such as hydrogen sulfide and ammonia in such facilities. It is therefore advisable to wear appropriate protective respiratory equipment when entering an enclosed area that contains manure. However, nitrogenous emissions are also of considerable concerns outside the manure management and storage facilities.

Nitrogen excretions could also lead to degradation of ground and surface waters through contributions to nitrate runoff and nutrient loading. This is particularly important because chicken manure is also a rich source of several other elemental minerals/nutrients, which could find their ways into the ecosystem. Some of these nutrients rich in chicken manure include sodium (Na), potassium (K) phosphorous (P), magnesium (Mg), calcium (Ca), and sulfur (S). Therefore, the nutrient profile of chicken manure makes it valuable for use in crop and livestock production and at the same time a potential source of hazards (**Table 7**). About 30–50% of total N in chicken manure is readily available as a nutrient to plant [20]. However, due to limited availability of land and lack of nutrient test to determine requirements before applications, soils applied with chicken manure could have excess N and P [21]. Consequently, mineral nutrients from chicken manure are potential environmental risk factor, especially in soil and water pollution. Risks of nutrients, organic material, and pathogens contaminating water bodies are common with increased manure spread.

4.2. Some potential hazards associated with ammonia emissions

Ammonia is a major harmful gas associated with chicken production. Poultry production has the potential to be a large contributor of ammonia, which plays critical role in the formation of particulate matter emissions to the atmospheric environment [23]. Elevated concentrations of ammonia in chicken houses have negative effects on the health of the workers exposed to them and also on the chicken through reduced feed intake and impeded growth rate. Ammonia plays critical roles in the environment, and its control could be of immense benefits, particularly through the reduction of excessive loading of nutrients and acidification. In view of the nutrient profile of chicken manure, ammonia volatilization from the resource can be considered a loss of its fertilizer value. Ammonia is also a nutrient source to microbiological and plant communities; however, its excessive deposition in the ecosystem could have detrimental effects causing eutrophication and degradation of water bodies.

Component	**Broiler litter**		**Chicken manure**	
	Mean	**Range**	**Mean**	**Range**
	g kg^{-1} material		**g kg^{-1} material**	
Moisture	245	20–291	657	369–770
Total C	376	277–414	289	224–328
Total N	41	17–68	46	18–72
NH_4-N	2.6	0.1–20	14	0.2–30
NO_3-N	0.2	0–0.7	0.4	0.03–1.5
P	14	8–26	21	14–34
K	21	13–46	21	12–32
Ca	14	0.8–17	39	36–60
Mg	3.1	1.4–4.2	5	1.8–6.6
Na	3.3	0.7–5.3	4.2	2–7.4
	mg kg^{-1} material		**mg kg^{-1} material**	
Mn	268	175–321	304	259–600
Fe	842	526–1000	320	80–560
Cu	56	25–127	53	36–68
Zn	188	105–272	354	298–388

Source: [22].

Table 7. Chemical properties of broiler litter and chicken manure.

5. Strategies for reducing emissions

This section discusses some nutritional and manure management strategies for mitigating nitrogen emissions in chicken production. Several evidences are available to demonstrate that feeding low-protein diets is an effective approach for mitigating nitrogen emissions in chicken production by contributing to a significant reduction in nitrogen excretions. However, feeding low-protein diets may present some undesirable challenges which must be addressed to ensure sustainability of chicken production. Some manure handling and management measures to reduce nitrogen emissions are also presented.

5.1. Nutrition approaches for mitigation of nitrogen excretions in chicken production

In view of its effects on costs, performance and profitability of chicken production, emphasis is placed on protein in feed formulation. Dietary protein level has major effects on growth and overall cost of the finished poultry product and affects the carcass composition of the birds [24], while recent advances and progress in animal breeding has resulted in highly efficient breeds in terms of feed conversion and growth, it is important to seriously consider the pros and cons that may be associated with the dietary protein levels to be adopted in chicken production in a bid to ensure sustainability. This is because of the need to take adequate measures to balance the effects of dietary protein levels for more beneficial chicken production outcomes. For example, excess dietary protein results in lean birds but reduces feed efficiency thereby resulting in elevated nitrogen excretions, whereas less than optimal protein content increases fat retention [25]. This therefore underscores the need to maintain a balance in both dietary protein and amino acid contents of the diets for optimal production performance in chicken. Several research findings have demonstrated a wide range of effects of feeding and nutrition strategies for mitigation nitrogen emissions in chicken production. Nutritional strategies include feeding low dietary protein, formulating diets based on amino acids requirements while supplementing limiting amino acids with synthetic source, and use of enzymes in chicken production.

5.1.1. Effects of feeding low-protein diets on nitrogen excretions in chicken production

Dietary protein manipulation could be an effective way of reducing nitrogen excretion in chicken production. Dietary amino acids in excess of the requirements cannot be stored in the body; instead, they are transaminated and/or deaminated, with the majority of the excess nitrogen excreted as uric acid in poultry. Accordingly, the excess dietary protein could be described as wasteful and represents an economic loss to the farmer. In addition, challenges involved with disposal of excreted nitrogen include offensive odors and environmental pollution. Therefore, to address the growing concern of increased nitrogen emissions from livestock, a combination of adjustment in dietary content of amino acids to animals' requirements at a given age and lowering the amount of dietary crude protein with the use of crystalline amino acids. It is possible to lower the CP content of the chicken diet and still meet established amino acid requirements by replacing part of the intact protein with crystalline amino acids

[26]. This helps to obtain a balance of dietary amino acids closer to the animal's requirements. Feeding low-protein diets may therefore enable a farmer to cut down on the cost of the diet depending on the constituents of the feed while at the same time reducing nitrogen loss and its attendant environmental challenges. Formulating complete diets for specific amino acids rather than crude protein content can reduce the oversupply of amino acids provided in most protein-rich feedstuffs, thereby reducing nitrogen excretion (**Table 8**). Reduced nitrogen excretion and anthropogenic propensity without compromising animal performance have been demonstrated for this approach [27].

In layers, a direct relationship between dietary protein level and nitrogen excretion, as well as better utilization of protein, has been reported, when hens were fed diets with lower protein concentrations than the requirements [31]. However, a reduction in the dietary concentration of protein may result in imbalance of amino acid concentrations and may also change the optimal requirements of the limiting amino acids (lysine and methionine) at lower dietary protein levels. Taking steps to correct factors that may have triggered poor performance measured in terms of some parameters in layers may yield encouraging results. There are indications that the resultant lowering effect of nitrogen output in broilers fed low-protein diets appeared to be less effective as the quantum of reduction in dietary protein increased [30]. Therefore, to minimize performance losses of broilers fed low-CP diets while at the same time maintaining a significant reduction in environmental risks resulting from nitrogen excretions, there is a limit to which dietary protein could be reduced [32, 33].

Type of chicken	Protein level	N-related parameter	Level of reduction in N-related parameters
Broiler	16–20%	Nitrogen output	49.2–65.6%
		Nitrogen output intensity	12.50–45.83%
Broiler	20–22% with met. + Lys.	Nitrogen output	16–38%
		Nitrogen output intensity	18.75–40.63%
Broiler	20% + enzymes supplementation	Nitrogen output	25.8–35.1%
		Nitrogen output intensity	37.5–43.8%
Laying hens	11.5–17.5%	Nitrogen output	26.6–36.3%
		Nitrogen output intensity	20.0–33.3%
Laying hens	13.5% + enzymes supplementation	Nitrogen output	Similar
		Nitrogen output intensity	12.5–43.7%

Sources: Based on [28–30].

Table 8. Effects of feeding low-CP diets on nitrogen output of chickens.

5.1.2. Undesirable effects of feeding low-protein diets to watch out for in chicken production

Feed intake is one of the areas in which some marked differences in the response of birds to low dietary protein has been observed when compared with those on higher dietary protein regime. Effects of low dietary protein levels on feed intake of birds have some degree of variation which could range from no effects on consumption to higher or depressed feed intake. Reduced or increased feed intake in chickens fed low-protein diets is desirable if accompanied with similar or improved performance per unit input when compared with birds fed high protein diets. However, it calls for concern if it leads to poor performance in the birds. Suspected factors contributing to cases of lower feed intake in birds fed low-protein diets have been identified. These include increased methionine level, ambient temperatures, extent of reduction of CP contents, change in dietary net energy concentration and protein ratio, the class and age of birds, and the extent to which the intact protein sources are kept at constant ratios to minimize amino acid imbalance [34–36].

Feeding low-protein diets could result in a wide range of response on different production and economic performance parameters. These could range from lowering, neutral, and/or raising effect on some critical parameters such as growth, feeding intake, carcass yield, egg production, egg weight, and feed efficiency. A similar performance between birds fed low-protein diets and those fed higher levels may be considered a desirable development particularly if it translates to lower cost of production and lower feed conversion ratio [28]. However, there is a limit to which dietary protein could be reduced without any adverse effects on the performance of the birds. This means that dietary protein should not be increased or lowered arbitrarily but care must be taken to ensure that the physiological and other requirements of the birds are met by the adopted feed regime to guide against negative impact on performance, profit, and the environment.

5.1.3. Some issues of and corrective measures for undesirable effects of feeding low-protein diets in chicken production

Some reasons alluded for poor performances of birds fed low-protein diets, which provides a level of insights for providing corrective measures for sustainability. This includes:

i. There are some potential toxic effects of supplying amino acids in excess of requirements, reduced level of potassium or altered ionic balance, and lack of sufficient nitrogen pool to provide nonessential or dispensable amino acids [24]. Therefore, when supplying amino acids in excess of recommended requirements, care must be taken to ensure that it is kept within permissible limits. For example, [29] observed that supplementing low-protein diet (20% CP) with methionine and lysine at 10% level higher than levels recommended by [37] corrected the performance of the birds to be at par with those fed 22% CP without any observed adverse effect.

ii. The dietary regime that does not match the age/stage of growth of broilers and layers may negatively affect some performance the characteristics of the birds [38]. This means that lowering dietary protein beyond reasonable levels in broilers and layers will negate production performances and even some environmental benefits. Therefore, the supplied diets must match the requirements for the stage of growth of the birds in order to optimize the performance. In other words, reduction in crude protein must not be excessive but kept within reasonable limits that do not negate the performance of the birds while retaining the environmental benefits. Ref. [34] indicated that egg weight increased when dietary protein level was increased from 15 to 16.5% during the early laying phase. They reported that on the basis of egg weight, body weight, and feed efficiency data, 15% CP is adequate for layers during the entire laying cycle of 21–72 weeks of age.

iii. Altered ionic imbalance owing to lower potassium levels in the diets particularly when soybean meal is reduced in the diet [39]. Ref. [40] reported that FCR and egg production were significantly improved in the low-protein diet group with high electrolyte balance. This suggests that correcting some of the factors responsible for inferior performance of low-protein diets in hens could lead to additional benefits in form of improvement in performance parameters.

iv. Deficiencies or Inadequate intake of some amino acids has been implicated for poor performance in terms of egg weight and/or egg mass and body weight gain in chickens fed low-protein diets [41]. There are cases of recovery or better performance of the birds with the supplementation of the diets with the limiting amino acids [42, 43].

v. Use of low-quality feedstuffs and/or inadequate utilization of some components of the supplied diets. A wide range of enzymes have been used to correct some of the performance deficiencies and/or even lead to some superior performance in chicken supplied with low-protein diets compared with those on higher levels (**Table 8**).

5.1.4. Cobenefits of feeding low-protein diets to chickens

Some co-benefits have been observed when reductions in dietary protein are kept within the limits that do not adversely affect the performance of the chicken. One of the cobenefits of feeding low-CP diets to chicken is perhaps better utilization of protein.

Another cobenefit of feeding low dietary protein is reduced cost of production per unit of product (egg or meat) especially when reduction in offered protein level is kept within limits that will not adversely affect performance. Economic returns of chickens during the starter phase could be improved by increasing the amino acid density of the diets.

Significant reduction in excretion of nutrients other than nitrogen in chickens fed low dietary proteins could be of immense benefits to the environment and the producers [43]. Low-protein diets are also a potential means of reducing mineral excretions, such as phosphorus, calcium, magnesium, potassium, sodium, manganese, zinc, and copper, and lead in poultry production [43, 44].

Lowered amount of excreted nitrogen (including NH_3) contributes to reductions in potentially offensive odor and pollution from broiler production facility [45]. Quantitative reduction in nitrogen output with lower dietary protein could imply reduction in risk for the environment due to significant reduction in the amount of fecal nitrogen available for conversion to ammonia and nitrous oxide and eventual release into the atmosphere.

5.2. Manure management strategies for reducing nitrogen emissions in chicken production

One of the most important aims of manure management is possibly ensuring the loss of nutrients is prevented or kept at the minimum in the manure chain. The manure chain is the period from collection to storage, treatment, and application for feed production. Handling chicken manure in an environmentally sustainable way would help realize its value as a nutrient resource for crops and as a feedstock for renewable energy. Emissions at the various stages of manure management could be tackled in animal house, during storage, processing, and application/discharge. Thus, instead of losing nutrients into the environment, efforts should be directed at keeping them in the food and/or feed chain where they could enhance crop growths and contribute to significant reduction in the use of inorganic fertilizers. Sustainable manure management will contribute to household food security and income, improvement in agricultural production, reduction in public health risks, reduction in environmental pollution and greenhouse gases emissions, and decelerate global warming. Although several approaches and technologies are available to achieve this goal, unsustainable manure management practices are still very prevalent in some countries. Some of these unsustainable manure management practices include direct application and indiscriminate disposal of manure such discharge into water bodies, burning or open dumping and indiscriminate land application. Lack of relevant policies and/or regulations, as well as nonenforcement of some of the relevant available policies or regulations, are among the major contributor to unsustainable manure management practices. Ref. [5] provided some valuable information or tips that would contribute to handling and managing manure in such a way that keeps the nutrients intact as much as practicable. Some of these are highlighted below:

Collection point: This could be in the barn or the house of the animal. The type of chicken management system affects the form in which the manure is handled. While manure is mostly in solid state in chickens raised on floor, it is in the wet form in layers raised in cages. It is critical to ensure that the animal housing allows for ease of manure collection and prevents losses. Consequently, the floor should be waterproof and covered against the rain to prevent losses through nutrient volatilization, run-off, and leaching.

Manure storage: Manure storage could be indoor or outdoor, and it is essential to ensure the nutrients are intact from the period of collection to application. Manure could also be stored either in dry or liquid form. Liquid storage could be in lagoons which can be covered or open. More nitrogen losses occur in open than in covered lagoon. It is important to store manure properly to ensure optimal application. It is therefore advisable to provide cover for the manure in outdoor storage. Storage roofing will prevent losses into the soil and water through leaching, run-off. Providing a storage facility that is air-tight will also prevent losses through volatilization. There are some marked differences in the major gaseous losses depending on the state in which the manure is stored. Nitrogen volatilization from chicken manure occurs mainly in the form of ammonia, nitrous oxide, and nitrogen gas in dry storage. However, nitrogen could be lost to the environment through leaching when there is contact with water. Apart from nitrogen, other nutrients in the manure could also find their way into the environment and cause some damages if excessive. In liquid storage, the main form of gaseous emission is methane, a greenhouse gas which is classified as a short-lived climate pollutant. To ensure proper capture of methane and prevent its losses to the atmosphere, anaerobic digesters could be used for storage. Anaerobic bio-digester technologies are relatively simple and adoptable at any level and scale, industrial, village, and farm level. The bio-digester must be recharged daily after biogas production commences. Manure used for biogas production is mixed with water in equal ratio (that is, 1 kg manure: 1 L of water) and fed into the bio-digester. The captured methane could be used as bio-energy, while the bio-slurry could be used as fertilizer as the nutrients are still intact. This could be a direct or an indirect source of additional income to farmers. Although chicken manure can yield considerable amount of biogas (310 m^3/ton DM), comparable to other feedstock materials, a major challenge with the use of chicken manure for biogas production is that it is high in ammonium, which could inhibit the process of methanogenesis or biomethanation. Therefore, it is advisable to use chicken manure in small quantity. Biogas is composed of 50–70% methane, 30–45% carbon dioxide, 0–3% nitrogen, hydrogen, oxygen and hydrogen sulfide and therefore could be purified and used to power generators. When used for household cooking, caution must be exercised because of the highly inflammable characteristic of methane which is the main component of biogas.

Manure treatment and processing: There are several reasons for treating manure, namely; to reduce the volume, to improve handling as well as increase its value, applicability, reduce health related risks, and to prevent nutrient losses to safeguard the environment. There are several available methods of manure treatments, ranging from simple to highly complex one. These include air drying, anaerobic digestion, separation, adding solid materials to liquid manure, refining, composting, and amendment with alum or use of acidifying agents, and so on.

Manure treatment could begin from the animal house. For example, treatment of poultry litter with alum is a practice that is known to reduce manure nitrogen losses and commonly carried out during chicken production operations. Several types of alum used for water treatments could also be used effectively for chicken manure amendment. Ref. [46] compared poultry litters treated with salt solution, alum, and air exclusion and reported that alum treated feces had significantly higher percentage nitrogen retention and lower nitrogen depletion rate than salt and air-tight treatments. Ref. [46] also observed that maize seeds planted on alum treated and air excluded litter soils had an average germination percentage (GP) range of 65–75% and 54–75%, respectively, which were comparable to the average GP of 75% recorded for soil treated with the control manure. Sorghum plots also recorded a mean value of 99% GP on alum treated soil within 2 weeks of planting, surpassing airtight treated soil with mean value of 89% GP; however, seeds planted on salt treated litter soil recorded 0% germination. Ref. [30] suggested that ammonium alum was the least effective in preventing nitrogen losses in stored chicken manure compared with other forms of alum. Some of the benefits of using alum in chicken manure amendment include decreases in chicken house ammonia level, reduction in energy usage, improvement in birds' performance, precipitation of soluble phosphorus, reduction of phosphorus and heavy metals runoff, and imposition of drying effect that reduces litter moisture.

Composting could be carried out using heap or pit method. Composting could be done in small and in large scale, and solid or liquid manure could be used. A major disadvantage of composting is that it could be labor intensive. Air drying could practically lead to the loss of manure nitrogen into the atmosphere. Air drying manure should only be done on waterproof floor. Air dried manure are easy to handle as they be bulked.

Manure application as organic fertilizer: Manure could be used as a valuable fertilizer resource. It is however critical to carry out both soil and manure tests to establish the nutrient levels and needs to avoid nutrient overload. Manure applications as fertilizer must be strictly need-based. It is advised that manure be incorporated into the soil during application.

6. Conclusions

Environmental approach to chicken production is an increasingly important consideration all over the world. Major emissions in chicken production include ammonia, nitrous oxide, and other oxides of nitrogen and methane produced through the poultry supply chain. Uncontrolled emissions of deleterious gases into the environment could pose serious challenges and negatively impact the future use of resources. Sustainability approaches to chicken production hold immense benefits for the planet and the people while at the same time guaranteeing profitability. Several technologies are available for use in reducing the environmental footprint of chicken. To minimize the loss of nutrients, appropriate knowledge of various emissions/losses is required, and appropriate measures are taken across the entire chicken and manure management chain. Enactment and enforcement of relevant policies, laws, regulations, and creating enabling environments will considerably promote sustainable practices in chicken production.

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Chapter 4

Quality of Chicken Meat

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Abstract

Chicken meat is considered as an easily available source of high-quality protein and other nutrients that are necessary for proper body functioning. In order to meet the consumers' growing demands for high-quality protein, the poultry industry focused on selection of fast-growing broilers, which reach a body mass of about 2.5 kg within 6-week-intensive fattening. Relatively low sales prices of chicken meat, in comparison to other types of meat, speak in favor of the increased chicken meat consumption. In addition, chicken meat is known by its nutritional quality, as it contains significant amount of high-quality and easily digestible protein and a low portion of saturated fat. Therefore, chicken meat is recommended for consumption by all age groups. The technological parameters of chicken meat quality are related to various factors (keeping conditions, feeding treatment, feed composition, transport, stress before slaughter, etc.). Composition of chicken meat can be influenced through modification of chicken feed composition (addition of different types of oils, vitamins, microelements and amino acids), to produce meat enriched with functional ingredients (n-3 PUFA, carnosine, selenium and vitamin E). By this way, chicken meat becomes a foodstuff with added value, which, in addition to high-quality nutritional composition, also contains ingredients that are beneficial to human health.

Keywords: chicken meat, nutritive value, meat quality, n-3 PUFA, carnosine, selenium, health benefit

1. Introduction

Throughout the world, poultry meat consumption continues to grow, both in developed and in the developing countries. In 1999, global production of chickens reached 40 billion, and by 2020 this trend is expected to continue to grow, so that poultry meat will become the consumers' first choice [1]. Fresh chicken meat and chicken products are universally popular. This occurrence can be explained by the fact that this meat is not a subject of culturally or religiously set limitations, and it is perceived as nutritionally valuable foodstuff with low content of fat, in which there are more desirable unsaturated fatty acids than in other types of meat [2, 3]. More importantly, quality poultry products are available at affordable prices, although their production costs may vary [4]. If referring to overall consumption of all types of meat, poultry meat consumption takes one of the leading places in all countries throughout the world [3]. Such good rating of poultry meat is influenced by many factors, such as short fattening duration, excellent space utilization, high reproductive ability of poultry, excellent feed conversion, satisfactory nutritional value of poultry meat and relatively low sales prices. The quality of broiler meat is affected by a number of factors, as follows: fattening system, duration of fattening, hybrid and sex, feeding treatment, handling before slaughter, freezing of carcasses, storage time, etc. [5–11]. It should be emphasized that nowadays poultry is fattened in an intensive way, so the stress is an inevitable factor, and the feed, with increased content of microalgae and vegetable and fish oils used to enrich poultry products with desirable fatty acids, is susceptible to oxidation [11–14]. The same as designed poultry feed mixtures with increased microalgae or oil content, poultry products (meat and eggs) enriched with omega-3 fatty acids are also subjected to oxidation. In order to reduce oxidation in poultry feed, it is necessary to supplement it with some antioxidants, such as selenium or vitamin E. Such chicken meat is considered as "functional food", as it has the increased content of bioactive substances, which positively influences consumers' health. The most common bioactive substances used to enrich chicken meat are conjugated linoleic acid (CLA), vitamins, microelements, amino acids, microalgae and oils rich in omega-3 PUFA (polyunsaturated fatty acids) [14–19].

The aim of this research was to present the nutritive value of chicken meat, as well as to assess the influence of different fattening system factors that determine the meat quality. Furthermore, the aim was to elaborate the possibility of enriching the meat with omega-3 fatty acids, carnosine and selenium, and to point out the benefits that consumption of enriched chicken meat has on human health.

2. Nutritional value of chicken meat

Chicken meat is appropriate for quick and simple preparation, yet it offers a variety of combinations with different foodstuffs, thus making itself as a usual choice of consumers faced with modern lifestyle. When compared to other types of meat (**Table 1**), it is proved that chicken meat (breasts) contains more protein and less fat than red meat, thus making it a dietetic product.

It is important to mention that chicken with skin contains 2–3 times more fat than chicken without skin, so it should be eaten without skin to ensure the intake of high-quality protein without extra calories and fat. When compared to red meat, the main advantage of white chicken meat is in its low caloric value and a low portion of saturated fat, so consumption of white chicken meat is recommended to people who want to reduce the fat intake, as well as

Nutrient	Chicken[1]	Pork[2]	Beef[3]	Lamb[4]
Energy/kcal	165	165	185	180
Water/g	65.26	65.75	64.83	64.92
Protein/g	31.02	28.86	27.23	28.17
Total fat/g	3.57	4.62	7.63	6.67
Saturated fatty acids	1.010	1.451	2.661	2.380
Monounsaturated fatty acids	1.240	1.878	3.214	2.920
Polyunsaturated fatty acids	0.770	1.066	0.285	0.440
Cholesterol (mg)	85	86	78	87

Source: [20].[1]Chicken, broilers or fryers, breast, meat only, cooked, roasted.

[2]Pork, fresh, leg (ham), rump half, separable lean only, cooked, roasted.

[3]Beef, round, bottom round, roast, separable lean only, trimmed to 0″ fat, choice, cooked, roasted.

[4]Lamb, domestic, leg, shank half, separable lean only, trimmed to 1/4″ fat, choice, cooked, roasted.

Table 1. Nutritive content of different types of meat (per 100 g).

to people suffering from heart and coronary diseases. When compared to cholesterol content, white chicken meat does not differ much from other types of meat, however, if considering other benefits (more protein, less total fat, less saturated fat and less calories), it has better nutritional quality and therefore, it is recommended for consumption to anyone who takes care of diet and health. High protein content makes chicken meat an ideal foodstuff for all consumers who need high-quality, easily degradable protein (athletes, children, the elderly). Average daily requirement (AR—average requirements) of adults for protein is 0.66 g/kg body weight (BW), while young children and athletes' needs are twice as high (1.12 g/kg body weight). Pregnant women's needs for protein are considerably higher and they depend on the pregnancy trimester, by increasing to an additional 23 g/day for the third pregnancy trimester [21]. Because of all stated above, chicken meat is recommended as a rich source of high-quality protein in human nutrition. Chicken meat contains low collagen levels, which is another positive characteristic. Collagen is a structural protein that reduces meat digestibility, so chicken meat is easier to digest than other types of meat [22].

Chicken meat is also a good source of some minerals and vitamins (**Table 2**). When compared to red meat (except for pork meat), it contains more calcium, magnesium, phosphorus and sodium. Content of iron is almost the same as in pork. Iron is necessary for creation of hemoglobin, for prevention of anemia, as well as for normal muscle activity. Calcium and phosphorus are important for healthy bones and teeth. Sodium is an electrolyte, and magnesium is important for normal synthesis of protein and proper muscle activity. Out of the total content of vitamin in chicken meat, niacin (vitamin B3) is contained in highest portion, and content of vitamins A and B6 is also higher than in other types of meat. Niacin is very important for proper metabolism of carbohydrates and for energy creation. It is also important for healthy skin, hair and eyes, as well as for nervous system. It plays a role in the synthesis

	Chicken[1]	**Pork**[2]	**Beef**[3]	**Lamb**[4]
Minerals				
Calcium (mg)	15	16	6	8
Iron (mg)	1.04	0.97	2.40	2.06
Magnesium (mg)	29	27	18	26
Phosphorus (mg)	228	273	172	208
Potassium (mg)	256	425	222	342
Sodium (mg)	74	80	36	66
Zinc (mg)	1.00	2.48	4.74	5.02
Vitamins				
Vitamin C (mg)	0.0	0.0	0.0	0,0
Thiamin (mg)	0.070	0.523	0.057	0.110
Riboflavin (mg)	0.114	0,408	0.170	0,280
Niacin (mg)	13.712	7.940	5.232	6.390
Vitamin B6 (mg)	0.600	0.538	0.380	0.170
Folate (µg)	4	0	9	24
Vitamin B12 (µg)	0.34	0.67	1.61	2.71
Vitamin A (µg)	6	1	0	0
Vitamin E (mg)	0.27	0.26	0.37	0.18
Vitamin D (D2 + D3) (µg)	0.1	0.3	—	—
Vitamin K (µg)	0.3	0.0	1.3	—

Source: [20].[1]Chicken, broilers or fryers, breast, meat only, cooked, roasted.

[2]Pork, fresh, leg (ham), rump half, separable lean only, cooked, roasted.

[3]Beef, round, bottom round, roast, separable lean only, trimmed to 0″ fat, choice, cooked, roasted.

[4]Lamb, domestic, leg, shank half, separable lean only, trimmed to 1/4″ fat, choice, cooked, roasted.

Table 2. Content of minerals and vitamins in different types of meat (per 100 g).

of sex hormones and in improving circulation and reducing cholesterol level. Niacin is often used as an additional therapy in patients that take drugs for lowering of blood lipids. In this case, it is scientifically proven that niacin affects the increase of high density lipoprotein (HDL) cholesterol level, but it does not affect the improvement of cardiovascular disease state [23, 24]. When niacin is taken as an independent therapy, it reduces the development of cardiovascular diseases, and lowers the mortality associated with cardiac or cardiovascular diseases [25, 26]. The chronic lack of niacin in the organism causes pelagic disease, which is characterized by uneven skin pigmentation (skin redness), gastrointestinal disorders (diarrhea) and brain function disorder (dementia), [27]. In light of the abovementioned, chicken meat is considered as convenient, affordable and acceptable source of basic nutrients, vitamins and minerals necessary for proper body functioning.

By applying different feeding treatments, the nutritional profile of chicken meat, such as fat and cholesterol content and fatty acid profile, can be modified in order to produce a foodstuff of improved nutritional value. Furthermore, supplementation of various antioxidants (selenium and vitamin E) to chicken feed influences their deposition in chicken tissue, thus enabling production of enriched foodstuff. The possibilities of enriching chicken meat with favorable omega-3 fatty acids and antioxidants are explored in the following text.

2.1. Health benefit of chicken meat

In present times, emphasis is put on importance of chicken meat consumption for maintaining and reducing body weight. It is known that the intake of dietary protein is effective in reducing body weight, so the chicken meat is often a part of the diet aimed to reduce body weight, because of its high protein and low fat content. The studies have shown that weight loss was higher in people who consumed low calorie meals rich in protein in comparison with low calorie meals with low protein content. This is due to the fact that protein provides a greater sense of satiety, so that people consume less calories during the day, thus reducing the intake of carbohydrates [28, 29].

Chicken meat is considered as desirable foodstuff in prevention of cardiovascular diseases. Saturated fat, cholesterol and heme iron, which is more contained in red than in white meat, are very important factors in development of atherosclerosis, cardiovascular diseases, hypertension and in increase of blood cholesterol [30]. According to the data of Bernstein et al., by replacing meals with red meat with white chicken meat, the risk of cardiovascular disease occurrence can be lowered by 19% [31]. The authors assumed that this was a consequence of less intake of heme iron and sodium, and of more polyunsaturated fatty acids in meals. Therefore, chicken meat, as a source of protein, could be a significant factor in reducing risks of cardiovascular disease development.

There has been recently a lot of evidence on how the lifestyle has been influencing the increase or the decrease of disease risk occurrence, such as diabetes. Changes in our lifestyle and nutrition can significantly affect the decrease of that disease occurrence. The increased risk of developing diabetes is related to various factors, of which the intake of saturated animal fat is among the most significant ones [32]. The authors stated a positive correlation between the intake of saturated fat intake and the resistance to insulin. The research results of Pan et al. pointed out that consumption of red meat, especially of red meat products, was associated with increased risk of developing the type 2 diabetes [33]. Although the increased intake of protein of animal origin represents a risk of developing diabetes, consumption of chicken meat, as a part of balanced diet, is recommended for prevention of disease development and its control [34]. Healthy lifestyle, which includes consumption of chicken meat, fruit, legumes, nuts, whole grains and vegetable oils, is associated with reduced risk of death in patients suffering from diabetes [35]. The results of these studies encourage the change of lifestyle and dietary habits, within which white chicken meat with low content of saturated fat serves as a healthier alternative to animal protein intake in daily meals, so it is recommended as a part of a healthy diet.

As stated above, excessive intake of proteins of animal origin is associated with the risk of developing diabetes. Still, some studies have also confirmed that excessive intake of meat, especially of red meat, is a potential risk factor for development of certain types of cancer. Red meat contains more potentially harmful ingredients than white meat. These potentially harmful ingredients are saturated fat, heme iron, sodium, N-nitroso compounds and aromatic amines produced by high temperature cooking, so the consumption of red meat represents a risk of developing cancers. Therefore, red meat is associated with a higher risk of cancers, while white meat shows neutral or moderately protective correlation to cancer occurrence [36, 37]. Cancers in digestive system are usually associated with consumption of animal products. This conclusion was confirmed by researches carried out among populations with significantly higher consumption of meat than recommended. It is assumed that myoglobin from red meat activates pre-cancerous damage by accelerating the heme iron influence on the formation of carcinogenic N-nitroso compounds and by developing cytotoxic and genotoxic aldehydes through the lipid peroxidation process [38]. These facts are in favor of supporting consumption of white chicken meat. Zhu et al. carried out a comprehensive review of literature on the occurrence of esophageal cancer, and concluded that there was a reverse correlation between the number of chicken meat meals a week and the risk of developing esophageal cancer [39]. The authors stated researches showed the decreasing risk of developing esophageal cancer by about 53% in Europe in cases of increased consumption of chicken meat. Of course, such research conclusions should be interpreted cautiously, because it cannot be stated with full certainty that red meat causes cancers and white meat does not, yet there is a lot of evidence that consumption of white meat is more favorable than consumption of red meat.

3. Parameters of chicken meat quality

When considering nutritional aspects, poultry meat is good for consumers because it is rich in protein and minerals, and contains a small amount of fat with high portion of unsaturated fatty acids and a low cholesterol level [2]. Changes in consumers' lifestyle in developed countries have influenced the meat market by changing the demand and supply of certain types of meat, which the food industry used as an advantage to market so called "fast food" and more recently also "functional food". In both food groups, chicken meat is highly represented [3]. This growing demand for poultry meat influenced the scientists to create chickens of fast-growing genotypes, which have good feed conversion, better carcass formation (higher portion of breast meat and less abdominal fat), lower mortality, etc. However, all of these positive changes in new chicken genotypes cause greater stress, and many researchers point out that this fast growth of chickens resulted in histological and biochemical modifications of muscle tissue [40, 41, 42]. The researches proved that selection of fast-growing chickens had negative effects on some meat quality parameters: reduced water holding capacity of meat, poor cohesiveness in cooked meat, appearance of pale, soft, exudative (PSE) meat, that is, of dark, firm, dry (DFD) meat [43, 44]. In addition to the mentioned factors, the available literature states that parameters of chicken meat quality are affected by the keeping system and duration of chicken fattening, feeding treatment and sex of chickens, pre-slaughter handling, transport to slaughterhouse, etc.

An important factor for consumers when deciding on the purchase of meat is its appearance, therefore, in this chapter are described some technological features such as color, pH value, drip loss, cooking loss and water holding capacity (WHC), that have a direct impact on meat appearance. Consumers connect the color of meat with its freshness. The color of meat can be determined visually or using instruments (colorimeters). For the visual evaluation of the meat color, it is necessary to have trained panelists, who evaluate the appearance of meat by using the hedonic scale. The instrumental determination of meat color is more efficient and the methods of reflection or extraction are used to quantify the amount of pigment. The color of foods can be defined as the interaction of a light, an object, an observer and the surroundings of the food. Recently, the International Commission on Illumination described how background can influence the appreciation of color. Instruments used for evaluation of meat color by reflection method are colorimeters, for example, CR Minolta 300 or 400 that work on the principle of meat color comparison in regard to standard color values. The International Commission on Illumination lists three values: CIE L*, a* and b*. CIE L* indicates lightness, where values range from 0 (black) to 100 (white). The value of CIE a* shows redness while CIE b* indicates yellowness. Negative a* and b* values indicate the appearance of green and blue color of the meat.

3.1. Influence of genotype, sex and feeding on the chicken meat quality

Kralik et al. reported that the chicken genotype did not influence the CIE L* (lightness) and CIE b* (yellowness) values referring to meat color [45]. As of the results, the CIE L* 49.93 and CIE b* 10.17 was reported for chicken meat of Cobb 500 genotype, and for the Hubbard Classic, the values were CIE L* 51.11 and CIE b* 10.50 ($P > 0.05$). Furthermore, the authors stated that there was a negative correlation between pH and CIE L* value $r = -0.285$ for Cobb 500 and $r = -0.438$ for Hubbard Classic genotypes. In the research into the influence of chicken sex on the quality of fresh and cooked meat, Salakova et al. also determined the negative correlation between pH and CIE L* value measured in fresh and cooked breast meat of the Ross 308 chicken genotype ($r = -0.41$, $P < 0.001$ and $r = -0.31$, $P < 0.05$), [46]. The authors stated that male chickens of the Ross 308 genotype had statistically significantly higher pH values than female chickens ($P < 0.05$), which was not depending on the portion of crude protein in the finisher mixture (A = 22.6%, B = 20.1% and C = 18.7%). The highest pH values were measured in breast meat of male and female chickens of the group A (pH = 6.08 and pH = 5.97, respectively), while in feeding treatments with lower portion of crude protein in feeding mixture the value of pH in breast meat of both sexes decreased (♂ B = 5.99 and C ♂ =5.77 and ♀ B = 5.85 and ♀ C = 5.66). Female chickens had statistically significantly brighter meat color than male chickens in the A treatment (CIE L* 54.90 and CIE L* 52.24, respectively; $P < 0.01$). The same trend referring to the meat color was noticed in other feeding treatments, however, the differences were not statistically significant (♀ B=CIE L* 59.43 C=CIE L* 58.11 and ♂ B=CIE L* 58.36 C=CIE L*55.17). The research of Živković et al. describes the influence of extruded linseed in chicken feed on the physico-chemical and sensory traits of meat [47]. They fattened chicken separated by sex in control and experimental group. The control group (C) consumed the commercial mixture and the experimental group (E) had mixture supplemented with 6% of extruded linseed. The authors concluded that feeding treatment influenced the protein content in meat of thighs of females only (C = 19.27% E = 17.76%; $P < 0.05$). The feeding treatment had effect on the breast meat color ($P < 0.05$). Experimental group of chickens had lighter breast meat color than the control. Male chickens had statistically significantly lighter breast meat than females ($P < 0.05$). The value of CIE a* (redness) reduced significantly in *m. pectoralis profundus*, and CIE b* increased in *m. pectoralis superficialis* in both chicken sexes ($P < 0.001$). In thigh muscles (*m. biceps femoris*), the value of CIE a* reduced significantly ($P < 0.05$) in meat of male chickens, while in female chickens the values of CIE b* increased significantly ($P < 0.05$). The feeding treatment, sex and their interaction did not influence the results of chicken meat sensory analysis. In their research into the effects of genotype on some parameters of chicken meat quality, Kralik et al. reported that breast meat of the Hubbard Classic genotype was of better quality than the breast meat of Cobb 500 and Ross 308 genotypes [48]. Hubbard Classic chickens had better pH_{45min} and CIE L* values than other two genotypes (Cobb 500 and Ross 308). The highest pH_{45min} was determined in Cobb 500 chickens, while the values for pH_{45min} in Ross 308 and Hubbard Classic chicken were similar (6.05, 5.99 and 5.98, respectively; $P > 0.05$). Genotype had no effect on pH_{24h} values ($P > 0.05$). Hubbard Classic chickens had the lowest CIE L* value in breast muscle tissue (53.86), while Ross 308 and Cobb 500 chickens had slightly higher CIE L* values (55.12 and 54.36, respectively; $P > 0.05$). Kralik et al. reported statistically significant influence of genotype on pH_1 ($P = 0.004$) and pH_2 ($P < 0.001$), drip loss ($P = 0.015$) and meat color (CIE L* $P = 0.015$ and CIE a* $P < 0.001$) in their research [49]. The values of pH were measured 45 minutes after slaughtering (pH_1) and 24 h after slaughtering and cooling of chickens (pH_2). The authors stated that chicken sex had statistically significant influence on meat color ($P < 0.001$). Female chickens had lower CIE L* values than male chickens (Cobb ♀ = CIE L* 49.24 and ♂ = CIE L* 50.60, i.e. Hubbard ♀ = CIE L* 49.97 and ♂ = CIE L* 52.61). Influence of interaction between genotype and sex was observed in breast texture values ($P < 0.020$). In the research into the influence of pH values on the meat quality of different chicken genotypes, Ristić and Damme concluded that the chicken genotype and sex had statistically significant effect on the pH measured 15 minutes after slaughtering of chickens [50]. Male chickens had statistically significantly lower pH values than females. In the research into the influence of chicken genotype (Cobb, Ross and Hubbard) and the age (42 and 50 days) on the quality of meat, Glamoclija et al. stated that the pH values measured at different times after slaughtering (pH_{15min}; pH_{24h} and pH_{48h}) were influenced by the chicken age at slaughter ($P < 0.05$), [51]. Older chickens had higher pH values of breast meat than younger ones. Interaction of chicken genotype and age had effect on the pH_{15min} value, while the genotype did not affect the pH values ($P > 0.05$).

3.2. Influence of keeping system and fattening duration on the chicken meat quality

Bogosavljević-Bošković et al. determined that the fattening system (intensive or semi-intensive) had statistically significant influence on the portion of breasts and drumsticks with thighs ($P < 0.05$), [52]. The authors indicated that the portion of muscle tissue in chickens kept in semi-intensive system was by 1.44% higher ($P < 0.01$), but the same chickens had the portion of bone and skin by 0.82 and 0.67% lower than chickens fattened in the intensive system ($P < 0.05$). Li et al. investigated the influence of chicken keeping systems (free range, cage and litter) on production parameters and meat quality and they reported that the keeping system had statistically significant influence on the final weight of chickens and feed consumption, as well as on the texture and portion of intramuscular fat in breast meat ($P < 0.05$), [53]. However, chicken keeping system had no effect on pH and drip loss in breast meat ($P > 0.05$). Castellini et al. [54] studied the influence of keeping systems (K = conventional and O = organic) and duration of fattening of chickens (56 and 81 days) on the quality of chicken meat, and they confirmed that breast and thigh meat of chickens kept in organic production had lower WHC values and pH_{24h} than meat of chickens fattened conventionally. The breast meat had the following WHC values:

$K_{56\ days}$ = 52.02% and $K_{81\ days}$ = 55.26%, and $O_{56\ days}$ = 51.82% and $O_{81\ days}$ = 53.17% ($P < 0.05$), while the values in thighs were as follows: $K_{56\ days}$ = 59.69% and $K_{81\ days}$ = 60.15%, and $O_{56\ days}$ = 56.21% and $O_{81\ days}$ = 57.45% ($P < 0.05$). The values of pH in breast muscles of the treatments $K_{56\ days}$ and $K_{81\ days}$ were statistically significantly higher ($P < 0.05$) than in the treatments $O_{56\ days}$ and $O_{81\ days}$ (pH 5.96 and pH 5.98, and pH 5.75 and pH 5.80, respectively). Referring to all other meat quality parameters of both tested tissue (breasts and thighs), chicken meat from organic production had better values than the meat produced in conventional fattening system (cooking loss %, CIE L*, CIE a*, CIE b* and shear value kg/cm^2).

3.3. Influence of transport and pre-slaughter handling on the chicken meat quality

When animals are exposed to long-lasting stress (long-distance transport, lack of feed before transport and slaughter, overcrowded transport cages, high or low temperatures in the production facility or during transport, etc.), they will be exhausted and the glycogen stored in muscles will turn into lactic acid, which will then lead to a sudden lowering of pH value in muscles after slaughter, while the carcass is still warm. High temperature and low pH in chicken meat will stimulate protein denaturation, which will further influence lowering of the water holding capacity in meat. Low pH values stimulate the oxidation of myoglobin (pink color) and oxyhemoglobin (red color) to metamyoglobin (brown meat color). If animals are exposed to longer stress before slaughtering, they will have less stored glycogen in muscles because of exhaustion. Reduced glycogen reserve affects postmortem changes after slaughtering, meaning that the pH value remains high, which causes the occurrence of DFD meat. In this meat, protein denaturation and drip loss are slowed down [41]. In their study about influences of transport-caused stress on the meat quality parameters, Doktor and Połtowicz [55] stated that after 42 days of fattening of Hubbard Flex chickens, their treatment before and during transport to slaughterhouse had statistically significant influence only on pH_1, while other meat quality parameters were not influenced (pH_2, meat color (L*, a*, b*), drip loss (%), water holding capacity—WHC (%), shear force (N)). Bressan and Beraquet studied the influence of heat stress during fattening on the chicken meat quality and determined that chickens exposed to high daily temperatures (ambient temperature 30°C) had higher cooking loss measured in breast meat when compared to chickens kept at lower ambient temperatures (17°C), (28.7 and 27.2%, respectively), [56].

3.4. Influence of some technological parameters on the chicken meat quality

Since appearance and odor, as the parameters of meat quality, significantly affect the consumers' preferences at purchase, it is important to achieve "normal" meat color with the odor typical for fresh meat [57]. The stated authors assessed the consumers' opinions toward pale, soft and exudative chicken meat. In their research they used meat of lighter color (L* = 59.26), that is, the meat color that was considered as normal for chicken filets (L* = 49.24). The examinees made differences between PSE and meat of normal quality in stores, while panelists assessed sensory quality of cooked meat and showed preference toward control samples (meat of "normal" quality). Qiao et al. determined the border values for color of chicken breast muscle: lighter than normal (L* > 53), normal (48 < L* < 53) and darker than normal (L* < 48), [58]. Furthermore, the authors defined the values for breast muscle color measured 24 hours post mortem, as of the following: dark L* 45.68, normal L* 51.32 and light L* 55.95. Woelfel et al.

determined the border values for "normal" chicken breasts L* 52.15, drip loss 3.32% and cooking loss 21.02%, while for PSE meat these values were: L* 59.81, drip loss 4.38% and cooking loss 26.39% [59]. Border values reported by Karunanayaka et al. are slightly higher than those determined by the abovementioned authors [60]. According to Karunanayaka et al., the values for normal meat are L* 56.82 and WHC 77.95, while the PSE meat has the following values: L* 61.83 and WHC 77.12 [60]. **Table 3** presents border values for PSE, normal and DFD chicken meat, as reported by various authors.

According to Zhang and Barbut, meat color typical to PSE meat is L* > 53, the meat of normal quality has the values ranging between 46 < L* < 53, and the DFD meat has the value L* < 46 [63]. The same authors stated the cooking loss of meat classified as of color: 20.96% for PSE meat, 25.77% for normal meat and 21.32% for DFD meat. Referring to the values of meat color (L*, a* and b*), Kissel et al. classified the chicken meat as normal, with measured values of L* = 51.42, a* = 7.26 and b* = 6.74, and as PSE meat with measured values L* = 57.63, a* = 2.11 and b* = 5.46 [62]. In their research into the PSE chicken meat in further processing (marinating and cooking), Barbut et al. [64] reported that fresh PSE meat was of lighter color (L* = 57.7) and had lower pH (5.72), while DFD meat was of darker color L* = 44.8 and higher pH (6.27). Carvalho et al. determined that PSE meat had L* = 58.90; drip loss = 6.52%, cooking loss = 27.02% and WHC 79.84% [61]. The authors defined the meat to be of normal quality if exhibiting the following values: L* = 56.86; drip loss = 4.04, cooking loss = 24.41% and WHC = 85.43%.

Condition	pH Value of meat	References
PSE	pH_{24h} 5.75	[61]
	pH 5.83	[60]
	pH 5.61	[57]
	pH ≤ 5.8	[50]
	pH_{24h} 5.77	[62]
	pH < 5.7	[63]
	pH 5.72	[64]
	pH 5.76	[59]
Normal	pH_{24h} 5.94	[61]
	pH 5.97	[60]
	pH 5.96	[57]
	pH 5.9–6.2	[50]
	pH_{24h} 5.93	[62]
	pH < 6.1	[63]
	pH 6.07	[59]
DFD	pH ≥6.3	[50]
	pH > 6.1	[63]
	pH 6.27	[64]

Table 3. Typical limits of pH values for PSE, normal and DFD chicken meat.

4. Enrichment of chicken meat with functional ingredients

4.1. Polyunsaturated fatty acids (n-3 PUFA)

Science on nutrition has developed over the years, and new analytical methods have enabled the determination of various functional food ingredients that have a beneficial effect on human health and that help to reduce the disease risks. Such ingredients, called nutricines, have an important biological activity in human cells [65]. The concept of functional food has been first mentioned in Japan in the 1980s. The project foods for specified health uses (FOSHU) was focused on food that was expected to have a specific health effect based on the content of some important and useful ingredients [66]. Ingredients in which consumers show interest are n-3 PUFA, Se, vitamin E, lutein and carnosine. Chicken meat can be enriched with n-3 PUFA if the content of FA (Fatty Acids) is changed in their feed [10, 67, 68, 69]. The optimal ratio of n-6 PUFA:n-3 PUFA is from 10:1 to 5:1 [70, 71]. The RDI (Recommended Daily Intake) for n-3 long-chain PUFA is 350–400 mg. Vegetable and fish oils are predominant sources of omega-3 fatty acids. Vegetable oils are the main source of α-linolenic acid (C18:3n3, ALA), and fish oils are the main source of eicosapentaenoic acid (C20:5n3, EPA) and docosahexaenoic acid (C22:6n-3, DHA), [72]. Vegetable oils contain significant amounts of polyunsaturated omega-6 fatty acids, of which linoleic acid (C18:2n-6, LA) is the most significant. It is also present in sunflower and soybean oils [65]. Metabolic processes are initiated over arachidonic acid (C20:4n6, AA) and EPA in endoplasmic reticulum, and further carried out by the enzymes elongase Δ6 and desaturase Δ5. The mechanism of conversion into DHA is still not fully known, yet is believed that this

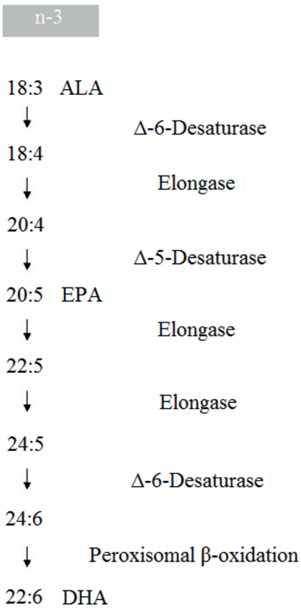

Figure 1. Metabolism of n-3 and n-6 PUFA [76].

process is supported by the enzyme desaturase Δ4 [73]. Infante and Huszagh stated that DHA is synthesized in mitochondrial membranes, while EPA and AA are synthesized in the endoplasmic reticulum [74, 75]. **Figure 1** presents the metabolism of n-3 and n-6 PUFA.

There are two reasons for increasing the concentration of n-3 PUFA in chicken meat. The first reason is that nutritionists recommend the reduced consumption of saturated fatty acids (SFA)

Reference	Diet	ALA	EPA	DHA
		% of total FA		
[12]	Sunflower oil 2.5% + fish oil 2.5%	3.16	0.79	5.62
	Soybean oil 2.5% + fish oil 2.5%	2.37	0.93	6.44
	Rapeseed oil 2.5% + fish oil 2.5%	2.36	1.32	8.95
	Linseed 2.5% + fish oil 2.5%	6.25	1.18	5.66
[77]	Control	0.72	0.75	0.87
	Rapeseed oil 2%	0.37	1.18	2.03
	Rapeseed oil 4%	0.61	0.62	0.75
[78]	Poultry fat 3%	1.59	1.04	0.15
	Poultry fat 2% + fish oil 1%	0.70	5.84	0.66
	Poultry fat 1% + fish oil 2%	2.17	8.53	2.39
	Fish oil 3%	2.14	10.54	3.80
[10]	Linseed oil 6%	7.09	0.77	0.90
	Linseed oil 6% + 0.3% Se	8.51	0.73	0.93
	Linseed oil 6% + 0.5% Se	6.78	0.51	0.84
[79]	Sunflower oil 3% + linseed oil 3%	5.14	0.29	0.39
	Sunflower oil 3% + linseed oil 3% + 0.3 mg Se/kg feed	6.29	0.34	0.59
	Sunflower oil 3% + linseed oil 3% + 0.5 mg Se/kg feed	4.39	0.29	0.50
[80]	Corn oil 15%	2.21	–	0.07
	Canola oil 5% + corn oil 10%	2.01	–	0.05
	Canola oil 10% + corn oil 5%	3.41	–	0.13
	Canola oil 15%	3.52	–	0.07
[81]*	Rice bran oil S 1% + F 2%	0.33	0.15	0.43
	Rice bran oil (S 0.7% + F 1.6%) + linseed oil (S 0.3% + F 0.4%)	0.86	0.50	0.88
	Rice bran oil (S 0.3% + F 1.0%) + linseed oil (S 0.7% + F 1.0%)	0.98	0.98	1.77
[11]**	Sunflower oil S 2% + F 3%	0.23	0.17	0.23
	Soybean oil S 2% + F 3%	0.92	0.25	0.63
	Mustard oil S 2% + F3%	3.23	0.63	1.47
	Linseed oil S 2% + F 3%	5.02	1.74	3.51
	Fish oil S 2% + F 3%	4.60	2.72	5.76

S-starter diet.

F-finisher diet.*Rice bran oil and linseed oil are supplemented to S and F diets in the amounts as presented.

**Oils of different origin are supplemented in the amount of 2% to S and 3% to F diets.

Table 4. Supplementation of oils in chicken feeding mixtures and their effect on enriching of breast muscles with n-3 PUFA.

to lower the risk of cardiovascular diseases development [82]. The second reason is that fats are replaced by polyunsaturated oils [83, 84, 85]. It is known that fish flour and oil are rich in essential n-3 PUFAs (EPA, DHA), however it is also proved that, if supplemented to chicken feed in higher amounts, they have negative effect on organoleptic properties of meat [86]. For that reason, as an alternative to fish oil, scientists use vegetable oils as supplements to chicken feed (soybean, rapeseed, sunflower and linseed oils), as well as combinations of those oils [11, 12, 77, 87]. In addition to oils, chicken feed can be supplemented also by extruded linseed or rapeseed [88], in order to change the FA profile. References about the use of various oils in chicken diets for the purpose of enriching broiler meat with n-3 PUFA are overviewed in **Tables 4** and **5**.

According to some researches, people have changed their dietary habits, so that over the past 150 years, once favorable and very narrow n-6 PUFA/n-3 PUFA ratio turned into unfavorable and wide ratio. There is also increased consumption of saturated fat originating from livestock fed grains, as well as increased consumption of trans-fatty acids originating from hydrogenated vegetable oils, along with significantly increased consumption of n-6 PUFA [91]. In developed countries, there is daily consumption of about 2.92 mg ALA, 48 mg EPA and 72 mg DHA [92], which is considered as insufficient. The studies have shown that human nutrition in Western European countries is lacking n-3 PUFA, and due to the significant amounts of n-6 PUFA in animal products, the n-6 PUFA/n-3 PUFA ratio is unfavorable, as it ranges from 15/1 to 16.7/1 [93, 94]. At present times, our diet is richer in calories than the food that man consumed in the Paleolithic. Nutrition in industrial societies is characterized by a surplus of calories, by increased consumption of SFA, n-6 PUFA and trans-fatty acids, and at

Reference	**Diet**	**ALA**	**EPA**	**DHA**
		% of total FA		
[89]	Fish oil 6%	1.01	5.66	6.27
	Fish oil 4% + 2% linseed oil	1.80	3.83	4.72
	Fish oil 2% + 2% linseed oil +2% sunflower oil	2.27	1.94	2.84
	Soybean oil 6%	3.37	-	0.72
[80]	Corn oil 15%	1.97	–	0.09
	Canola oil 5% + corn oil 10%	2.13	–	0.08
	Canola oil 10% + corn oil 5%	3.55	–	0.14
	Canola oil 15%	3.67	0.01	0.03
[10]	Linseed oil 6%	6.75	0.17	0.17
	Linseed oil 6% + 0.3% Se	11.90	0.26	0.18
	Linseed oil 6% + 0.5% Se	8.28	0.17	0.19
[90]	Sunflower oil 3% + linseed oil 3%	4.755	0.107	0.107
	Sunflower oil 3% + linseed oil 3% + 0.5 mg Se/kg feed	5.692	0.100	0.127
[81]*	Rice bran oil S 1% + F 2%	0.41	0.82	1.20
	Rice bran oil (S 0.7% + F 1.6%) + linseed oil (S 0.3% + F 0.4%)	0.07	0.35	0.48
	Rice bran oil (S 0.3% + F 1.0%) + linseed oil (S 0.7% + F 1.0%)	0.20	0.71	1.23

*Rice bran oil and linseed oil supplemented to starter (S) and finisher (F) mixtures in the amounts as presented.

Table 5. Supplementation of oils to chicken diets and their effects on enrichment of thigh muscles with n-3 PUFA.

Period – area	n-6/n-3
Paleolithic	0.79
Greece prior to 1960	1.00–2.00
Current Japan	4.00
Current India, rural	5–6.1
Current UK and Northern Europe	15.00
Current US	16.74
Current India, urban	38–50

Table 6. Ratio of n-6 PUFA/n-3 PUFA in human nutrition.

the same time, by reduced consumption of n-3 PUFA, as well as of fruits, vegetables, protein, antioxidants and calcium. **Table 6** gives an overview of the n-6 PUFA/n-3 PUFA ratios in human nutrition according to different time periods and geographic locations [95].

4.2. The increase of PUFA in chicken meat

Within conventional chicken feeding treatment, fat contained in chicken meat is dominated by palmitic and stearic fatty acids from the SFA group. Among the unsaturated fatty acids, the most present are oleic and linoleic acids, α-linolenic and arachidonic acids are represented in small amounts. Eicosapentaenoic and docosahexaenoic fatty acids are present only in traces or not present at all. In order to ensure the deposition of desirable fatty acids into poultry muscle tissue, chickens should be fed diet rich in polyunsaturated fatty acids. Vegetable oils, such as rapeseed and linseed oils, are rich in α-LNA, but they do not contain EPA and DHA. When supplementing fish oil to poultry feed, meat can obtain a "fishy" smell and taste that is undesirable for consumers [86]. Intensive researches into the effects of different diets on the content and profile of fatty acids in chicken meat are carried out, with the aim to produce meat with increased portion of n-3 PUFA and to retain organoleptic properties that are acceptable to consumers. Zelenka et al. concluded that broilers have limited capacity of desaturation and elongation of ALA into long-chain FA [96]. This conclusion was confirmed also by Lopez-Ferrer et al. [97]. Within the research into efficiency of enriching meat with EPA and DHA by using individual vegetable oils, such as sunflower, soybean, rapeseed and linseed oil in the amount of 5% as dietary supplements, it was proven that the most efficient was linseed oil as chicken feed supplement, as it achieved in muscle lipids the following results: 0.89% EPA and 1.85% DHA, which was, respectively, 7.41 and 1.92 times higher than the results achieved by the control fed sunflower oil [98].

Rahimi et al. fattened broilers with linseed and rapeseed as dietary supplements (7.5 and 15%, respectively), as well as with combination of both seeds (10 + 10%), and they determined that the combination of seeds influenced the increase of n-3 PUFA concentration in breast muscle when compared to the control group (0.004–0.25 mg/g meat), and the decrease of AA (0.08–0.03 mg/g), as well as the decrease of n-6/n-3 PUFA ratio (from 47.78 to 8.14), [13]. The authors pointed out that the most favorable ratio of n-3/n-6 fatty acids in chicken thighs was determined in the group of chickens which consumed diets supplemented with 15% linseed ($P < 0.05$). Furthermore, the same group had the highest content of n-3 PUFA (1.15 mg/g), while the least content of those fatty acids was determined in the control group (0.26 mg/g). Better tendency of

Fatty Acid	Control[1]		Lofish		Hifish		P	
	Ross[2]	Cobb	Ross	Cobb	Ross	Cobb	Breed	Diet
EPA	7.5	6.9	17.4	20.0	27.2	30.8	NS*	<0.001
DHA	39.6	38.6	54.9	64.3	118	126	NS	<0.001

[1] Diets contained fish oil at Control 0, Lofish 20 and Hifish 40 g/kg diet.

[2] Breed of birds used, Ross 308 and Cobb 500.

*NS: Not Significant.

Table 7. Effects of fish oil in the diet and breed of chicken on the mean EPA and DHA concentration (mg/100 g meat) in white chicken meat.

ALA deposition was noticed in thighs than in breasts, and it was not depending on the feeding treatment. These results can be explained by the fact that thigh meat has higher content of fat than breast meat in all investigated groups. The content of fat in thighs was ranging from 8.97% (7.5% linseed) to 9.85% (combination 10% rapeseed + 10% linseed), and in breasts it was 6.79% (7.5% linseed). Combination of linseed and rapeseed as dietary supplement proved to be the most efficient in enriching of chicken meat (breasts and thighs) with the n-3 PUFA, however, the same group had statistically significantly higher concentration of MDA μg/kg thigh meat than meat of other investigated groups ($P < 0.01$). The authors explained the statistically significantly higher oxidation of fat in meat of the mentioned group by the weak stability of n-3 PUFA.

Rymer and Givens [99], citation Givens [16], stated that there was a possibility of enriching white chicken meat by using fish oil (**Table 7**).

The authors concluded that the chicken genotype did not influence the incorporation of EPA and DHA in muscle tissue, however, the dosage of fish oil to feed is very significant (20 g/kg feed, i.e. 40 g/kg feed). The stated amounts enriched white chicken meat with n-3 PUFA for 171 and 573%, respectively. The authors recommended the supplementation of 200 mg/kg vitamin E to chicken feed in order to preserve oxidative stability and organoleptic traits. Yan and Kim reported the efficient usage of microalgae in enrichment of poultry products (meat and eggs) with DHA [14].

4.3. The increase of carnosine in chicken meat

Carnosine is a dipeptide composed of ß-alanine and L-histidine, which is considered as a bioactive food component because of its physiological role in an organism. As a dipeptide precursor, L-histidine is important in the synthesis of carnosine (ß-alanine – L-histidine), homocarnosine (γ-glutamine – L-histidine) and anserine (ß-alanine – 3-methyl-L-histidine). Haug et al. supplemented histidine in the amount of 1 g/kg of feed and achieved the increase in carnosine concentration in chicken breast muscle for 64%, as well as the increase of anserine for 10% [100]. The authors concluded that higher amounts of histidine can cause the growth depression and the increase in feed conversion. Hu et al. did not determine the influence of carnosine supplementation (0.5% from 1st–21st day and from 22nd–42nd day of fattening) on the growth performances [101]. Experimental groups had higher weight of breast muscle and reduced thiobarbituric acid reactive substances (TBARS) values, while the meat color and pH values did not depend on the supplemented amount of carnosine to diets. Kopec et al.

determined that supplementation of histidine to turkey diet resulted in the increased diphenyl-2-picrylhydrazyl (DPPH) radical scavenging capacity in breast muscles and blood, but did not result in the increased histidine dipeptide concentration [102]. The enzymatic antioxidant system of turkey blood was affected by the diet-containing spray dried blood cells (SDBC). In the plasma, the SDBC addition increased both superoxide dismutase (SOD) and glutathione peroxidase (GPx) activity and decreased GPx activity in the erythrocytes. Turkeys fed with diet-containing SDBC had increased BW (body weight) and the content of isoleucine and valine in breast muscles. Kralik et al. investigated the effects of dietary supplementation with 0, 0.1, 0.2 and 0.3% histidine on the quality of meat and the content of carnosine in breast and thigh muscles in Cobb 500 and Hubbard Classic chickens [103]. Dietary supplementation with L-histidine significantly affected live weight, carcass weight, weight of drumsticks and thighs, backs and wings, share of back and the a* value ($P < 0.05$), as well as the content of carnosine in breast muscle ($P = 0.003$). The Cobb 500 broiler chickens deposited more carnosine in meat than Hubbard Classic chickens. Chicken breast muscle had higher content of carnosine than thighs and drumsticks [18, 104, 105, 106]. Results of studies into the enrichment of chicken meat with carnosine through implementation of different dietary treatments indicated the need for further investigations in order to determine the most efficient dietary treatment for synthesis and deposition of carnosine in chicken muscle tissues [19, 100, 101, 107–109]. In order to enrich chicken meat with carnosine, Kralik et al. added to chicken feed, apart of 0.10% L-histidine, also 0.20% β-alanine and 0.24% MgO as a catalyzer [110]. The research results proved more efficient synthesis and deposition of carnosine in broiler meat of experimental group than in the control group (breasts 1443.35:664.1 mg/kg, $P < 0.01$; thighs 452.62:342.14 mg/kg, $P = 0.057$). Carnosine plays an important role in physiological functions of an organism. Recent researches into enrichment of chicken meat with carnosine as a functional ingredient confirmed that carnosine influences regulation of intracellular pH, it prevents oxidation and it is also important for maintaining the neurotransmission [111, 112]. Poultry meat is susceptible to oxidative processes which cause the changes in color, smell and taste [101]. Lipid oxidation can be controlled during meat storage by means of antioxidants (vitamin C, selenium and carnosine).

4.4. Enrichment of chicken meat with selenium

In the food chain, plants are the main source of selenium for animals. Plants get selenium from the soil, so it is important that soil is well supplied with this microelement. The supply of plant with selenium depends on its availability in the soil, therefore, plants from different areas have different selenium content. As poultry feeding mixtures are made from grains produced on different fields, the content of selenium is not equalized. If inorganic fertilizers that contain sulfur are used in agricultural production, then the selenium availability for plants is reduced. Also, acidification of soil significantly reduces the availability of selenium for plants. Instead of the inorganic form of selenium, scientists pointed out that organic form of selenium produced in form of selenized yeast shall be introduced as an animal feed supplement [17, 113, 114]. Recently, biofortification of plants with selenium has been carried out in arable crop production in order to increase the availability of selenium to plants, and to make them further available as a feed for animals, to consequently enrich final animal products with selenium [115, 116]. The source of selenium (inorganic—sodium selenite or organic—selenomethionine in the form of yeasts or algae) used in animal feed has significant effect on its exploitation in the organism [15, 117, 118]. Wang and Hu determined statistically significant higher activity of GPx in blood of fattening chicken that consumed diet with higher content of selenium ($P < 0.05$), [15]. Furthermore, they stated that the source of selenium influenced the selenium content and GPx activity in chicken blood ($P = 0.01$). Better results were obtained in chickens fed diet supplemented with organic selenium. In their research into the influence of selenium sources on chicken meat quality, Ševčikova et al. used chickens of the Ross 308 provenience and fed them for 42 days with three feeding mixtures (C = without selenium, P1 = 0.3 mg/kg Se-yeast and P2 = 0.3 mg/kg Se-Chlorella), [119]. In their results, the authors reported that the content of selenium in chicken thighs (C = 52.11, P1 = 217.39 and P2 = 123.21 μg/kg) and in breasts (C = 70.95, P1 = 247.87 and P2 = 147.61 μg/kg) increased in experimental groups in comparison with the control group ($P < 0.05$). Choct et al. stated that the increased content of selenium in chicken feed from 0.1 to 0.25 mg/kg affected the increase of selenium content in breast muscles from 0.232 to 0.278 mg/kg [120]. Kralik et al. investigated the influence of selenium content in chicken feed on the selenium content in breast muscles, by using 60 male chickens of the Ross 308 provenience, divided into three groups: P1 = without selenium, P2 = 0.3 mg Se/kg feed and P3 = 0.5 mg Se/kg feed [79]. All groups of chickens had feed that contained a total of 6% oils (3% sunflower oil and 3% linseed oil). Experimental groups' feed were supplemented by organic selenium Sel-Plex®, produced by Alltech. The authors pointed out that breast muscle tissue in the group P3 contained significantly more selenium (0.265 mg/kg tissue) than groups P2 (0.183 mg Se/kg tissue) and P1 (0.087 mg/kg tissue, $P < 0.05$). The increase in the content of selenium in feed from 0.0 to 0.3 mg/kg influenced the change of the fatty acid profile in breast muscle tissue. More precisely, it caused the increase in portion of ALA, EPA, DPA and DHA, that is, in portion of total n-3 PUFA, and it affected also the lowering of the total SFA and MUFA portion. The results that support the mentioned fact are also pointed out by Haug et al., as they reported significant influence of selenium contained in chicken feed on the content of EPA, DPA and DHA in thigh muscles [121]. This means that the increased content of selenium in feed affects the increase of the mentioned fatty acids in thigh muscles ($P < 0.05$). The authors explained this fact by confirming that higher content of selenium in feed had influence on the activity of Δ6-, Δ5- and Δ4- desaturase and elongase, which catalyze elongation and desaturation of short-chain fatty acids to long-chain fatty acids, or that such intake led to slowed speed of long-chain fatty acids degradation within peroxidation processes. Furthermore, Kralik et al. stated that the increase of selenium content in feed to a level of 0.5 mg/kg caused the portion of n-3 PUFA to equalize with the values recorded in the P1 group, which did not have organic selenium added to feed [79]. The authors assumed that the surplus of selenium in feed of the P3 group was required for saturation of various antioxidative selenoenzymes in cells, since it was noticed that the value of lipid oxidation in that group was the lowest. The values of lipid oxidation in meat (TBARS) measured in fresh and frozen meat 28 days in a freezer at −20°C) were similar in all groups (fresh meat: P1 = 3.97 nmol MDA (Malondialdehyde)/g tissue, P2 = 3.56 nmol MDA/g tissue, P3 = 3.44 nmol MDA/g tissue and frozen meat: P1 = 5.50 nmol MDA/g tissue, P2 = 5.44 nmol MDA/g tissue and P3 = 4.94 nmol MDA/g tissue; $P > 0.05$). Dlouhá et al. reported that organic selenium in chicken feed reduced the lipid oxidation in breast muscle tissue, both in fresh and in stored meat [122]. Wang et al. pointed out that the level of selenium in feed (0.0 and 0.6 mg/kg) statistically significantly reduced the lipid oxidation in breast muscle tissue (0.34–0.30 mg/kg MDA; $P < 0.001$), [123].

5. Effects of omega-3 fatty acids, carnosine and selenium on human health

In recent years, many studies have been performed to determine the effect of **omega-3 fatty acids** on human health. In human nutrition, α-linolenic acid is the most represented fatty acid because it is found in vegetable sources (vegetable oils, seeds, nuts leafy vegetables). However, ALA has less expressed positive effect on human health than EPA and DHA, and its efficiency of conversion to EPA and DHA in the human body is only 2–10% [124] or even less. Therefore, it is necessary to introduce into diet some foodstuffs rich in EPA and DHA (fish and oils of fish and marine organisms), or to consume products enriched with these fatty acids, such as eggs and poultry meat. Omega-3 fatty acids are associated with many positive effects on human health. Since they are a constituent part of cell membranes, they are spread throughout the body. In the cells, these fatty acids act anti-inflammatory and help to maintain membrane viscosity [125]. DHA is an integral part of all cell membranes, and it is especially represented in the brain tissue. When compared to EPA, the researches proved that DHA has a more important role in maintenance of normal cell membrane function and that it is crucial for proper development of fetal brain and retina [126]. It was also found that the intake of EPA and DHA during pregnancy helps to reduce the incidence of premature birth, which causes many diseases in newborns. It is assumed that EPA and DHA reduce the production of prostaglandins E2 and F2α, thus helping to reduce uterine inflammation associated with premature birth [127]. Omega-3 fatty acids are usually mentioned in association with the prevention of heart and blood vessel diseases, which are usually caused by chronic inflammation processes in the body. EPA and DHA have anti-inflammatory and antioxidative activity [128] and help to maintain good condition of heart and blood vessels. The researches into the use of EPA and DHA in prevention of heart diseases are often controversial, but many of them prove positive effects of the stated fatty acids. For example, Kris-Etherton et al. [129] and Tavazzi et al. [130] determined a positive correlation between the intake of EPA and DHA and the reduced risk of reoccurring cardiac artery disease, sudden cardiac death after acute myocardial infarct and reduced heart failure occurrence. In addition, the omega-3 fatty acids have a positive role in prevention of atherosclerosis and peripheral artery diseases. It is believed that EPA and DHA improve plaque stability, reduce endothelial activation and improve blood vessel permeability, thus reducing the risk of cardiovascular disease occurrence [131]. Since DHA is largely present in phospholipids of the nerve cell membranes, where it is involved in the proper functioning of the nervous system, it is considered to have a preventive role in the development of Alzheimer's disease [132]. When considering the contradictory results of research into the effects of omega-3 fatty acids on various diseases, there is further research required to determine the exact protective mechanism of these fatty acids not only against the abovementioned diseases, but also against some other diseases.

Carnosine is a natural dipeptide composed of amino acids β-alanine and L-histidine through the action of the carnosine synthase enzyme. It is synthesized and present in large quantities in muscular and nervous tissue of mammals, birds and fish. It easily absorbs into the digestive tract, penetrates through the blood and brain barrier, and with its great bioavailability it acts as a cell membrane stabilizer [133]. In general, carnosine is more concentrated in white muscle tissue than in dark tissue [134], which was also confirmed in the research by Kralik et al., within which it was determined that chicken breast muscle contained higher concentrations of carnosine than the thigh muscle [101]. There are many physiological roles attributed to carnosine, such as: buffer activity, antioxidative activity, hydroxyl radicals, aldehydes and carbonyls scavenger, copper and zinc ions chelator, protein degradation stimulator, reaction with protein carbonyls, activator of enzyme action, suppressor of protein networking [135]. Still, carnosine is the best known by its buffer activity in the organism. It is assumed that this buffer activity is the reason for carnosine's predominant association with white muscles in the organism. White, glycolytic muscle fibers contain few mitochondria and therefore, they produce lactic acid, within which the ability of carnosine to directly suppress the growth of hydrogen ion concentration is being emphasized [135]. As a chelator of metal ions (calcium, copper and zinc), carnosine participates in regulation of their metabolism in muscle and brain tissue [136]. Carnosine has also an important role in antioxidant protection, as it has the ability to catch reactive oxygen species (ROS), of which hydroxyl radical is the most dangerous one. Hydroxyl radical is formed from hydrogen peroxide in the presence of bivalent ions, such as copper. By catching and neutralizing the activity of free radicals, carnosine prevents oxidative damage occurrence. Researches confirmed its protective role in lipid oxidation [137] and protein oxidation [138]. The activity of carnosine in the process of slowing down glycosylation and protein networking is actually a consequence of its antioxidative activity, that is, its ability to block oxidation of biomolecules [133]. There is further research required to determine the role of carnosine in physiological processes that occur in human organism.

Selenium is one of the important trace elements required for the normal functioning of a living organism. If there is deficit of any micro- or macro-element in the body, health can be disturbed and serious disorders or illness may arise. The occurrence of Keshan (endemic cardiomyopathy) and Kashin-Beck (endemic osteochondropathy) diseases are known to happen due to low selenium status in human population, which is a consequence of selenium-deficient soil, especially in northeastern to southwestern China [139]. Selenium concentration in tissues, plasma or serum depends on the intake and varies by country. It is generally lower in Eastern Europe than in North America [140]. Selenium in the body is a part of selenoproteins that have a wide range of health benefits. The most important of them are glutathione peroxidases (GPxs), thioredoxin reductases (TrxR) and iodothyronine deiodinases. They show antioxidant and anti-inflammatory effects and are included in the production of active thyroid hormone [140]. One of the most important health benefits of selenium is its role in cancer prevention. Duffield-Lillico et al. showed that treatment with 200 μg selenium per day (as selenium yeast) for a mean of 4.5 years resulted in a significant reduction in cancer mortality (50%) and in the incidence of total (37%), prostate (67%), colorectal (58%) and lung (46%) cancers after a follow-up of 6.4 years [141]. Low selenium status is associated with poor immune function. Selenium supplementation enhances proliferation of activated T cells and increase total T cell count, hence boosting immune response [142]. Selenium is also very important to human fertility and reproduction. It is shown that glutathione peroxidase GPx4 protects spermatozoa by its antioxidant function and with other proteins forms structural component of the flagellum which is essential for sperm motility [143]. Low selenium status was connected with pre-eclampsia [144] and premature birth [145] in women. At the end, it is important to note that additional selenium intake may benefit people with low selenium status, while those who have adequate or high status should be careful and not take selenium supplements, since it may have adverse effect [140].

6. Conclusion

World poultry meat consumption is constantly growing. Chicken meat is a source of high-quality protein with a relatively low content of fat. The quality of chicken meat is influenced by a number of factors like genotype, sex, feeding treatment, production technology, transport and pre-slaughter handling, all of which should be taken into account. In the production of chicken meat, it is very important to choose a good chicken genotype and to have good production conditions. It is also important to have devices on the slaughter line that can quickly provide meat quality data. It is necessary to improve chicken meat production technology year after year and to offer new products to the market. The production of enriched or functional products of animal origin is on this track. In poultry production, meat and eggs stand out. Functional ingredients are supplemented to chicken feed to improve the nutritional value of chicken meat, thus making chicken meat a foodstuff with added value (enriched or functional product), as it contains ingredients that are beneficial to human health. Chicken meat has become a functional food through the increase in the content of bioactive substances (n-3 PUFA, carnosine, selenium, etc.) that have beneficial effects on consumers' health.

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Chapter 5

Feeding

Figen Kırkpınar and Zümrüt Açıkgöz

Abstract

Animal nutrition and feed science are the main scientific promote for today's modern breeding and feed industries. Animal nutrition is the most important factor affecting performance, reproduction and products quality. Improving productivity through better nutrition is determined by some interrelated considerations such as the availability of nutrients, type of feeding system and the level of feeding management. Poor nutrition affects growth, reproduction and immune system. Besides, feed has financially the largest share in animal production, irrespective of species and production system. Feed accounts for 65–75% of total cost of livestock production. This chapter provides the fundamental concepts of animal nutrition a general awareness on nutrition and feeding of livestock (swine, poultry, beef and dairy cattle, sheep and goat). Besides, feed is financially the single most important element of animal production in most production system.

Keywords: digestive systems, feedstuffs, nutrition, swine, poultry, beef and dairy cattle, sheep and goat

1. Introduction

Feed costs can be as high as 65–75% of the total production costs. The good quality feed also increases the incomes of producers. One way to reduce these costs is to ensure the animal has a balanced diet. A balanced diet is one that meets the nutritional needs requirements of the livestock, based on its age, gender and physiological stage. Adequate nutrients are essential for the metabolic function and health of any animal. Prolonged deficiency of nutrients would result in loss of condition and productive. Poor quality feeds may lead to a shortage of some dietary essentials or other factors may cause the development of serious nutritional diseases. Overfeeding may be disastrous as underfeeding.

On the other hand, the safety and quality of animal feedstuffs are also vital for preventing hazardous substances entering the food chain and affecting human health. Feedstuffs and additives, diet formulation and, in some cases, diet distribution have an influence on both animal well-being and the characteristics and composition of animal products as meat, milk or egg, and so on, for human consumption.

The main constraint to livestock development in many developing countries is the scarcity and inadequate quantity and quality of feed supply, poor quality and nutrient imbalance in many native pastures and crop residues, lack of or limited use of commercial concentrate feeds.

2. Feedstuffs and feed additives

This part provides some details of the feedstuffs and feed additives that are fed to animals, including their main nutritional composition and function that need to be taken into account when they are used in animals diets. Feedstuffs are the edible materials, after ingestion by animals is capable of being digested, absorbed and utilised. The main components of feedstuffs are given in **Figure 1**. Feedstuffs consist of water and dry matter. The water (moisture) content of feedstuffs is very variable and can range from 60 g/kg (in concentrates) to 900 g/kg (in some root crops). Owing to this wide variation, it is generally preferred that the feedstuff composition is specified on dry matter basis. In this perspective, the nutrient contents of feedstuffs might be effectively compared [1].

Nutritional components of a feedstuff can greatly influence production performance of animals. The feed value of a feedstuff is a measure of its main nutritional components. For livestock, the feed value of any feedstuffs depends mainly on the concentration of energy (carbohydrates, fats, proteins and their digestibility), protein (including NPN and aspects of degradability), vitamins and minerals contents in the dry matter, special aspects (like keeping quality, availability, handling, taste, toxins, influence on sensory quality of meat, milk or egg etc.), physical aspects and price.

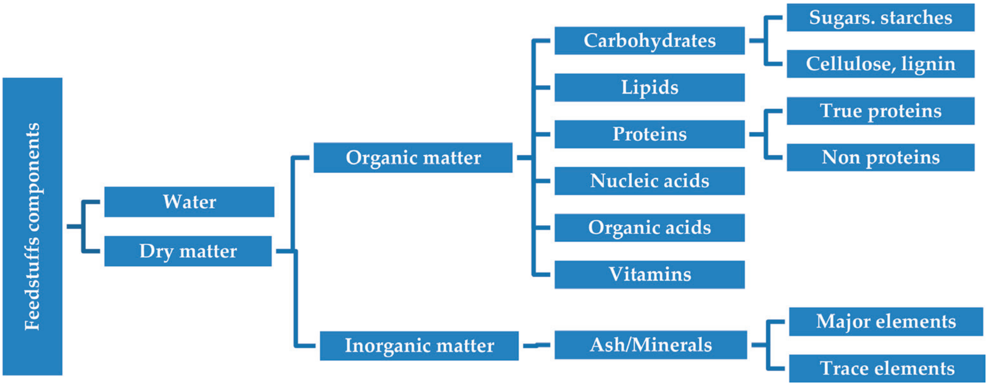

Figure 1. The main components of a feedstuff.

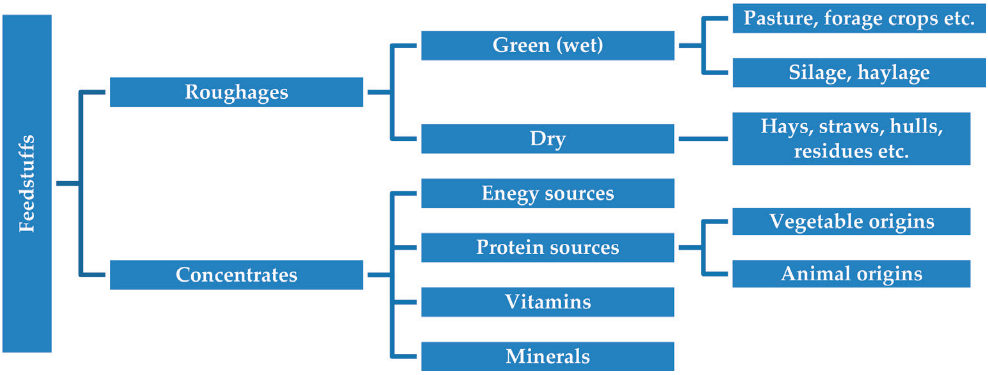

Figure 2. Classification of feedstuffs.

Class	Characteristics
Roughages	Roughages are bulky feeds containing relatively large amounts of poorly digestible material. These groups contain more than 18% crude fibre. They can be two major categories, namely dry and wet based on their moisture content. Wet roughages contain more than 75% moisture and include pasture, range plants and forages fed green, cultivated fodder crops, grasses legumes, tree leaves and silage/haylage while dry roughages contain only 10–15% and include hays, straws, hulls and crop residues as seed coats, pods, bran. Silages/haylages include ensiled forages. The process of ensiling plant materials under anaerobic conditions, which is a common storage method for feeds. The plant material undergoes a controlled fermentation that produces acids that then kill off bacteria, moulds and other destructive organisms. Fermentation uses nutrients and thus reduces nutritive content of the material.
Concentrates	Energy-rich feeds contain less than 18% crude fibre, less than 20% protein. The protein digestibility ranges from 50 to 80%, but the protein quality is generally poor. These are fed to ruminants and cecal fermenters to increase the energy density of their diets, and to monogastrics as the primary source of energy. Examples of energy sources are: cereal grains, for example, corn, wheat, barley, oats, rye, sorghum, triticale; other grains, for example, buckwheat; grain milling by-products, for example, wheat bran, corn gluten meal; roots, tubers, for example, cassava, potatoes; food processing by-products, for example, molasses, bakery waste, citrus pulp, distillers and brewers by-products; industrial by-products, for example, wood molasses, fats and oils. Protein supplements contain 20% or more of protein; some have high-energy contents as well from plant or animal origin. Examples of protein sources are: oilseed meals, for example, soybean, cottonseed, rapeseed, canola, linseed, peanut, safflower, sunflower; grain legumes, for example, beans, peas, lupines; single-cell protein, synthetic amino acids, non-protein nitrogen sources, for example, urea, biuret and by-pass proteins, for example, corn gluten meal for ruminants; animals proteins, for example, meat meal, fish meal, tankage, feather meal, bone meal, dried milk or products as whey, poultry by-products. Depending on the feeds used to balance a ration for the other nutrients, concentrated sources of vitamins and minerals may be needed. Some vitamin supplements include ensiled yeast, liver meal, fish oil, wheat germ oil and purified forms of individual vitamins (A, D, E, K, C and B vitamins like thiamine, riboflavin, niacin, pantothenic acid, biotin, vitamin B_6, vitamin B_{12} and folate). Some common mineral supplements include: salt (often trace mineralised), bone meal, oyster shell, calcium carbonate, limestone and fairly pure forms of other specific minerals (Major elements: Na, Ca, P, CL, K, S, Mg, Trace Elements: I, Mn, F, Co, B, Zn, Fe, Cu, M).

Table 1. Classes of feeds and characteristics.

Categories	**Feed additives**
1. Technological additives: any substance added to feed for a technological purpose	**a.** Preservatives
	b. Antioxidants
	c. Emulsifiers
	d. Stabilisers
	e. Thickeners
	f. Gelling agents
	g. Binders
	h. Substances for control ofradionucleide contamination
	i. Anticaking agents
	j. Acidity regulators
	k. Silage additives
	l. Denaturants
	m. Substances for reduction of the contamination of feed by mycotoxins
2. Sensory additives: any substance, the addition of which to feed improves or changes the organoleptic properties of the feed, or the visual characteristics of the food derived from animals	**a.** Colorants
	b. Flavoring compounds
3. Nutritional additives	**a.** Vitamins, pro-vitamins and chemically well-defined substances having similar effect
	b. Compounds of trace elements
	c. Amino acids, their salts and analogues
	d. Urea and its derivatives
4. Zootechnical additives: any additive used to affect favourably the performance of animals in good health or used to affect favourably the environment	**a.** Digestibility enhancers: substances which, when fed to animals, increase the digestibility of the diet, through action on target feed materials
	b. Gut flora stabilisers: micro-organisms or other chemically defined substances, which, when fed to animals, have a positive effect on the gut flora
	c. Substances which favourably affect the environment
	d. Other zootechnical additives
5. Coccidiostats and histomonostats	These substances that one or more of the functional groups, intended to kill or inhibit protozoa

EC, No 1831/2003 [2].

Table 2. Categories of feed additives.

On the other hand, for example, production can be significantly restricted by a number of mineral and vitamin deficiencies, such as calcium, magnesium, phosphorus, copper, cobalt, vitamins A or D, and so on. In addition, excesses of particular substances in feedstuffs can cause lowered production and even death. For example, nitrite poisoning from some grasses and weeds, cyanide poisoning from immature sorghums and some weeds, alkaloid poisoning from immature some leguminous and copper toxicity. Feeds are classified according to the number of specific nutrients they supply. Two main classes of feedstuffs are roughages/forage and concentrate. In addition, feeds can be further subclassified as shown in **Figure 2** and characteristics in **Table 1**.

Feed additives are used to increase feed conversion, improve the amount and quality of animal products in terms of hygienic quality and standards, protect animal health and reduced production costs. From the point of view of being able to control the effects of these substances on human health, it is very important that additives should be able to be determined in both feeds and final products. In recent years, animal production has been fundamental changes, particularly, European Union has brought some changes feed additives used feed industry, taking into account animal, human health and environment. A tendency to return to natural methods in animal production and consume healthy products has given rise to discussions concerning feed additives. At the same time, for example, because of problems resulting from the intensive use of antibiotics, the use of alternative feed additives has come to the fore. Categories of feed additives are shown in **Table 2**.

3. Digestive system and digestion

Livestock has a tube-type digestive tract. This tube has different organs that play a specific role in the digestive process. Digestive system mechanically and chemically breaks down from complex macromolecules (lipid, polysaccharide and protein) into their component parts. These nutrients can be absorbed and used for energy, growth and maintenance of body tissues. There are three types of digestive tract in farm animals: monogastric, poultry and ruminant.

3.1. Monogastric digestive system and digestion

The digestive system of monogastric animals (dog, cat, swine, rabbit, horse, etc.) consists of mouth, oesophagus, stomach, small intestine, cecum, large intestine, anus and supportive organs (pancreas, liver and gall bladder). Digestion processes of swine are shown in **Table 3** [3–5].

3.2. Poultry digestive system and digestion

Poultry (chicken, turkey, quail, goose, ducks, etc.) digestive system begins at the mouth/beak and ends at the cloaca and has several important organs in between [oesophagus, crop, stomach (proventriculus and gizzard), small intestine, cecum, large intestine]. Pancreas, liver and gall bladder are accessory organs in digestion. Digestion processes of poultry are summarised in **Table 4** [6, 7].

3.3. Ruminant digestive system and digestion

Ruminant (polygastric) (cattle, sheep, goat, etc.) digestive system includes mouth, oesophagus, stomach (rumen, reticulum, omasum and abomasum), small intestine, cecum, large

Organs	Secretion/Enzyme	Function
Mouth	Teeth	Mechanically reduces particle size and increases surface area
	Saliva	Lubricates and softens feed
	Salivary amylase (ptyalin)	Begins starch digestion
Oesophagus	—	Carries feed from mouth to stomach
Stomach	HCL	Decreases pH, denatures protein, activates pepsinogen, kills bacteria
	Pepsins	Begin protein digestion
	Lipase	Hydrolyses lipid (particularly in milk-fed young swine)
	Rennins	Coagulate milk protein (casein) in postnatal period
Small intestine	Pancreatic amylase and intestinal disaccharidases (maltase, isomaltase, sucrase, lactase)	Hydrolyse starch
	Bile acids	Emulsify lipid
	Pancreatic lipase, cholesterol esterase,and phospholipase	Hydrolyse lipid
	Pancreatic (trypsin,chymotrypsins, carboxypeptidases, elastase) and intestinal (aminopeptidases, dipeptidases, tripeptidases) proteases	Hydrolyse proteins
	Pancreatic and intestinal nucleases	Hydrolyse nucleic acids
	—	Absorbs nutrients
Cecum	—	Ferments undigested nutrients by microbes
Large intestine	—	Absorbs water, volatile fatty acids (VFAs) and minerals and forms faeces
Anus	—	Removes faeces

Table 3. Digestive processes of swine.

Organs	Secretion/Enzyme	Function
Mouth/beak(No lips and teeth)	—	Obtains feed
	Saliva	Lubricates and softens feed
	Salivary amylase (ptyalin)	Begins starch digestion
Oesophagus	—	Carries feed from mouth to crop
Crop	Mucus	Lubricates and softens feed
Proventriculus	HCL	Decreases pH, denatures protein, activates pepsinogen, kills bacteria
	Pepsins	Begin protein digestion
	Lipase	Begins lipid digestion (particularly in carnivore avian species such as raptors)

Organs	Secretion/Enzyme	Function
Gizzard	—	Mechanically grinds and mixes of ingesta and continues enzymatic digestion
Small intestine	Pancreatic amylase and intestinal disaccharidases (maltase, isomaltase, sucrase)	Hydrolyse starch
	Bile acids	Emulsify lipid
	Pancreatic lipase, cholesterol esterase,and phospholipase	Hydrolyse lipid
	Pancreatic (trypsin,chymotrypsins, carboxypeptidases, elastase) and intestinal (aminopeptidases, dipeptidases, tripeptidases) proteases	Hydrolyse protein
	Pancreatic and intestinal nucleases	Hydrolyse nucleic acids
	—	Absorbs nutrients
Cecum	—	Ferments undigested nutrients by microbes
Large intestine	—	Absorbs water and minerals and storages waste
Cloaca	—	Serves as common opening of the digestive, reproductive and urinary systems

Table 4. Digestive processes of poultry.

Organs	Secretion/Enzyme	Function
Mouth	—	Obtains and chews feeds, releases of fermentation gases (mostly CO_2 and CH_4) and ruminates
	Saliva	Moistens feed to aid in swallowing
Oesophagus	—	Transports feed from mouth to rumen
Rumen	Microbial enzymes	Degradation of carbohydrates, protein and lipids, synthesis of microbial protein/lipid and some vitamins (K and B-complex), absorption of VFAs and ammonia, and biohydrogenation
Reticulum	—	Continues ruminal fermentation
Omasum	—	Grinds feeds and absorbs water and VFAs
Abomasum	HCL	Decreases pH, denatures protein, activates pepsinogen, kills bacteria
	Pepsins	Hydrolyse microbial and by-pass proteins
	Lipase	Hydrolyses lipid (particularly in milk-fed young ruminant)
	Rennins	Coagulate milk protein (casein) in postnatal period

Organs	Secretion/Enzyme	Function
Small intestine	Pancreatic amylase and intestinal disaccharidases (maltase, isomaltase, lactase)	Hydrolyse starch escaping ruminal digestion
	Bile acids	Emulsify lipid
	Pancreatic lipase, cholesterol esterase,and phospholipase	Hydrolyse lipid
	Pancreatic (trypsin, chymotrypsins, carboxypeptidases, elastase) and intestinal (aminopeptidases, dipeptidases, tripeptidases) proteases	Hydrolyse microbial and by-pass proteins
	Pancreatic and intestinal nucleases	Hydrolyse nucleic acids
	—	Absorbs nutrients
Cecum	—	Further microbial fermentation
Large intestine	—	Absorbs water, VFAs and minerals and forms faeces
Anus		Removes faeces

Table 5. Digestive processes of ruminant.

intestine, anus and supportive organs (pancreas, liver and gall bladder). Digestion processes of ruminant are given in **Table 5** [5, 8, 9].

4. Nutrition and feeding of swine

Swine have a long history of providing food for people. Swine require a number of essential nutrients to meet their needs for maintenance, growth, reproduction, lactation and other living functions. However, factors such as growth rate, genetic variation, gender, stage of gestation, feed quality and intake, availability of nutrients in feedstuffs, energy density of the diets, disease, environment temperature, management factors, for example, crowding and other stress factors may change also increase the needed level of nutrients for optimal performance. Performance of weanling, growing and finishing swine, gestating and lactating sows is related to the quality of the diet and the amount consumed daily. The National Research Council (NRC) [10] provides estimates of the amounts of energy, protein, amino acids, minerals and vitamins for various classes of swine under average conditions. Although nutritionists, feed manufacturers and producers may wish to include higher levels of some nutrients than those listed by the NRC to ensure adequate intake of nutrients and for a certain amount of safety commercially, therefore the NRC values are thought of as minimum requirements without any safety allowances. In addition, the dietary concentrations listed in the NRC tables are based on a given amount of feed intake, if feed intake is less than the amount listed, dietary concentration may need to be increased to guarantee an adequate daily intake of the nutrients. In general, swine require six classes of nutrients: energy (carbohydrates, fats), protein (amino acids), minerals, vitamins and water.

Energy requirements are expressed as kilocalories (kcal) of digestible energy (DE), metabolizable energy (ME), or net energy (NE). DE and ME values are most commonly used; however, NE has been preferred in the industry recently. Energy requirements of swine are basically influenced by their body weight, body weight gain, genetic capacity, lean tissue growth or milk production and the environmental temperature. One of the largest expenses for swine diets is energy. Carbohydrates (sugar, starch and fibre) from cereal grains (corn, sorghum, wheat, barley, triticale, oats, rye) and their by-products and their by-products provide most of the energy in typical swine diets so utilising lower cost alternative feedstuffs or forages for swine can use to lower feed costs. Fats and oils are excellent energy sources in swine diets. Protein sources also provide a significant amount of energy in swine diets. Protein commonly contributes 15–20% of the total energy in the diet. The amount of feed consumed by swine is controlled by the energy content of the diet fed *ad-libitum*. The diet contains high energy and low fibre generally. Protein and amino acids are required for maintenance, muscle growth, development of foetuses, nutrition of gestating and lactating sows both supporting tissue and milk production. Arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine are essential amino acids for swine. The essential amino acids of greatest practical importance in diet formulation especially lysine, tryptophan, threonine and methionine.

Corn is markedly deficient in lysine and tryptophan. Sorghum, barley and wheat are low in lysine and threonine. The first limiting amino acid in soybean meal is methionine. Animal protein sources are good for supplemental essential amino acids. Soybean meal is basic source of amino acids, also used alternative plant origin sources as cottonseed meal, canola meal, sunflower meal and peanut meal, animal sources as meat and bone meal, fish meal, poultry meal, spray-dried whey, egg and blood; grain by-products dried distillers and corn gluten meal or synthetic amino acids. Swine require linoleic acid and other polyunsaturated fatty acids. The requirement is generally met by natural dietary ingredients from oil in corn. Linoleic acid is considered the dietary essential fatty acid so the longer chain fatty acids can be synthesised from the linoleic acid [11]. Swine should have free and convenient access to good quality water. Minerals and vitamins are required for maintenance, metabolic function, development of tissues, health and growth. Mineral and vitamin premixes or complete manufactured supplements are commercially available. Feed additives have commonly been added to swine diets to promote growth. The levels of feed additives and withdrawal requirements should be legal restrictions.

The typical diet containing 3300–3400 kcal of ME/kg based on corn-soybean meal diet for the various weights of growing swine as estimated by the NRC [10]. Feed intakes may be slightly higher for barrows and slightly less for gilts. If the diet containing 3300 kcal of ME/kg based on corn-soybean meal diet for gestating and lactating (during a 21-day lactation) gilts and sows, it provides sufficient energy at the optimum feeding level. However, higher feeding levels will be needed to meet the sow’s daily energy requirement used oats, alfalfa meal or other energy diluents on gestation diets. High-energy diets recommended fed *ad-libitum* to sows during lactation. If this is not possible, sows should be hand-fed three times daily. The requirement of energy depends on the number of swine nursed, weight gain and milk production. If sows have lost excess weight and feed consumption is low significantly, there is recommended additional fat approximately 3–6% to lactation diet. Sows need diets containing 16–18% or more crude protein (minimum of 0.9% lysine) [12]. If energy intake is sufficient, high protein diets will minimise weight loss in sows during lactation. Newborn swine should be consumed colostrum during the first 24 h post-farrowing. If the sow is slow in coming into milk, commercial milk replacers can be used. A palatable swine starter diet should be provided beginning at 2–3 weeks if pigs are weaned later than 3–4 weeks of age [12]. It is recommended that the starter diet contains dried whey and/or lactose, dried blood products and a high level of lysine. The nutritional requirements of growing and finishing swine met by full feeding program. Besides, restricted feeding may improve carcass quality of finishing pigs. The nutrient composition of ingredients should be known when formulating diets to meet the recommended nutrient requirements of swine. Compositions of ingredients commonly used in swine diets are given in various tables.

For additional information, see nutrient requirements of swine [10]. The NRC estimates of nutrient requirements for various body weights of swine, requirements for gestating and lactating sows, expressed as dietary concentrations are given in various tables. These nutritional macro and trace minerals and vitamins play many important metabolic functions in the body. The estimated dietary requirements for the essential micronutrients are given by NRC in Tables [10].

5. Nutrition and feeding of poultry

Over recent decades, broiler and layer performances have considerably improved as the result of the advancements of breeding, feeding, disease control, housing and husbandry technologies. Nutrient requirements of the modern layer and broiler strains have changed because of their high production potential.

Nowadays, the fattening period varies between 35 and 42 days in conventional broiler production sector. In this period, it is used different diets (starter, grower and finisher) due to the alteration of nutrient requirements of broiler with age. Not only age, all factors affecting nutrient requirements should be considered together while diet density is adjusted. Corn and soybean meal are used as basal feed ingredients in broiler diets. In corn-soybean meal diet, methionine is the first limiting amino acid followed by lysine. All diets containing low crude fibre are provided adlibitum to birds throughout the production period.

Recently, it is recommended that natural growth promoters, such as organic acids, probiotics, prebiotics, synbiotics, essential oils, enzymes etc., are supplemented to diets to optimise performance. The main purpose of using these feed additives is to maintain and enhance gastrointestinal health [13]. In this context, it is currently being examined the usable potential of various bee products (propolis, pollen, etc.) as natural growth enhancers [14, 15]. Moreover, due to shortening slaughter age, pre-hatch (last phase of incubation) and immediate post-hatch periods in which occur many significant physiological and metabolic changes affecting broiler performance have become increasingly important. Therefore, early feeding practices such as in-ovo feeding, hatching supplement (hydrated nutritional supplement) and pre-starter diets are suggested to apply in these periods in order to achieve maximum growth performance of fast-growing broilers [16–18].

Unlike broiler sector, the laying period of modern brown and white layers has prolonged and they may be kept up to 80 weeks in production, without moulting. During the first half of the rearing period, feeding program needs to focus on an optimal supply of digestible amino acids and minerals to ensure the basic growth of the inner organs, muscles and skeleton. These physiological developments of the pullet continue at a slower rate in the second half of the rearing phase therefore protein and amino acids requirements reduce. On the other hand, it is recommended to increase dietary fibre level (5–6%) in this stage for crop, gizzard and intestinal development. The pullet is started to feed with pre-lay diet about 2 weeks prior to first egg (after 15 weeks of age). On reaching about 5% egg production, the layer diet should be used instead of the pre-layer diet. Common mistakes are feeding pre-lay diet too early or for too long, which may result in poor peak rate of lay [19]. The pre-lay diet contains 2–2.5% calcium while the other nutrients are similar to a layer diet. The purpose of using the pre-lay diets is to build up the medullary reserves [20].

Daily feed intake of layers is relatively low between the onset of egg production and peak egg production (approximately 32 weeks of age). Nevertheless, nutrient requirements increase during this critical stage because bird continues to grow, and the size and production of egg rises. Therefore, the first layer diet should be fairly concentrated. The nutrient requirements of laying hens depend on the daily egg mass in post peaking period. The best way of ensuring proper nutrition is the use of a phase feeding system matched to the changes in nutrient requirements [20].

Layer diets have higher calcium content than per-lay diet since egg weight and production increase for peaking period and the hens' ability to absorb calcium from the diet diminishes for post peaking period. The eggshell contains about 2.2 g calcium. Adequate dietary levels of calcium should be provided to ensure proper calcification of the eggshell. The source and particle size of calcium used in laying hen diets are also of importance. To maintain adequate calcium blood level overnight when feed is not consumed and calcium requirement is high due to eggshell formation, a laying hen's diet needs to include coarse limestone and/or oyster shell with lower solubility [21].

For additional information, see nutrient requirements of broilers and egg layers [22–24]. The NRC [22] and Aviagen Ross 308 [23] estimates of nutrient requirements and essential micronutrients of broilers and NRC [22] and Lohmann LSL-CLASSIC [24] estimates of nutrient requirements and essential micronutrients of egg layers.

6. Nutrition and feeding of large ruminants: Beef and dairy cattle

Feed accounts for over 70% of the cost of beef cattle production generally. If the feeding is efficient, the cost of production is reduced while the productivity and profitability of beef production increases. Grazing amount and management are important to reduce production costs. Cattle are ruminant animals and beneficial relationship with their rumen microorganisms (bacteria, protozoa, fungi) to help those digesting fibrous feedstuffs. Beef cattle require nutrients to meet their needs for maintenance, physical activity, growth, milk production, reproduction and health. These requirements of cattle may change age, sex, breed and production cycle. If mature and young growing cattle consume sufficient high-quality pasture as mixed grasses and legumes, they meet nutrients for maintenance and growth. However, pasture quality will depend on many factors, including geographic location, soil structure and environmental conditions as temperature, humidity, precipitation, type of grass and/or legume, grazing management. The negative harvested condition may be so reduced in nutritive value particularly energy, protein, phosphorus and β-carotene that they are suitable only for a maintenance ration for adult cattle. Such feedstuffs should be supplemented with good quality concentrate, vitamin-mineral mixture, and feed additives if used for any other purposes. Beef cattle except for calves due to pre-ruminant can meet their maintenance energy requirements from good quality forages and roughages. Additional energy sources may be necessary for production. Cattle should be fed an adequate ration may receive the recommended nutrients for optimal performance, reproduction, cow and calf health, and growth of all classes of cattle.

Protein requirements for cattle are stated in terms of metabolizable protein is defined as the true protein absorbed by the small intestine and is composed of rumen undegradable protein (RUP) often has been called “bypass” protein and microbial crude protein (MCP). A portion of the feed protein is used by microorganisms as bacteria and protozoa that use the protein to manufacture microbial proteins. Protein supply to rumen microbes is expressed in terms of rumen degradable (RDP). The metabolizable protein used for maintenance and production. Urea and other sources of non-protein nitrogen (NPN) are used commonly in commercial protein supplements to supply one-third or more of the total nitrogen requirement[25]. Vitamin K and the B complex vitamins are synthesised in sufficient amounts by the ruminalmicroflora and vitamin C is synthesised in the tissues of all cattle in normal condition. Beef and dairy cattle have similar mineral elements requirements in qualitatively except for some exceptions. The salt (NaCl) requirement for cattle is quite low. Water should be free access for cattle. Many factors, including body temperature, body weight, growth, reproduction, lactation, digestion, metabolism, excretion affect water consumption and restricting water intake decreases performance.

Lactation is a major physiological and biochemical undertaking. The yield and composition of milk are affected by many factors such as species, breed, strain within the breed, age and stage of lactation. The efficiencies of metabolizable energy utilisation for maintenance and milk production are concerned with the energy contents of the diet and are very similar. High energy intakes must include a certain level of roughage in the diet if an acceptable rumen fermentation is to be maintained and problems of acidosis, reduced intake and low-fat milk are to be avoided [1]. Lactating dietary requirements differ from non-lactating ones with required higher levels of energy, nearly doubled levels of protein, calcium and phosphorus, but no change in vitamin A [26]. It is very important to regulate the amount and quality of concentrate during lactation. With this arrangement, nutrient requirements should be met adequately as well as no way should the animal be allowed to become too fat. Otherwise, production performance can lower in mid and late lactation. At the same time, feeding should be economical. Especially in early lactation period, at least 30% of the total ration should consist of roughage. Protein levels of concentrates are another important consideration during the different stages of lactation. Extra digestible crude protein (10–15%) would be beneficial for early lactation period, and it should be preferred wider digestible crude protein/energy ratio for milk production during the later phase of lactation cycle with inclusion of dry period [27].

Since the cow herd is still growing, as well as producing a calf, first-calf heifers should receive high-quality forage and protein-energy supplement. Calves graze forage and suckle cows for several months. At 3–4 weeks of age, they begin to graze forage, which during the next few months becomes their major nutrients source [28]. A program of management, which provides energy feeds other than milk, plus grass or hay usually, is defined as a creep feeding arrangement. Creep feeding usually results in increased calf gain during its suckling period. Creep feeding may be expected to make a difference in calf performance at almost any time of the year, but the greatest benefit may be expected when pasture or hay is of less than optimal quality and quantity [29]. Creep feed should be based on grain and protein supplement. Post-weaning calves and replacement heifers feed good quality forage free choice. Supplement with grain and protein supplement as necessary to produce desired level body weight gain. Weaned calves may be raised on roughage for a year or more before entering the feedlot, or they may enter the feedlot directly after weaning [28]. Stocker growth is nourished, normally, with a preponderance of roughages, balanced with adequate protein, minerals and vitamins [30].

Nutrient requirements of the various physiological conditions of beef and dairy cattle have been given by NRC. Nutrient requirements of pregnant replacement heifers, beef cows, growing bulls and large-breed dairy cattle are given by NRC in various tables [31, 32]. For additional information, see Nutrient Requirements of Beef Cattle [31] and Nutrient Requirements of Dairy Cattle [32].

7. Feeding and nutrition of small ruminants: Sheep and goat

Nutrition largely affects flock reproduction, milk production and growth in ruminants. Sheep and goat should be fed according to their nutritional needs [33, 34]. Many factors affect their nutrient requirements such as breed, age, body weight, physiological stage and yield level.

The digestive efficiency of sheep, goat and cattle is similar [35]. In general, goat is considered better browsers than sheep, has a higher voluntary feed intake and can digest fibre more efficiently, particularly when fed low or medium-quality diets [36–39].

The digestive processes of neonate lamb and kid having undeveloped pre-stomach (rumen, reticulum and omasum) are very similar to those of monogastric animals. They are unable to digest ordinary carbohydrates except for lactose or grain-based feeds. The first meal of newborn is colostrum providing all nutrients and antibodies. By feeding on dry feeds (good quality roughage and concentrates), rumen becomes inoculated with microorganisms. As the microbes multiply and begin to digest feed, they stimulate the growth and development of the pre-stomach [40]. Lamb/kid's rumen is usually functional at 45–60 days old ages.

After adequate colostrum feeding, lamb/kid may be raised on sheep/goat milk (natural rearing) or milk replacer (artificial rearing). For various reasons such as inadequate milk production, higher milk price, reducing feed costs, and so on, producers may prefer to use artificial rearing. In both rearing system, it is recommended that liquid food feeding continues until lamb/kid weight reaches at least 10 kg. The composition of a good replacer for lamb is as follows: 22–24% crude protein, 25–35% ether extract, less than 1% crude fibre, 5–8% ash and 22–25% lactose [41].

From ~2 weeks of age, they begin to consume solid feeds and should be creep-fed when pasture quality or quantity is limited. Typical feed ingredients of creep ration are ground or cracked corn, alfalfa hay or meal, soybean meal, oat and molasses. The creep ration should have 18–20% crude protein and not be contained urea. *Ad-libitum* or free choice feeding of creep rations can stimulate rumen development and increases the performance of lamb/kids [42].

Nutrient requirements of sheep/goat are just above maintenance during early and mid-gestation occurring placental development. During the last 50 days of gestation, last trimester, nutrient requirements of them substantially increase due to rapid fetal growth, particularly for ewes/goats carrying multiple foetuses. In addition, this is the period when rumen volume decreases and mammary system develops or regenerates. For these reasons, the nutrient density of diet is necessary to increase for assuring adequate nutrition. Especially, energy is important as it affects lamb/kid size and vigour at birth [35].

Milk production of the ewes/goats peaks at 3–4 weeks following lambing/kidding. Ewes/goats with twin and triplet lambs/kids produce more milk than those with singles. They have the greatest nutrient requirements during early lactation period since they should be fed on high-quality forages supplemented with concentrates. The concentrate ratio of 50–60% is sufficient. After the first 60 days of lactation, the amount of consumed feed per animal should be reduced to prevent excess fat accumulation and to obtain optimum body condition score (2.5 or 3) [35].

Nutrient requirements of various physiological conditions of sheep and goat have been given by NRC in various tables [33, 34]. For additional information, see Nutrient Requirements of Sheep [33] and Nutrient Requirements of Goat [34].

8. Conclusion

Digestive process of ruminants and non-ruminants varies depending on morphological and functional differences of the digestive tract. These variations clearly affect feed source used their nutrition and the amount and kind of nutrients required by them. Because of differences in their digestive physiology, the availability of individual nutrients can vary from feedstuff to feedstuff. Animals must receive sufficient amounts of all essential nutrients (water, energy, amino acids, vitamins and minerals) to remain healthy, to grow and to produce. Inadequate and unbalanced nutrition causes various feeding disorders or even deaths. For economic animal production, it is important for producers to choose feedstuffs that have nutrients high in bioavailability.

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Managing Dietary Energy Intake by Broiler Chickens to Reduce Production Costs and Improve Product Quality

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Abstract

Feeding constitutes the highest variable cost in poultry production, accounting for at least 60% of such costs, especially in an intensive rearing system. Energy intake is an essential factor in broiler production because of its involvement in growth rate, carcass quality as well as its role in the development of certain metabolic diseases. Dietary energy is supplied in broiler nutrition through different feed resources. Dietary energy content strongly regulates feed consumption, and energy is the most expensive item in poultry diets. At the same time, excess energy intake may result in an increased fat deposition, which affects meat quality and consumer health. This chapter explores the implication of imbalance in energy intake, possible nutritional strategies to restrict energy intake without reducing performance and hence improving meat quality.

Keywords: broiler chickens, energy intake, health, meat quality, nutrition production cost

1. Introduction

One of the objectives of any poultry producer is to feed the chickens with balanced diet at least cost and also generate products that will attract premium prices in order to maximise profit. For many decades, farmers and feed manufacturers have been facing the challenge of effectively reducing the cost of poultry production and produce quality products. Several factors such as genotype, diet composition, digestible nutrient content, energy to protein ratio, feed form, feed processing, environment, and disease could affect the cost of production and poultry product quality through influencing feed intake, body weight gain and feed conversion ratio (FCR). Dietary management of energy intake has been reported to decrease the cost of production and improve product quality to a greater extent than the abovementioned factors [1]. However, most energy feed ingredients that will help in achieving improved performance, health, reduced production costs and improved product quality in poultry production are continuously becoming scarce and expensive for use in broiler production due to the stiff competition for available energy sources used by industries for biofuel and as food for humans. Feeds that provide the basic nutrients which help to achieve quality broiler carcass yield accounts for over 70% of the overall cost of poultry production, with energy sources being the largest in terms of quantity (40–70%) and invariably the most expensive [2–4].

The continuous increase in the cost of poultry feed ingredients (especially energy sources) has forced some farmers as well as feed manufacturers to use poor quality energy feed ingredients. This practice has resulted to poor feed intake, weight gain, FCR and meat quality [5]. The importance of dietary energy in poultry feeding cannot be over-emphasised because increasing or decreasing the dietary energy has been reported to affect feed intake in addition to promoting or undermining efficient feed utilisation and growth rate [6–9]. Singh and Panda [10] concluded that birds usually eat with the aim of satisfying their energy requirement, and once this aim is achieved, the birds will stop eating irrespective of the fact that other key nutrient requirements such as protein, minerals, and vitamins have not been met. This scenario tends to lead to malnutrition, poor performance, increased deposition of excess abdominal fat or carcass fat in broilers [9, 11], and this fat deposit is usually considered to be waste product when birds are processed. High fat deposition is regarded as an economic loss for poultry producers. Furthermore, energy intake is considered a fundamental factor in broiler production because it not only affects growth rate and carcass characteristics but also causes some metabolic diseases such as ascites and fatty liver syndrome in broiler chickens [12, 13].

Therefore, appropriate focus is usually placed on the inclusion levels of various dietary energy sources when formulating diets for broiler chickens since an increase or decrease of dietary energy could play a key factor in determining not just cost but also the final product quality [7–9]. The nutrient density in the diet should be adjusted to enable appropriate nutrient intake based on requirements and the actual feed intake. Based on these facts, several poultry researchers and nutritionists have over the years directed their research toward finding various strategies aimed at managing dietary energy intake in poultry birds in order to cut down on the cost of production and also improve the quality of poultry products. Results obtained so far have been conflicting, with some authors concluding that dietary energy content could be managed to influence broiler performance and carcass quality [8, 9, 14, 15]. Other authors report that changing the dietary energy content has no effect on broiler performance and carcass quality [16]. Kim et al. [17] reported different responses to energy concentration with different strains of broiler chickens. The management of dietary energy intake in broiler chicken production aimed at reducing production costs and improve the product quality of broiler birds has been practiced for many decades with varying outcomes. Research geared towards achieving both a reduction in the cost of production and improvement of quality broiler products has also been inconsistent so far. The variability when dietary energy strategies are applied could be due to various factors such as genotype, diet composition, digestible nutrient content, energy to protein ratio, feed form and feed processing, environment and disease. Suitable mechanisms to keep these sources of variation constant when dietary energy management is applied are worth considering. This chapter seeks to review the shortfall and progress that have been achieved in research into the management of energy content to reduce feed costs, sustain productivity and improve product quality. The nutritive value of energy sources for poultry, recent advances in understanding energy requirements of poultry, cost implications of energy sources, regulation of dietary energy and feed intake in poultry nutrition will also be discussed. The effect/implication of imbalance in energy intake on poultry (growth, fat deposition, potential disease disposition, meat quality), nutritional strategies to restrict energy intake and various implications/benefits of restricted energy intake in poultry production.

2. Dietary energy sources for poultry

Energy and protein are the second most important feed constituents after water and are needed to maintain health, growth, and production. This explains why energy and protein sources are the most important feed ingredients for poultry feeding. Oilseed cakes and animal protein meals are considered as secondary sources due to their substantial energy content [18]. Cereal grains provide 60–70% of dietary energy for poultry, while other energy and protein sources supply the rest. Although the interaction of protein sources with the main energy sources influences the overall energy supply and utilisation, it is important to determine precisely the energy values of diets containing vegetable sources, whether for least-cost formulation purposes or for adapting feed supply to energy requirements of animals [19]. Some data on global production of energy sources are shown in **Table 1**.

2.1. Cereals grains energy feed ingredients

Cereals are the grain-producing plants, which can be used as energy sources in animal and human food. These form the largest part of the energy source in poultry diets and consist of the highest inclusion level in a standard poultry diet. Corn, wheat, sorghum, barley, rye, oats, triticale and millet [34–38] represent the main cereal grains used as energy sources in broiler diets. Cereal grains are cultivated in large quantities and provide more starch worldwide in comparison with other types of crops. Recently, grain by-products such as distiller's dried grains with soluble (DDGS) have been used in poultry feeding. Starch constitutes the basis of energy in grains, which is highly digestible especially for poultry. The metabolisable energy content of frequently used grains for poultry ranges from 2734 kcal/kg in rye to 3300 kcal/kg in corn. The nutritional profiles of ground cereal grains vary according to type, location, season, cultivation, harvesting and handling conditions. Although they contain highly digestible starch, most of the grains contain anti-nutrients, which negatively affect the digestion, absorption, and availability of nutrients [39, 40].

Ingredient	**Global production (m tonnes)**	**Top producers**	**References**
Cereal grains			
Corn	1031.6	USA, China, Brazil, European Union, Argentina.	[20]
Wheat	2627	China, India, Russia, USA, France.	[21, 22]
Sorghum	59.34	USA, Nigeria, Mexico, India, Sudan	[23]
Barley	137.47	European Union, Russia, Australia, Canada, Ukraine.	[24]
Oat	23.3	European Union, Russia, Canada, Poland, Finland	[24]
Rye	12.6	European Union, Russia, Belarus, Ukraine, Turkey.	[24]
Triticale	5.2	Poland, Germany, Belarus, France, Russia.	[25]
Millet	29.9	India, Nigeria, Niger, China, Mali.	[26]
Root and tuber energy sources			
Cassava	27.0	Nigeria, Thailand, Indonesia, Brazil, Vietnam	[27]
Potato	393.75	China, India, Russia, Ukraine, USA.	[28]
Plant protein energy sources			
Soybean meal	345.9	USA, Brazil, Argentina, China, India	[29, 30]
Sunflower meal	45.6	Ukraine, Russia, European Union, Argentina, Turkey.	[31]
Cotton seed meal	13.9	India, China, Pakistan, Brazil, USA.	[32, 33]

Table 1. Global production and major producers of different energy feed sources (2017).

2.1.1. Corn

Corn, also called maize, was first grown in America by the American-Indians. According to the physical appearance of the kernel, there are seven types of corn worldwide, including flint, flour, dent, pop, sweet, waxy and pod. Nowadays, most of the grown corn is the hybrid, produced by crossing inbred lines through several generations. As a plant, corn is efficient at converting great amounts of sunlight into constant forms of energy and stored as starch, cellulose, and oil. The corn bushel approximately consists of 65.6% starch, 26% gluten feed, 5.2% gluten meal and 3.2% corn oil. Corn is the principal cereal grain for poultry feeds around the world, especially in the United States [41]. Due to its good energy content (3300 kcal/kg of energy for poultry), high starch digestibility and low fibre, it is extremely palatable and almost free from anti-nutritional factors (ANF). Corn is considered as the standard by which alternative grains are evaluated.

2.1.2. Wheat

China, India, the USA, the Russian Federation, France, Pakistan, Germany, Canada, and Turkey represent the main wheat producing countries. Generally, wheat is grown for human consumption. Wheat inclusion in animal feeds depends on seasonal production, price fluctuation during harvesting and the relative market prices of the other energy sources. Wheat is the premier source of energy for poultry diets in Canada, parts of Europe, Australia, and New Zealand [42]. Wheat has high starch content (about 70% DM), providing around 3153 kcal/kg energy for poultry. In addition to its high nutrient digestibility, rolled wheat is very palatable; therefore, it is considered an efficient energy source for all classes of poultry. Wheat has been classified into hard and soft varieties, depending on gluten content. Soft varieties are commonly used as main ingredients in poultry feeds [43].

2.1.3. Barley

Barley is one of the popular cereal grains. It is cultivated in more than 100 countries, almost across all continents. The USA, Canada, Australia, Russia, UK, France, Germany, Ukraine, Spain and Turkey produce around three-quarters of the total world production. This important seasonal plant is ranked fourth after maize, rice and wheat [42]. Barley provides around 2795 kcal/kg energy for poultry, with a low starch content, relatively high fibre content and some ANFs [44]. The lower metabolisable energy (ME) value limits the inclusion of barley in high-energy poultry diet formulation, and it is not included at high rates, particularly in diets for young birds [45].

2.1.4. Sorghum

Sorghum is mainly grown in warmer climates, especially in Africa, Asia and Central America. Kafir, Milo, Feterita, Durra and Hegari are the common African and Mediterranean varieties of sorghum, while Sballu, and Kaoliang are Asian types. United States varieties were originally produced from crossing Kafir and Milo. In addition, sorghum is classified according to the tannin content to high- and low-tannin types. Tannins are ANFs, which reduce the availability of protein during digestion [46]. The content of tannin in sorghum limits its use in poultry diets, although tannin-free varieties are available now but in inadequate amounts. Sorghum is considered the major source of energy for poultry feeds in some Asian and most African countries, due to its high energy content (3263 kcal/kg). Using rolled sorghum is a common practice in poultry feed formulation, although sometimes whole grain feeding is well known in rural areas [47].

2.1.5. Rye

Rye is originally a south-west Asian plant, but now it is growing in all Asia, Europe, Africa and North America (especially Canada). Rye contains high starch content (around 62%), with an energy content of about 2734 kcal/kg energy for poultry and has a low fibre content. Despite the rich nutrient profile, rye is not competitive as a source of energy for poultry because of the presence of ergotism, resorcinols and large amounts of soluble arabinoxylans, which decrease the nutrient bioavailability for birds, leading to a depression in growth and productivity. On the other hand, this composition makes it a good source of low-fibre energy diets. Rye is considered less palatable than other cereal grains [48].

2.1.6. Oats

Oats are one of the cool and high moisture area plants, also they can grow at high altitude of tropical areas. Russia and Canada are considered the main producers of oats followed by Poland and Australia, respectively. Undehulled oats are low in starch (around 40%), offering about 2756 kcal/kg energy for poultry, while the dehulled oats contain around 60% starch. The presence of ANF such as β-glucans and high fibre contents are the common constraints to the use of oats in poultry diets. In addition, the high oil content of oats can lead to development of off flavour in chicken meat. Inclusion of oats in low amounts is suitable for pullets and breeders [49].

2.1.7. Triticale

Triticale is the result of crossbreeding between wheat (mainly durum type) and rye, so it is a hybrid grain produced in German and Scottish laboratories in the nineteenth century. This crossing process introduced a new cereal grain species with wide adaptability, environmental tolerance, and improved nutritional value, to be grown in areas not proper for maize, rye and wheat around the world [50]. The currently developed varieties of triticale contain on average, 110 kcal/kg energy for poultry, with low fibre content; therefore, it has been included at rates up to 30% in broiler diets, and at slightly lower levels in layers diets. Furthermore, unlike the other cereal grains, different varieties of triticale almost similar in their energy content, which maintains consistent poultry performance [51].

2.2. Root and tubers

Starchy root and tuber crops are second only in importance to cereals [52]. Most of these roots and tubers are high in metabolisable energy, but their usage as poultry feed ingredients is limited because of the presence of anti-nutritional factors. However, these anti-nutrients are reduced or eliminated through adequate processing methods. Examples of these crops include cassava, cocoyam and potato [53–56].

2.3. Fats and oils

Fats and oils are collectively known as lipids. They provide significant amounts of energy to poultry diets, but there is a large variation in composition, quality, feeding value, and price. These notwithstanding, they are regularly used in poultry feeds to satisfy the energy need of the animal as lipids have more than twice the amount of ME than carbohydrates or proteins per kg weight. However, they are normally included at a maximum level of 4–5%. The commonly used types of fat in poultry diets include tallow, poultry fat, feed-grade animal fat and yellow grease. Animal fats provide an average ME of 8850 kcal/kg for poultry. Similarly, oils have a high content of energy, the average ME content of different types of vegetable oils ranging between 8300 and 8975 kcal/kg. The commonly used oils in broiler diets are soybean oil, canola oil, and palm oil. Besides the concentrated energy, including fats and oils in poultry diets improves the physical traits and palatability of diet, increases pellet durability and enhances the essential fatty acid contents of the diets, especially linoleic acid [57–59].

2.4. Energy from protein sources

While cereal grains provide 60–70% of dietary energy for poultry, protein sources also supply a considerable amount of energy. There are plant and animal protein sources. On their own, proteins are denser in energy than carbohydrates although they are not used as energy sources due to cost and physiological burden of excreting them from the body.

2.4.1. Plant protein sources

Although the energy value of various plant protein sources is not as high as the cereal or root and tuber energy ingredient source, they have a considerable amount of energy that helps in furnishing the required energy needed for optimum poultry performance and cost reduction. Examples include soybean meal, canola meal, cottonseed meal, sunflower meal, peas and lupin [36–38]. Geographical location of production, the season of production, method of cultivation, genetic and environmental impacts, as well as processing method and the amount of remaining oil are the main causes of differences in energy content between different vegetable protein sources.

2.4.2. Animal protein sources

Although they are major sources of protein, they also contain considerable amounts of energy. Examples include meat meal, fish meal, blood meal, feather meal and poultry by-product [36–38]. The differences in the energy content of animal protein sources may be attributed to animal species, part of the body, and processing methods. Soybean, canola, cottonseed and sunflower seed contain an average of 2557, 2000, 2350, 2205 kcal/kg ME for poultry, while meat and bone, meat, fish, poultry by-product contain around 2475, 2500, 2720, 2950 kcal/kg for poultry, respectively [60].

3. Nutritive value of energy sources in poultry

Feed formulation involves a prudent usage of various (available) feed ingredients to supply sufficient amount and proportions of several nutrients required by poultry. Poultry feed is made up of many ingredients, and these ingredients are grouped into those that provide energy (fats, oils, and carbohydrates), protein (amino acids), vitamins, and minerals. Among the feed nutrients, dietary energy is one of the most important because it influences the utilisation of other nutrients through its ability to regulate feed intake to a high degree. Formulating poultry diets should be done with the aim of achieving optimum energy level based on the composition of the feed ingredient to lower feed cost per unit of poultry product and produce quality end-products. In animal feeds, energy supply represents a major part of the cost of the formula. Since feed ingredients that supply energy in a standard broiler diet are in the highest amount (40–70%) in terms of inclusion level [2–4, 61], it is important to improve the knowledge of energy utilisation and energy requirement by the animal to better meet its energy needs. Therefore, having systems in place to evaluate the energy content of raw materials

Ingredients	Metabolisable energy (kcal/kg)	References
Cereal grains		
Corn	3300–3319	[34–38]
Wheat	3153–3430	[34, 37, 38]
Sorghum	3263–3550	[34–38]
Barley	2734–2760	[36–38]
Oat grain	2550–2756	[36–38]
Rye	2710–2734	[36, 38]
Triticale	3110–3150	[36–38]
Millet	3240	[36, 37]
Roots and tubers		
Cassava	3000–3279	[63, 64]
Cocoyam	3476	[55, 56]
Potato	2370–3190	[25, 26]
Plant proteins		
Soybean meal	2557	[36, 38]
Canola meal	2000–2186	[36–38, 65]
Sunflower meal	2205–2310	[36–38]
Cotton seed meal	2350–2640	[36–38]
Peas	2550	[38]
Lupine	3000	[36, 38]
Animal proteins		
Meat meal	2500–2685	[37, 38]
Blood meal	2690–3220	[36–38]
Fish meal	2600–2970	[37, 38]
Feather meal	2880–3016	[37, 38]
Poultry by products	2950	[38]
Fats and oils		
Animal tallow	6020–7780	[57, 59]
Lard	7200–9854	[57, 59, 66–68]
Soybean oil	8800–9659	[57, 59]
Canola oil	9000–9260	[57, 59]
Cotton seed oil	8160–8630	[57, 59]
Palm oil	5302–7810	[57, 59]
Fish oil	8270–8690	[57, 59]
Poultry fat	8020–10,212	[57, 59]
Molasses	900–1080	[36, 37]

Table 2. Metabolisable energy values of different energy sources for poultry nutrition.

and feeds is a determining factor in least-cost formulation. The energy requirement for broilers at different phases of growth and breeds are 3000 kcal ME/kg or 12.55 MJ/kg (starter); 3100 kcal ME/kg or 12.97 MJ/kg (growers) and 3200 kcal ME/kg or 13.39 MJ/kg (finisher) [62]. Since management of dietary energy could influence cost and product quality based on the inclusion levels of various feed ingredients, a summarised table showing various feed ingredients that supply high to moderate energy to show farmers and feed manufacturers that are interested in manipulating cost and achieving improved broiler products through the use of dietary energy will not only give the targeted audience a sense of direction but also save cost. The nutrient composition of various energy feedstuffs is shown in **Table 2**. Each energy source has a different composition due to factors such as regional location, manufacturing practices and climatic conditions [37].

Adequate knowledge of broiler nutritional requirements based on breed, the energy composition of a feed ingredient, availability and cost of these ingredients is fundamental in least cost formulation and achieving improved broiler performance. Manipulating dietary energy has been reported to influence feed intake with a resultant effect on performance and carcass quality. Poultry adjust their feed intake to accommodate a wide range of diets with differing energy contents at different ages and in response to various factors, including dietary energy [69]. Therefore, appropriately analysed information on different dietary energy contents of several energy-rich feedstuffs becomes important. However, the high cost of feed analysis makes it always difficult for farmers (especially for small-scale farmers) and feed manufacturers to analyse each batch of feedstuff for its nutrient content. Invariably, they usually rely on feedstuff composition data that have been compiled based on many laboratory analyses. Therefore, it becomes imperative to present a reasonable, accurate and summarised estimate of energy contents of feed ingredient for farmers, researchers and feed manufacturers, to enable them to cut down on cost and time that would have been taken to analyse and obtain more accurate laboratory data. The energy which a bird uses for maintenance and productive functions is obtained mainly from starches (carbohydrates), lipids and protein. Energy feed ingredients could be classified into cereal grains, root and tubers, plant protein sources, animal protein sources, fats and oil, as discussed in Section 2 of this chapter. These feed ingredients provide high to moderate dietary energy. Therefore, adequate knowledge and skills are required in using these ingredients to get the best possible least-cost formulation and achieve improved product quality.

4. Cost implications of energy sources

The poultry industry relies on a limited number of energy sources, mainly cereal grains and their by-products, in addition to oils and fats, which are normally included in small proportions in poultry diets [70]. Utilising the low-cost locally available energy sources to feed poultry is a nutritionally and economically proven way to reduce the cost and product inefficiency. Annual production, availability, cost of production, prices of other sources, productivity variations and the stiff competition with humans are the main factors affecting the prices of vital cereal grains needed for poultry feeding. Scientifically, assessing cost of feed ingredients depends on its quality evaluation, which is very important to specify ingredient suitability to meet the nutrient specification of poultry to such production type. The ingredient dry matter content and metabolisable energy concentration are crucial keys to evaluate the cereal grain quality and enable real calculation of energy cost for each source. In addition, poultry performance is highly correlated to energy intake, therefore the best energy source is that which supports the best products to maximise the returns [71].

Feed manufacturers target the available energy sources with reasonable price to use, so availability, price, competition, and quality represent the main handicaps that facing processors to produce cost-efficient and high quality feeds. Globally, corn is the premier energy source, but the high demand for it by humans and animals affects its price and availability. Therefore, to solve this problem, in the most consuming countries such as US, Brazil, and some Asian countries they have started to use a major co-product – distillers' dried grains with soluble (DDGS), because of its cost-effectiveness, good nutrient profile and ready availability. Wheat has been used to replace corn in some parts of the USA, China and India due to the price difference. The expansion in poultry production in the developing countries is forcing the producers to import feed ingredients, increasing the pressure on the prices and quality of feeds. In Australia, because of the low price of sorghum it has been used instead of expensive wheat in summer, while barley and rye are used in some European countries when their prices are lower [72, 73].

The principal goals of manipulations in use of energy sources are to adjust ingredient costs, to reduce the cost of production and maintain the sustainability of the poultry industry. This can be achieved by meeting the nutrient requirements of birds and producing low-cost meat and eggs to satisfy the consumer desire. The rate of inclusion of cereal grains in poultry diets mainly depends on their current costs and nutritive values, therefore changing and replacing energy sources should not be in huge and sudden, to prevent digestive upsets and feed intake depression, which will reduce birds' productivity and production efficiency. Likewise, the price of energy sources has an impact on the cost of poultry feed and a corresponding increase in the total cost of poultry production and the cost of poultry products. This dilemma has affected the profitability of poultry production globally, reducing the interest of existing and potential poultry farmers in the business. Furthermore, this situation, coupled with the increasing demand for animal protein by humans, has caused great concern globally [74].

5. Recent advances in understanding energy requirements of poultry

Meremikwu [75] reported that one of the technical constraints to successful poultry production in the tropics is strict adherence to nutritional standards. According to Meremikwu [75], nutritional standards such as NRC [57] may over-specify diets in many low-income, resource-poor countries (particularly those in the humid tropics) because of environmental constraints. For decades, the widely accepted theory was that birds eat to constant energy intake, irrespective of the energy level of the feed. However, with advances in genetic selection over the years, this understanding has shifted drastically. The continuous improvement of poultry birds, especially broiler chickens through genetic selection, initially developed by focusing on growth and laying rate, then, by taking other physiological aspects into account has reinforced the poultry bird's potential for better feed efficiency. From a nutritional perspective, such genetic selection has led to changes in nutrient requirements of improved birds, which infers that feed characteristics have had to be continuously changed by feed manufacturers [76], to possibly meet the demand imposed by this development. The performance of poultry in terms of feed conversion ratio is largely dependent on ME values of feed ingredients. While Pym [77] and Fairfull and Chambers [78] once postulated that the effect of genetic selection on ME is relatively insignificant, this theory requires a second look at recent studies indicate otherwise, with growing birds fed wheat-based diets showing high heritability of ME values [79]. The assumption is that birds selected for fast growth rate should require a higher energy. However, one possibility may be that broiler genetic improvement results in the consequent loss of sensitivity to control feed intake based on dietary energy level. Richards [80] reported that feed intake is not properly regulated voluntarily in broilers selected both for faster body weight gain and deposition of muscle according to energy level, as in an *ad libitum* program where compulsive appetite and excessive fat accumulation was observed. Hence, the energy concentration of diets used for broiler selection has remained unchanged over time, suggesting that selection has accustomed broilers to a diluted diet compared to the concentration required to support their growth rate [76]. Hence, determining the energy requirements of poultry with the recent improvement may require species-specific as well as selection information to obtain optimal energy requirement for birds.

6. Regulation of dietary energy and feed intake in poultry nutrition

The amount of feed consumed by an animal determines the amount of nutrient that is available to the animal for maintenance and production functions [81]. Feed intake tends to influence body weight gain, FCR, cost and carcass quality. Based on these facts, adequate regulation of feed intake using several strategies becomes a critical action aimed towards achieving quality product and controls the cost of poultry production. Factors such as dietary factors (dietary nutrient composition, feed formulation, feedstuff inclusion levels and pellet quality) and managerial factors (feed and water availability to the birds, environmental management, stocking density and disease regulation) individually or collectively influence feed intake in poultry production [1, 81]. Among the abovementioned factors, dietary factors (dietary nutrient composition) have been reported to have a great/significant effect, with dietary energy intake having the most predictable effect on feed intake when applied on poultry [1, 82]. Feed intake has been reported to increase or decrease as dietary energy intake decreases or increases, respectively [69]. This increase or decrease in feed intake in relationship to dietary energy content is influenced by the amount of feed in the gut or other physiological limitations. Dietary energy intake has been reported to also influence growth rate and carcass quality through its effect on feed intake [83]. The ability to sense energy status and adjust metabolic pathway activity in response is a basic function of cells in all animal species [84]. Energy-sensing pathways are present in the central nervous system (CNS) and peripheral tissues of birds, and they represent another set of regulatory mechanisms that are used to modulate peripheral tissue metabolic activity as well as regulate feed intake, energy expenditure to maintain energy balance and body weight [85]. To regulate feed intake, dietary energy intake must be balanced with energy expenditure in the birds. This is monitored/controlled by the hypothalamus [86]. The hypothalamus in the brain of poultry plays an essential role in interpreting all information and generating the appropriate responses in feed intake and energy requirement needed to maintain energy homeostasis [84]. As shown in **Figure 1**, the hypothalamic melanocortin system comprises the vital feeding regulatory neural circuitry, which consists of two groups of neurons, the first group expresses neuropeptide Y (**NPY**) and agouti-related protein (**AgRP**) while the second group expresses proopiomelanocortin (**POMC**), a precursor containing α-melanocyte-stimulating hormone. Stimulation of NPY/AgRP-expressing (anabolic) neurons mediates a net increase in feed intake and energy storage, whereas activation of the POMC-expressing (catabolic) neurons results in a net decrease in energy intake and storage. Initiation of AMPK in the hypothalamus in response to lowered energy status stimulates the activity of the NPY/AgRP-expressing (anabolic) neurons and thus leads to increased feed intake and reduced energy expenditure, which work together to increase energy status. On the other hand, activation of mTOR causes increased activity of the POMC-expressing (catabolic) neurons, which in turn causes a reduction in feed intake as a result of the presence of increased energy expenditure, thereby promoting the utilisation of energy for maintenance, growth, and reproduction. Thus, balance in the activity of hypothalamic melanocortin system

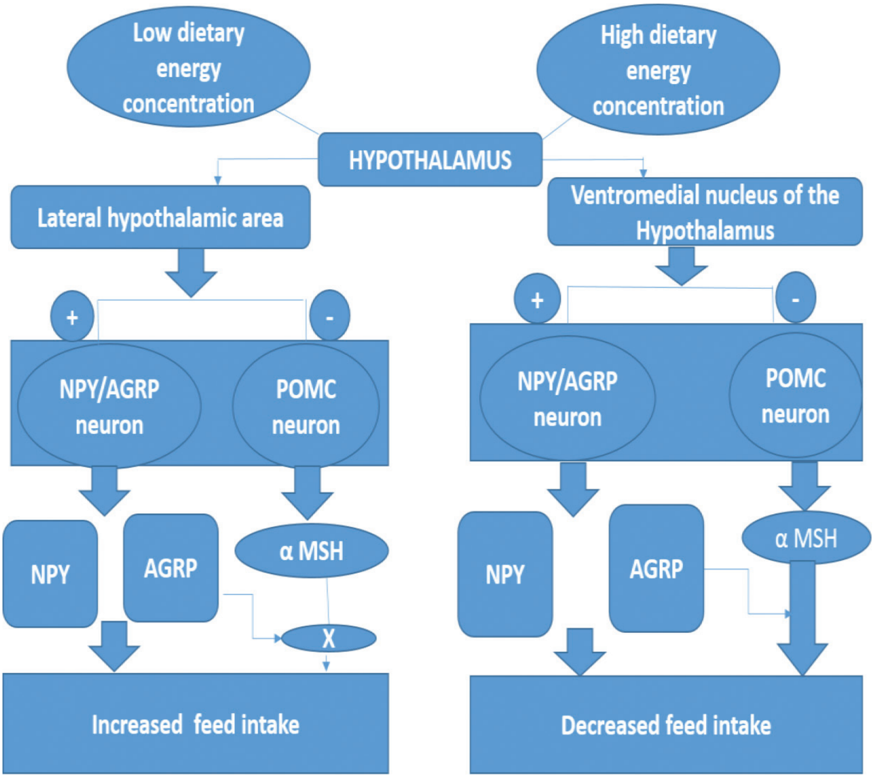

Figure 1. Diagram showing hypothalamic response in regulating feed intake when dietary energy intake is reduced or increased in poultry. Adopted and slightly modified from Bungo et al. [86]. NPY = neuropeptide Y; AGPR = agouti-related protein; POMC = pro-opiomelanocortin; α MSH = α-melanocyte – stimulating hormone; ARC = arcuate nucleus, + = activate; − = inhibit.

neurons is what ultimately determines feed intake considering dietary energy concentration and a resultant improvement in whole-body energy balance and body weight.

However, reports and research on the influence of dietary energy intake on feed intake in poultry have been conflicting. These inconsistencies could be due to differences in genotype/strain, environmental influence, stocking density, size of bird used, among other factors [81]. It is worthy to note that low-mass birds such as laying hens because of their size tend to adjust their feed intake in response to dietary energy concentration effectively than heavier birds such as broilers that maintain a constant feed intake, irrespective of the dietary energy concentration except this is limited by the gut content or other physiological factors [1]. Although there is a topic of great debate and discussion, a great number of research have reported the effect of high or low dietary energy in increasing or decreasing the feed intake in broiler chickens. It is well documented that most broiler chickens and laying hens tend to eat to satisfy their energy requirements or that they will consume a reduced amount of a feed greater in energy content than the one with a reduced energy concentration [87–89]. For instance, an earlier report by Sheriff et al. [90] indicated a higher feed consumption in broilers fed with low-energy diet. Moraes et al. [91] reported that high ME content results in low feed intake in laying hens. Almeida et al. [92] agreed with Moraes et al. [91] by also concluding that high dietary energy concentration led to a reduction in feed intake of commercial laying hen. Harms et al. [93] also observed that hens receiving the low-energy diet consumed significantly more feed than hens receiving the control and high-energy diets.

Van Krimpen et al. [94] concluded that hens that are fed low-energy diets or diets that are high in non-starch polysaccharides (NSP) spend more time on feed, compared with hens that were fed the normal control diets. Based on these facts, the authors concluded that laying hens adjust more rapidly to a decrease in dietary energy than to an increase in dietary energy. Compared to research results obtained using broilers and laying hens where an increase in dietary energy resulted to a decrease in feed intake and vice versa, Mbajiorgu et al. [81] observed an increase in feed intake when indigenous Venda chickens were fed increased dietary energy level. This difference in response between broiler chickens and laying hens compared to indigenous Venda chickens was attributed to the difference in intrinsic genetic limitations inherent in indigenous Venda chickens that may have led to the loss of sensitivity to influence feed intake when dietary energy regulatory strategy is applied [95]. Although there is a dearth of research on the nonsignificant effect of dietary energy concentration on feed intake of laying hens. Rather there are more consistent reports that laying hens can respond more effectively to dietary energy concentration on feed intake, unlike genetically improved broiler chickens. On the other hand, there are several reports that dietary energy intake did not affect feed intake especially in genetically modified broilers chickens. For instance, Araújo et al. [96] reported that there was no significant difference observed in feed intake among broilers fed high- and low-energy diets. A similar result was observed by Richards [80], who concluded that there was no effect on feed intake when varying concentration of dietary energy was administered on genetically improved broilers. Rosa et al. [97] also reported that feed intake was not affected by two different genetic broiler chicken groups. Richards and Proszkowiec-Weglarz [85] reported that modern commercial broiler breeders do not adequately control voluntary feed intake to meet their energy requirements and maintain energy balance. These authors thus advised that feeding must be limited in these birds using other feed intake regulatory strategies to avoid overconsumption, ascites and excessive fattening during production since dietary energy concentration does not influence feed intake in these breeds of birds.

From the aforementioned, reports on regulating feed intake through dietary energy intake have been inconsistent. These contradictions could be attributed to the influences of several factors as mentioned in this chapter. Factors such as genotype, environment, variability in stocking density, and so on must be kept uniform with dietary energy concentration being a major source of variation for future variation. More research needs to be geared towards confirming or considering the effects of other nutrients and ANF on energy concentration as regards its efficacy on feed intake regulation needs to be considered. The effect of size with regard to the response of heavy or light breeds of birds to dietary energy concentration and its effects on the amount of feed these birds consume. Thus, a better understanding of the interaction of dietary energy concentration with other factors will go a long way to understand the mechanism of how dietary energy intake affects feed intake and to what degree/level feed intake can be influenced in poultry birds. However, more reports favour the fact that dietary energy regulates feed intake more in laying hens and to some extent in broilers. The differences that have occurred between broilers and laying hens in terms of the response of these birds to feed intake according to dietary energy intake was explained by Denbow [98]. The author stated that due to years of genetic selection for improved growth in broiler chickens, the various mechanisms that control feed intake in broiler chickens have altered compared to laying chickens that have not been selected for growth. Invariably, the author recommended the need for comparative studies to investigate the mechanisms involved in feed intake regulation for broiler chickens that have been selected for growth against laying chickens that have not been selected for growth.

7. Effect and implication of imbalance in energy intake in poultry

Broiler chickens have been genetically bred for increased weight gain, feed efficiency, growth rate, and breast muscle weight to meet the requirements of consumers [99]. This process has produced modern commercial chicken lines with a faster growth rate, better breast meat yield and feed conversion, as well as higher body fat compared with unselected lines [100]. Dietary energy is essential for maintenance of the chicken’s normal metabolism and meat yield. However, when the amount of energy consumed by the bird exceeds that required for the purpose of maintenance and growth, the remainder is deposited as fat [101]. This situation may be further aided by the imbalance in nutrients in the diets, especially the energy to protein ratio [102, 103]. After hatching, birds are expected to increase their body weights over time and the amount and ratios of body protein and fat augment at various rates [104]; however, there is potential to deposit fat faster at later phases [102]. More so, the excessive fat in modern chicken strains is one of the most important challenges facing the poultry industry [105]. For example, Choct et al. [106] found that modern broilers contain 15–20% fat, and >85% of this fat is not required for physiological body processes. In general, disproportionate fat laydown is an undesirable trait for producers and consumers alike because it is considered a waste of dietary energy and a product with little economic value, which reduces carcass yield, and quality, and affects consumer acceptance [107]. In the modern broiler industry, carcass fat is always considered to be an unfavourable characteristic [108], as it decreases feed efficiency and carcass yield; moreover, it leads to rejection of the broiler meat by the consumers [109, 110]. However, fatty acids and overall fat, both in muscle or adipose tissue, impact vitally on many different areas of meat quality and are necessary to the nutritional value of meat [111]. Additionally, the development of flavour in meat is significantly affected by the lipids of fatty tissue. Lipids impact flavour through their influence on flavour generation, flavour perception (mouth-feel, aroma and taste) and flavour stability. Tumova and Teimouri [110] and Lawrence and Fowler [112] reported that high densities of linoleic acid in the fatty tissue could have a remarkable impact on flavour. Apart from the problem of fat deposition, there is a tendency for high mortality as well as development of metabolic diseases and skeletal disorders [110].

8. Various strategies employed to manage dietary energy intake

As discussed earlier in this chapter, high or low dietary energy content can lower or increase feed intake [69]. Low feed intake as a result of high energy content (leading to inadequate intake of other vital nutrients) has been reported to result in poor performance. In most cases, high dietary energy intake causes high fat deposition with a resultant poor quality end-product and increased mortality rate. On the other hand, low dietary energy intake has been reported to result in low energy storage, inability to achieve homeostasis and reduced body weight of poultry birds [101, 110]. Therefore, practices aimed at managing dietary energy will aid in ensuring adequate feed intake with a resultant improvement in performance, product quality as well as reduced cost of poultry production. For many decades, meat type broiler and broiler breeder farmers have knowingly and unknowingly used different methods individually or collectively to manage dietary energy intake. Examples of these practices include nutritional strategies (use of high or low energy and fibre diets, pelleting as well as the use of microbial enzymes); use of genetically improved breeds; feeding practices (panned restriction feeding system or *ad libitum* feeding practice); type of rearing system used (intensive housing system, free ranging system or semi-intensive system), and disease prevention practices [1, 81]. These practices will be briefly discussed in this section. The positive or negative effect of these practices as reported by various researchers will be concisely discussed. The application of these practices to manage dietary energy intake to improve productivity and reduce the cost of production for broiler farmers and hatcheries will also be discussed.

8.1. Nutritional strategies used to manage dietary energy intake

Reduction in abdominal fat is a current goal in poultry industry so as to improve the efficiency of diets and to provide a less fat-laden meat product for consumers. Different nutritional strategies provide an opportunity to reduce production costs and at the same time, improve carcass quality in broiler chickens. Lowering the dietary energy level has been used to achieve the reduction in abdominal fat deposition. A study by Rosa et al. [97] evaluated the effect of energy intake and broiler genotype on performance, carcass yield, and fat deposition in two different genetic groups of broilers and reported that genetic improvement had a significant effect on broiler energy metabolism, and that abdominal fat decreased with low energy intake

(2950 kcal/kg) compared to the other diets. In another study, Choct et al. [106] examined the influence of different fat sources at two dietary levels on lean growth in broilers and concluded that the addition of fish oil to broiler diets reduced the abdominal fat pad weights. Fish oil contains long-chain polyunsaturated fatty acids, which enhance low-density lipoprotein and triglyceride levels while increasing glucose uptake into the muscle tissue in blood and lessening the negative effects of the immune system on protein breakdown. However, one consideration with the use of fish oil is its development of off-flavour in bird diets and the reduced shelf life of the chicken meat, which can be improved with the use of preserving agents and antioxidants [113]. According to Leeson [114], the success of the use of lower-energy diets is in the ability to predict change in feed intake and corresponding modification to all other nutrients in the diet, hence, a reduced dietary energy intake may be triggered by excess or imbalance of other nutrients in broiler diet. Leeson [114] further proposed that when all nutrients are tied to dietary energy, broilers are able to remarkably maintain energy intake when confronted with a major reduction in dietary energy concentration. More so, a recent study at the University of New England tested the effect of dietary fibre and energy levels on energy intake. It was observed that low while an optimum energy level in diet in combination with high dietary fibre inclusion reduced abdominal fat and cost in broilers as shown in **Table 3** [115]. Another nutritional strategy that has been used to manage dietary energy intake in broiler chickens is supplementation with exogenous that target energy-yielding substrates. **Table 4** shows examples of various carbohydrate- and lipid-targeting enzymes as well as their targeted substrates and energy sources. Such exogenous enzymes aid in the release of trapped dietary energy, especially energy sources such as wheat, rye, barley and oat that are high in NSP [116]. Exogenous carbohydrase enzymes have been reported to reduce or eliminate the effect of NSP, thereby furnishing more nutrients. Increased feed consumption in broilers leads to increased dietary energy intake. In the same vein, increased dietary intake leads to increased fat deposition and poor product quality. Based on this fact, most poultry farmers have imbibed the practice of reducing the quantity of feed offered to their birds and simultaneously adding exogenous enzymes to help release nutrients bound by antinutritional factors. This practice has been reported to result in broilers that grow faster and also have leaner meat [117].

8.2. Managing dietary energy intake in broilers through selective genetic improvement

High carcass fat is considered unfavourable by consumers in most parts of the world. Based on this fact, breeding programs have been developed with the aim of selecting against high fat deposition in broiler carcass in order to improve the quality of the product [118]. Modern broilers have been genetically selected to have significantly reduced fat deposition and also have better weight gain and FCR as a result of significantly masking the effect of dietary energy content in the diet [119]. Because of the tremendous success achieved through artificial selection of broiler chickens, there has been a reduction in total feed and energy required to raise broiler chickens to slaughter or market weight. Genetically, lean birds have better energy use efficiency [120]. This achievement has also resulted to a reduction in cost of production [121]. It is worthy to note, however, that genetic improvement of broilers with the aim of controlling the effect of high or low dietary energy intake could be influenced by several factors such as: nutrition, health of the

Feed consumption and utilisation (0–35 d)

Dietary fibre content	Energy content	Feed intake (g/b)	Body weight (g/b)	Body weight gain (g/b)	FCR
Low	Optimum	3432.0	2250.9	2209.6	1.55
Low	Low	3248.0	2177.2	2136.1	1.52
Medium	Optimum	3332.9	2143.6	2102.2	1.59
Medium	Low	3337.7	2026.3	1984.7	1.68
High	Optimum	3510.5	2142.9	2101.7	1.67
High	Low	3324.7	2103.8	2062.8	1.61

Meat yield (g/kg live weight) (35 d)

Dietary fibre content	Energy content	Live weight	Carcass weight	Thigh	Drumstick	Breast (skin-less)	Abdominal fat pad
Low	Optimum	2248.4	1678.3	263.9	216.4	416.5	30.6
Low	Low	2201.0	1630.0	250.1	215.5	392.2	23.0
Medium	Optimum	2179.2	1629.3	250.9	213.5	395.0	25.1
Medium	Low	2093.2	1562.3	240.4	199.9	391.8	22.6
High	Optimum	2201.2	1621.2	244.2	207.5	413.4	22.2
High	Low	2250.6	1684.0	278.3	211.2	410.9	24.6

Economic analysis

Dietary fibre content	Energy content	Feed cost ($/bird)	Feed cost ($/kg gain)
Low	Optimum	1.25	0.57
Low	Low	1.16	0.54
Medium	Optimum	1.23	0.58
-Medium	Low	1.19	0.60
High	Optimum	1.30	0.62
High	Low	1.21	0.59

Source: Chen [115].

Table 3. Feed intake, feed utilisation, meat yield and economic analysis of broiler chickens fed finisher diets differing in fibre and energy contents.

bird, environment, and so on. The authors of Refs. [1, 97, 122] reported that the genetic make-up of a broiler bird is not the sole reason for the success achieved in managing dietary energy intake by some broiler producers. The authors suggested that the success achieved in this area may be as a result of the combination of genetics and other factors such as environmental influence, nutrition, management practices, age, sex of the birds and disease prevention strategies.

Enzyme	Substrate targeted	Mode of action	Feed ingredient of interest
β-Glucanase	β-Glucans		Oats, rye and barley
Xylanases	Arabinoxylans		Wheat, triticale, barley and rye
Amylase	Starch		Cereal grains, roots and tubers
Lipase	Lipid		Lipid in feed ingredient

Adopted from Ravindran [116].

Table 4. Different types of commercially available energy-targeting enzymes used to manage dietary energy.

8.3. Feeding practices used to manage dietary energy intake

Various practices such as restricted feeding and *ad libitum* feeding have been reported to influence dietary energy intake in meat broilers, laying hens as well as in broiler breeders [123]. These practices could have negative or positive effect on broiler performance and cost of production. Several researchers have reported the advantages and disadvantages of these feeding strategies [124–129]. For instance, Acar et al. [125] and Butzen et al. [128] both agreed that excessive fat deposition, ascites, sudden death syndrome as well as various metabolic disorders and disease in broiler can be reduced through planned feed restriction practice. To achieve success in managing dietary energy intake using these practices, adequate knowledge and skills in administering these strategies become key factors towards using them to achieve the right dietary energy intake in meat broilers, laying hens as well as in rearing broiler breeders.

8.3.1. Ad libitum feeding as a tool in controlling energy intake

Ad libitum feeding is defined as an animal husbandry practice in which animals are allowed unlimited access to feed on free choice basis [128, 130]. Feeding meat and breeder broilers *ad libitum* lead to increased feed and dietary energy intake and fat deposition compared to birds on restricted feeding [131]. According to Heck et al. [132], energy conversion (kJ/g egg) from 32 to 40 weeks of age was much higher in the broiler breeders on *ad libitum* feeding group than in broiler breeders that were on restricted feeding plan. The authors further explained that sexual maturity was delayed by 6 weeks in restricted breeders compared to *ad libitum* fed broiler breeders that started to lay at 20 weeks. On the contrary, the authors also reported that broiler breeder hens fed *ad libitum*, had low egg production and a high proportion of defective eggs, which was largely rectified by feed restriction.

8.3.2. Using feed restriction to manage energy intake

Feed restriction involves a calculated or planned practice of decreasing the amount of feed being offered to broiler birds with the aim of decreasing feed intake over a certain time interval in an attempt to slow the rate of weight gain, fat deposition and various metabolic disorders associated to excessive feeding. Contemporary commercial broilers are the product of intensive genetic selection for rapid growth. An unpremeditated result of these genetic selection programs has been the loss of ability by broilers to control feed intake to adequately meet up with maintenance, growth, and reproductive function [133]. Based on this fact, broilers tend to overfeed, and this uncontrollable feeding habit has been reported to cause nutritional, metabolic and health problems related to obesity. To manage this problem, most farmers have resorted to the subjecting of their meat or breeder broilers to planned feed restriction. Early age planned feeding restriction practice in meat or breeder broilers is geared towards ensuring that appropriate body composition and weight are achieved at important phases of the production cycle [133]. The success of a planned feed restriction in managing dietary energy intake depends on quantity of feed and timing of the feed restriction. This statement is in agreement with the report of Chenxi et al. [134] who concluded that feed restriction done by dilution of dietary energy and protein by 10% from 8 to 14 (early age planned feed restriction) is a suitable feeding program. The authors further explained that compared to the control group, there was no significant difference in body weight FCR and feed intake at 42 days. Chen et al. [135] also observed that 30% dietary energy restriction resulted in a decrease in fat deposition and an improvement in body weight and FCR at later phase of life. Bruggenan et al. [136] suggested that restriction applied at 7–15 weeks of age followed by either *ad libitum* feeding or continued feed restriction controlled feed and nutrient intake which was the best for improving reproductive performance in broiler breeder females.

8.4. Feed processing strategies aimed at managing dietary energy intake in poultry

Birds try to make adjustments geared towards controlling the amount of energy they consume. Feed processing is an important strategy used by poultry producers to manage dietary energy intake. The form in which feed is presented to broiler birds can affect the energy and nutrient (energy, protein, vitamins and mineral) intake. Feeding broilers with mash leads to ingredient selection, which results in poor performance [137]. According to Davis et al. [138] cited by Amerah et al. [139], poultry tends to select maize particles while ignoring soybean (protein source needed for growth and tissue build up), which would affect the intake of amino acids, vitamins and minerals, when fed with mash diets. The selection of maize feed particles tends to increase the dietary energy intake, with a resultant increase in fat deposition. This condition leads to poor growth and poor product quality in broilers. To solve this problem, broiler producers now use crumbles at the starter phase, and pellets at grower and finisher phases. This strategy tends to eliminate the issue of feed ingredient particle selection noticed when mash diets are fed to broilers. In laying hens, excessive fat deposition hinders egg production and thus feeding of mash to layers is a common practice, especially if the mash diet is properly/uniformly mixed.

8.5. Rearing system as a means of managing dietary energy intake

The increasing global demand by broiler meat and egg consumers for high-quality poultry products has necessitated the drive of breeders and producers towards meeting this demand at the least possible cost. In an effort to meet this demand, farmers are adopting different housing and rearing strategies (a deviation from the normal intensive system) such as free range and semi-intensive [140, 141]. It is well documented that the environment under which a poultry are reared plays a pivotal role in the quality of the product. Environment and housing system influence feed intake with a corresponding effect on dietary energy intake. Two types of rearing system are mostly employed in poultry production and they include intensive housing system and free range system. However, in order to reduce the shortcomings of these two rearing systems, a rearing strategy known as semi-intensive system is gradually gaining popularity [140]. Although free range and semi-intensive rearing systems are mostly used for egg laying hens, the increasing demand by consumers for meat produced from organically reared broilers is driving the introduction of these rearing systems in meat-type broiler production [141].

8.6. Managing dietary energy intake by controlling lightening regime

Light is a critical factor used to manipulate feed intake in broilers. By artificially increasing the length of time, the bird is subjected to light, its feed or dietary energy intake can be increased. On the other hand, lowered or total light-out tends to reduce feed intake in broilers. This fact is true because broilers tend to stop feeding once the light is off but resume feeding once the light is on. This technique has been employed in modern poultry systems to achieve optimum growth rates [142]. Intermittent lighting programs are routinely used by broiler producers. Buryse et al. [143] concluded that intermittent lighting program had a favourable effect on feed conversion and weight gain, with a decrease in fat deposition. Apeldoorn et al. [144] reported that the improvement in feed conversion with intermittent lighting programs was related to reduction in feed intake. This reduces the cost of production while growth rate and meat quality are unaltered. The author also showed that reduced feed efficiency was related to higher ME/GE utilisation.

8.7. Disease prevention practices as a tool in controlling dietary energy intake

Broilers in optimum health condition up to finisher phase have been reported to yield quality meat. Diseased birds tend to have reduced feed and dietary energy intake with a resultant decrease in meat, egg quality and mortality of poultry birds. The ability of a producer to effectively prevent disease or infections will go a long way to maintain feed and dietary energy intake and prevent unnecessary expenditure associated with purchase of drugs. Disease conditions tend to reduce feed intake and lead to malnutrition, which is a predisposing factor to various metabolic diseases [1]. Several disease prevention strategies such as the use of disease-free poultry birds, adherence to biosecurity, adequate and prompt vaccination when and if needed, isolation of sick birds, prevention of predators and potential disease-carrying vectors could go a long way to enable the birds to consume the right dietary energy content, leading to quality at least cost.

9. Conclusion

Improving poultry meat quality as well as cutting down on the cost of broiler production has been some of the major objectives of most farmers, processors and researchers. To achieve these objectives, several strategies have been adopted, one of which is dietary energy management.

Increasing or decreasing dietary energy intake has been reported to influence feed intake with a corresponding effect on performance and cost of production. Results on the use of this method have been inconsistent. These inconsistencies are due to several factors, including genotype, diet composition, digestible nutrient contents, energy to protein ratio, feed form, feed processing, dietary energy sources, physical environment and disease. However, the progress achieved is also very encouraging. It is therefore necessary to explore the effect of the abovementioned factors on dietary energy intake and seek for innovative ways to mask the effect of these factors so as to have a more consistent outcome when dietary energy intake strategy is used to influence the cost of production and product quality of broiler chickens. Various strategies aimed at reducing dietary energy intake through the use of high fibre diet combined with enzyme is very promising in improving carcass quality and reduce cost.

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Chapter 7

Current and Future Improvements in Livestock Nutrition and Feed Resources

Grace Opadoyin Tona

Abstract

This study reviews the current and future trends in the improvements being made in livestock nutrition and feed resources. There had been continuous improvements in global livestock production for past decades. Most of the improvements have been in response to increasing human populations, urbanization, income growth, production system efficiency, and environmental sustainability. To meet up with the increasing global demand for livestock products was the role earmarked to be played by animal nutritionists in a manner that there would be optimization of feed efficiency to achieve more livestock products from less feed. There has been the development and adoption of biotechnological applications such as the feeding of genetically modified plants and the use of in-feed additives such as antibiotics. In the past decades, the livestock feed industry had been centered on the use of antibiotics as livestock growth promoters. However, there has also been the negative development of microbial antibiotic resistance with various countries promulgating laws and regulations to ban and discourage in-feed antibiotic applications in the livestock feed industry. Thus, present and future improvements in livestock nutrition and feed resources are now being directed at the use of approved probiotics and the application of nanotechnology in livestock nutrition and feeding.

Keywords: improvements, livestock, nutrition, feeding, biotechnology

1. Introduction

Nutrition could be a serious limitation to livestock production especially when feed resources are inadequate in both quality and quantity. Global livestock production over the years has increased consistently and brought about increases in animal numbers [1, 2]. However, these increases in the number of animals have not always been accompanied by an improved availability of livestock feed resources. These may result in overgrazing, erosion, reduced health, and performance [2]. Feed quality and quantity combined with low producer prices have often forced farmers and feed producers to remain at low levels of animal feed production, compensated by large numbers of animals. It is evident that high global population growth, accompanied by high future projections of demand for livestock products, stresses the need for higher productivity per animal as well as increases in the number of animals. Inadequate feed quality and quantity impedes increased animal production. As the world population is expected to increase from 6 to about 8.3 billion in 2030 at an average growth rate of 1.1% per year, it is essential to be prepared to produce sufficient food for the increased population based on locally available feed resources especially in the developing countries [3]. These authors [3] also stated that there are opportunities and challenges for researchers to increase animal productivity in terms of quantity and quality, through the application of appropriate technologies in production systems, nutrition, and feeding of livestock. Feed is the most important input in all livestock production systems in terms of cost, and the availability of low priced, high-quality feeds is critical if livestock production is to remain competitive and continue to grow to meet demand for animal protein. A researcher [4] mentioned that conventional methods of livestock improvements (genetics and breeding, livestock nutrition and livestock disease management) have been used in the past and served the purpose of increasing livestock productivity. However, these options can no longer sustain higher production; consequently, new intensive techniques including biotechnology are now required to augment productivity. Modern biotechnology has the potential to provide new opportunities for achieving enhanced livestock productivity in a way that alleviates poverty, improve food security and nutrition, and promote sustainable use of natural resources.

Considerable improvement has occurred in livestock nutrition and feeding over the past two decades. Globally, livestock production is growing faster than any other sector, and by 2020, livestock is predicted to become the most important agricultural sector in terms of added value [5]. In a research conducted [6], it was also reported that the feeding of genetically engineered (GE) crops to livestock for the past 15 years has shown compositional equivalence and comparable levels of safety between GE crops and their conventional counterparts. Previous researchers [7] stated that recently production demands on the livestock industry have been centralized against the use of antibiotics as growth promoters due to growing concern over microbial antibiotic resistance. Thus, with many countries reporting increased incidences of antibiotic-resistant bacteria, laws and regulations are being updated to end in-feed antibiotic use in the animal production industry. This calls for suitable alternatives to be established for inclusion in livestock feed. Many reports have shown evidence that approved probiotics and nanoparticles may be better alternatives for animal growth promotion and antimicrobials. Researchers [7], however, explained that despite the expansion of antibiotic resistance in bacteria, antibiotics have not yet been rendered totally ineffective against them. And that the delivery and efficacy of antibiotics could, however, be enhanced by nanoparticle carriers, thereby potentially decreasing the dosage of antibiotics required for treatment.

Recent advances in livestock nutrition, especially in monogastrics, have focused on three main aspects: (i) developing the understanding of nutrient requirements of livestock, (ii) determining the supply and availability of nutrients in feed ingredients, and (iii) formulating least-cost diets that bring nutrient requirements and nutrient supply together efficiently.

2. Nutrient requirements for livestock

Nutrient requirement tables provide a summary of recommended minimum levels of nutrients for different livestock species. Livestock should be fed differently to meet body requirement based on their species, age, and purpose of production. The recommendations only serve as guidelines used for choosing dietary nutrient (energy, protein, essential amino acids, essential fatty acids, minerals, vitamins) concentrations in practical diets. Most nutrients are obtained from digestion of feedstuffs but few such as minerals, vitamins, and some essential amino acids are often supplied as synthetic supplements particularly in monogastrics.

2.1. Formulation of diets for poultry

Poultry raised under intensive system should be fed balanced diet based on species, age, and purpose of production. The major classes of chickens are meat chickens (broilers) and laying hens (layers). **Table 1** provides a summary of recommended minimum levels of selected

- Laying chickens

Nutrient requirements for laying chickens consuming between 80 and 120 g/hen/day are as follows: 12.50–18.80% crude protein, 2.71–4.06% calcium, 0.21–0.31% nonphytate phosphorus, 0.13–0.19% mg/kg potassium, 29.00–44.00 mg/kg zinc, and 0.13–0.19% sodium.

- Broiler chickens

Broilers of ages between 0 and 8 weeks old require the ranges of nutrients as follows: 18–23% crude protein; 0.80–1.00% calcium; 0.30–0.45% nonphytate phosphorus; 0.30% potassium; 8.00 mg/kg copper; 40.00 mg/kg zinc; 0.123–0.20% sodium.

- Broiler breeders

Broiler breeders require the following nutrients ranges: 19.5 g/day crude protein, 4.0 g/day calcium, 350.0 mg/day nonphytate phosphorus, and 150 mg/day sodium.

- Turkey poults

Turkey poults at 0–12 weeks old require the following ranges of nutrients: 22.0–28.0% crude protein, 0.85–1.20% calcium, 0.42–0.60% nonphytate phosphorus, 6.00–8.00 mg/kg copper, 50.00–70.00 mg/kg zinc, and 0.12–0.17% sodium.

- Turkeys 12–24 weeks old

Turkeys 12–24 weeks old require the following ranges of nutrients: 14.00–19.00% crude protein, 0.55–0.75% calcium, 0.28–0.38% nonphytate phosphorus, 6.00 mg/kg copper, 40.00 mg/kg zinc, and 0.12% sodium.

- Turkey tom breeders

Turkey tom breeders require the following ranges of nutrients: 12.00% crude protein, 0.50% calcium, 0.25% nonphytate phosphorus, 6.00 mg/kg copper, 40.00 mg/kg zinc, and 0.12% sodium.

- Turkey hen breeders

Turkey hen breeders require the following ranges of nutrients: 14.00% crude protein, 0.25% calcium, 0.35% nonphytate phosphorus, 8.00 mg/kg copper, 65.00 mg/kg zinc, and 0.12% sodium.

Table 1. Summary of recommended minimum levels of some nutrients for different classes of poultry.

nutrients for layers, broilers, broiler breeders, turkey poults, turkey growers, turkey tom breeders, and turkey hen breeders. In poultry, particularly in chickens, since each specific genotype has its own requirements, most commercial feed formulations are carried out based on minimum requirements recommended by the breeding companies from which they were obtained.

2.2. Formulation of diets for pigs

There are numerous feed ingredients that provide nutrients that pigs require for normal performance. Pigs do not require specific ingredients in their diets, but instead they require energy and nutrients such as amino acids, minerals, and vitamins. They should be fed diets that are balanced with respect to amino acids, containing adequate levels and ratios of the 10 essential amino acids required by pigs for maintenance, growth, reproduction, and lactation. The 10 essential amino acids are arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine. In a review article [8], it was explained that in pigs, amino acids are reported to be the chemical components of protein and are generally supplied to the pig from the crude protein in the diet. Failure to supplement low protein diet or feedstuff with sufficient amounts of good quality protein source was observed [8], which results in poor growth, insufficient feed utilization, increased carcass fatness, general unthriftiness, and or reduced reproductive performance. This researcher [8] also mentioned that in pigs, diet crude fiber should not exceed 10–15% of the diet as feed intake may be depressed. Growing and lactating pigs should be fed *ad libitum* while others could be limitedly fed. Presented in **Table 2** are some amino acid requirements in pigs.

Amino acid	Growers	Pregnancy	Lactation
Arginine	nd	0.15	0.41
Histidine	nd	nd	0.37
Isoleucine	nd	0.42	0.46
Lysine	1.10	0.43	0.55
Methionine	0.26	0.12	0.30–0.36
Methionine/cystine	0.57	0.06	nd
Phenylalanine	nd	nd	nd
Threonine	0.60–0.70	0.41	0.42
Tryptophan	0.18–0.20	nd	0.12
Valine	nd	0.32	0.53–0.68

nd, not determined; source: [9].

Table 2. Amino acid (%) requirements for pigs.

2.3. Formulation of diets for fish

Fish farmers need to make use of well-balanced, less expensive feeds as well as good fish farming management practices in order to achieve profitable production [10]. Species-specific feed formulations, which address the nutritional requirements of the different life stages of fish, are required in fish farming. Also, each specific genotype has its own nutrient requirements that meet the requirement for the different life stages. The fish larvae production and nutrition are usually undertaken by specialist breeding companies. Most commercial fish diets or feeds are formulated based on minimum requirements recommended by the breeding

Life stage/size class	**Range of values of crude protein (CP%)**
Fry	45–50
Fingerling	45
Juvenile	43
Grower	42
Broodstock	35–40
Amino acids	Requirement for all life stages (% aa)
Arginine	2.0
Histidine	0.7
Isoleucine	0.8
Leucine	1.4
Lysine	1.8
Methionine	1.0
Phenyalanine	1.2
Threonine	0.8
Tryptophan	0.2
Valine	1.3
Lipids	Requirement for all life stages is 8–10% lipids
Essential fatty acids	(minimum %)
Arachidonic acid (20:4n-6)	0.5
Eicosapentaenoic acid (EPA) (20:5n-3)	1.0
Docosahexaenoic acid (22:6n-3)	0.5
Carbohydrates (CHO)	Requirement for all life stages is 12% CHO
Crude fiber, % max.	3.0
Gross energy, min. kJ/g	15.5

Life stage/size class	Range of values of crude protein (CP%)
Digestible energy, min. kJ/g	15.5
Protein:energy ratio, mg/kJ	25.0
Minerals	Requirement for all life stages
Macroelements (%)	
Calcium, max.	1.0
Phosphorus, min.	0.8
Magnesium, min.	0.05
Sodium, min.	0.06
Microelements, min. (mg/kg)	
Potassium	0.7
Iron	60.0
Copper	3.0
Manganese	13.0
Zinc	30.0
Selenium	0.3
Iodine	1.1
Vitamins min. (IU/kg)	Requirement for all life stages
Vitamin A	2500
Vitamin D	2000–2400
Vitamins, min. (mg/kg)	Requirement for all life stages
Vitamin E	25–100
Vitamin K	1.0
Thiamine	10.0
Riboflavin	5.0
Pyridoxine	6.0
Pantothenic acid	20.0
Niacin	10.0
Folic acid	2.0
Vitamin B 12	0.02
Choline	800.0
Inositol	300.0
Biotin	0.15
Ascorbic acid	40.0

Requirements were measured in fingerling and juvenile fish. Values for other life-history stages are estimates. Data source: [12].

Table 3. Dietary nutrient requirements of rainbow trout (***Oncorhynchus mykiss***) (requirements are expressed for dry feed).

companies that supply the fry or fingerlings. Fish require nutrients such as crude protein, essential amino acids, essential fatty acids, lipids, carbohydrates, crude fiber, minerals, and vitamins [11]. **Table 3** presents the summary of dietary nutrient requirements and utilization of rainbow trout (*Oncorhynchus mykiss*) (fish) at different life stages or size classes.

2.3.1. Ingredient composition for different life stages of fish

Some of the ingredients required in early fry to brooder stages are as follows: fish meal of between 30 and 68%, corn meal of 0–4%, poultry by-product meal of 2–8%, ground wheat of 17–22%, fish oil of 9–12%, vitamin premix of 1.5%, and mineral premix of 0.5%. Sources: [10, 11].

2.3.2. Feed parameters and proximate composition for different life stages of fish

Some of the feed parameters and proximate composition requirements between early fry and brooder stages are as follows: 3–8% of body weight, 6 months maximum shelf life of feed, addition of probiotics to improve the feed conversion efficiency, 2–5 mm pellet size (mash for early fry), 35–48% crude protein, 8–21% crude lipid, 9–12% ash, less than 3–6% crude fiber, 12–13% nitrogen-free extract, and 17–21 kJ/g gross energy. Sources: [10, 11].

2.4. The feeding of ruminants: cattle, sheep, and goats

Ruminants have distinct advantage over monogastrics in being able to convert organic materials that are not suitable for human consumption into products that are of high nutritional value such as meat, milk, and by-products [13–15]. They also provide fertilizer from the faecal and undigested residues. The aim in the feeding of ruminants thus should be to feed as much forage as possible that could satisfy most of the nutrient requirements of the animal. The quantity and quality of roughage made available to the ruminant will then determine the amount and type of supplement or concentrate to be fed.

2.4.1. Feeding of young ruminants

In young stock, the rumen will not be developed and it will take a few months until the rumen is fully developed and starts functioning. Until then, the young ruminant is similar to a simple-stomached animal nutritionally. In young stock, essential amino acids should be provided in required quantity in the ration. The B-complex vitamins, vitamins A and D, and minerals should be provided usually from the milk. Colostrum should be given at days 1–3 after birth as antibodies (gamma globulins) are transferred from the dam to its young.

2.4.2. Feeding of adult ruminants

Ruminants have a forestomach composed of fermentation compartments, which contain large amounts of microorganisms (bacteria, protozoa, fungi). These break down the cellulose in fibrous plant material into a form that can be digested in the animal’s stomach and intestines. There is a symbiosis between ruminants and microorganisms, as the microorganisms need the energy and nutrients in forage for their own nutrition, and the microorganisms are finally broken down as protein source for the host ruminant. Thus, ruminants need lesser grains and concentrate diets than monogastrics such as pigs and poultry, which do not have a forestomach full of microorganisms, which act as protein source.

2.4.3. Ruminant nutrition

In ruminant nutrition, one must know the amount of energy required by an animal for a specific production function, if it is desired to obtain the most efficient utilization of a feedstuff. During food metabolism, energy in the diet is broken down from gross energy into net energy for maintenance and for production. To meet the energy requirements in ruminants, the energy value of feeds is most important but one also needs to have a balance of other nutrients such as proteins, amino acids, fats, minerals, and vitamins as shown in **Table 4**. The deficiency in any one of the nutrients may impair metabolism. To minimize the possibilities of nutritional deficiencies, various feeding systems have been formulated to assist nutritionists in selecting ration components. These systems involve (i) practical application of the basic concepts of energy systems, (ii) metabolic processes whereby energy is released from specific nutrients, and (iii) the roles played by volatile fatty acids in ruminant nutrition. It is important to know that in general, as the fiber level of ruminant rations decreases, the concentration of acetic acid in the rumen contents also decreases. The fiber fraction of feeds are usually broken down into acetic, propionic, and butyric acids, and about 60% of

- Dry matter
- Feed category/class (e.g., forages, concentrates, etc.)
- Processing factor (e.g., drying, ensiling, pellets production, urea treatment, multi-nutrients-blocks production, etc.)
- Neutral detergent fiber (NDF): 15–19% of DM of minimum forage NDF, 25–33% of DM of minimum NDF in diets
- Acid detergent fiber
- Lignin
- Nonfibrous carbohydrates (NFC): 36–44% of DM of maximum NFC* in diets
- Crude protein—rumen degradable protein (RDP), rumen undegradable protein (RUP)
- Fat
- Major minerals: Ca, P, K, Mg, Cl, Na
- Minor minerals: S, Co, Cu, I, Fe, Mn, Se, Zn
- Amino acids: methionine, lysine, arginine, histidine, isoleucine, leucine, cystine, phenylalanine, threonine, tryptophan, valine
- Vitamins: A, D, E
- Digestibility coefficients of: CP, NDF, fat, NFC
- Feed additives

*Starch as source of NFC.

Source: [17].

Table 4. Some nutrient supply input requirements and the limits of neutral detergent fiber (NDF) and nonfibrous carbohydrate (NFC) requirements in ruminant diets (%).

the digestible energy from fibrous carbohydrates is converted to volatile fatty acids (VFA) within the rumen. The conversion of carbohydrates to VFA is dependent on the microbes present in the ruminant digestive tract. The level of 8% crude protein of diets is required to provide the minimum ammonia levels required by microorganisms for optimum rumen activity [16].

2.4.3.1. Formulation of diet in ruminants

Tables of values of nutrients (CP, fat, minerals, vitamins, etc.) required by ruminants are never given because these values are calculated based on how rapidly the nutrients degrade in the rumen (rate of digestion) and how rapidly the feed passes through the rumen i.e., rate of passage [17]. The rate of digestion is related to the properties of the feed, while rate of passage increases with increasing dry matter intake (DMI), body weight of animal, etc. These values are usually not constant; however, effort is being made to calculate more approximate values. The protein requirement of ruminants can be divided into two groups: rumen degradable protein (RDP) or by pass proteins, which is degraded in the rumen by the rumen microbes e.g., groundnut cake, fish meal, soybean meal, rape seed cake, etc. [18]. These degraded proteins are then broken down into amino acids and urea. However, rapid fermentation of proteins in the rumen results largely to feed wastage (except in high milk production), since most of the ammonia by-products liberated are excreted as urea through urine. Rumen undegradable proteins (RUP) are not easily degraded by rumen microbes e.g., nonprotein nitrogen (NPN) compounds such as urea, uric acid, biuret (usually present in fermented forages) and other treated nitrogen sources, which normally escape the rumen fermentation. Shown in **Table 4** are some nutrient supply input requirements and the limits of neutral detergent fiber (NDF) and nonfibrous carbohydrates (NFC) requirements in ruminant diets.

3. Livestock feed availability and nutrition

Livestock nutrition can be categorized into diets for nonruminants (monogastrics) and ruminants. Most nonruminants are omnivorous, having simple digestive system commonly with nonfunctional caecum. However, the digestive system in ruminants has the four roughage diet digestion chambers, rumen, reticulum, omasum, and abomasum.

3.1. Commonly used conventional and alternative feedstuffs and/or agroindustrial by-products

Energy sources normally constitute the highest proportion (about 50–60%) of livestock diets, followed by plant protein sources (about (10–20%), next is the fiber and animal protein sources (10–15%), and the lowest rates of inclusions usually occur in the minerals and additives as feed ingredients. Globally, maize (corn) is the most commonly used energy source, and soybean meal or cake is a common plant protein source, while fishmeal is the major animal protein ingredient used in livestock rations. These three feed ingredients are known to be the conventional livestock feed ingredients, and they usually constitute a part of livestock concentrate feeds. They have been facing market competition with human food demands, especially in the developing countries, and this trend has been tagged as "feed-food competition" [19]. To cope

Conventional feedstuffs	Alternative feedstuffs	Range of inclusion rates (% of DM)
Energy source		
Maize, vegetable oils	Sorghum, cassava root meal or peel meal, yam peels, potato root meal or peel meal, palm oil slurry, sesame seed meal, forage plants	50–60
Fiber sources		
Wheat bran, maize bran	Rice bran/husk, maize husk	10–15
Plant protein sources		
Soybean meal, groundnut cake, Palm kernel cake	*Palm kernel cake, cotton seed cake, pigeon pea meal, cowpea vines, groundnut haulms, soybean haulms, potato vines	10–20
Animal protein sources		
Fish meal, blood meal	*Blood meal, poultry offal meal, hydrolyzed feather meal, dried poultry manure meal, snail meat meal, insect fly, pupal and larval meals, earthworms, crystalline amino acid sources	5–10
Mineral sources		
Oyster shells	Periwinkle shells	2–5
Bone meal	Limestone	2–3
Dicalcium phosphate	Malt dust	1–2
Feed additives		
Vitamin premix		1
Common salt		0.25–0.50
Others (probiotics, prebiotics		0.25–0.50

*Serves as both conventional and alternative feedstuff.

Table 5. Conventional and the alternative feedstuffs commonly used in nonruminant and ruminant concentrate diet formulations.

Ingredients (%)	DM	CP	EE	CF	NFE	Ash	Source
Wheat bran	88.0	14–19	6.5	10.6–16.0	59.5	4.0	[10, 20]
Maize bran	93.0	10–15	4.4	11.6	70.8	3.2	[10]
Rice bran	91.0	12–13	2.4–3.4	12.3	63.0	0.9	[20]
Maize	87.0	9.9	4.4	2–3	70.0	4.5	[21]
Cassava root meal	88.3	1.5–3.5	3.4	3.7	91.0	1.1	[20]
Cassava peel meal	33.5	6.5	1.3	16.6	68.5	5.9	[22]

Ingredients (%)	DM	CP	EE	CF	NFE	Ash	Source
Groundnut cake	90.0	45.3	11.0	5.0	27.5	1.2	[20]
Palm kernel cake	94.0	14–21	5–17	13–23	48.0	3–12	[23, 24]
Cotton seed cake	86–93	26–36	6.7	7.1	44.5	5.8	[10, 20]
Fish meal	95.0	35.0	8.6	17.6	45.0	9.1	[20]
Blood meal	89.5	76–80	1.2	1.5	47.1	1.3	[20]
Poultry manure	92.6	16.8	2.5	10.0	50.2	13.1	[25, 26]
Snail	86–91	65–67	7.9	3.06	17.2	7.8	[27]
House fly larva	nd	60.0	20.0	nd	nd	nd	[26, 28]
Leaf-meal (duck weed)	92.3	24.8	5.7	12.1	54.5	2.0	[20]

nd, not determined.

Table 6. Proximate analysis of some commonly used livestock feed ingredients.

with the feed-food competition, it has been necessary to explore the use of locally available, cheaper alternative feedstuffs for use in livestock feed formulations. A wide range of alternative feedstuffs are being used in livestock feeding globally, and these could be categorized into alternative energy, fiber, plant protein, animal protein sources, and feed additives as shown in **Table 5**. **Table 6** presents the proximate analysis of some commonly used livestock feed ingredients.

4. Formulation of least cost rations

The aim in formulating least cost rations, particularly on large commercial farms, is to undertake a precision feeding in order to lower cost and to maximize economic efficiency. In the past, there was a great tendency to over formulate diets when the exact requirements, especially for critical nutrients such as amino acids and phosphorus for monogastrics, were uncertain. This practice is currently known to be wasteful and also lead to the excretion of excess nutrients in manure, ultimately serving as source of environmental pollution [29].

After defining the nutritional needs of a group of livestock, next step would be to match these needs with the use of combination of ingredients and supplements to arrive in a balanced diet that provides appropriate quantities of biologically available nutrients, particularly for nonruminants. Thus, given the range of possible feedstuffs' proximate composition (as shown in **Table 6**), and the targeted dietary nutrient levels expected, a lot of calculations are then carried out to arrive at least-cost diets. However, over the years, feed formulation has evolved from a simple balancing of a few feedstuffs for a limited number of nutrients to a linear programming system that operates with the use of computers [29].

	Application	Examples	Functions
1.	Microbial proteins	Single-cell protein, multicellular (yeast protein)	To serve as new feed sources in the form of microbial proteins for livestock feeding
2.	Genetically engineered forage crops	Low phytate maize, high-oil maize	Reduce the levels of antinutrients in forages and other feedstuffs. Enhance nutrition
3.	Feed additives		
(a)	Crystalline amino acids	Methionine, lysine, threonine, tryptophan	Play vital role in improving protein utilization
(b)	Antioxidants	Butylated hydroxy toluene (BHT), butylated hydroxyl anisole (BHA), ethoxyquin	To prevent auto-oxidation of fats and oils in the diet
(c)	Antifungals	Aflatoxin	To control mold (e.g., *Aspergillus flavus*, *A. parasiticus*) growth in feed, to bind and reduce the negative effects of mycotoxins
(d)	Antibiotics	Avilamycin, virginiamycin, zinc bacitracin, avoparcin, tylosin, spiramycin	To control gram-positive, harmful bacterial species in the gut, improve production efficiency, used as a prophylactic measure against necrotic enteritis
(e)	Antibiotic replacers		
(i)	Probiotics	In-feed microbials	Source of beneficial microbial species such as *Lactobacilli* species and *Streptococci* species
(ii)	Prebiotics	Oligosaccharides	Renders harmful bacteria inactive

NB: The use of avoparcin, zinc bacitracin, spiramycin, virginiamycin, and tylosin phosphate as animal feed additives was banned in the European Union in 1998 and in 2006. The US, starting January, 2017, enforced a ban on the use of antimicrobials (antibiotics and antifungals) to promote food animal growth. Sources: [29, 32].

Table 7. Biotechnological and allied applications that are employed in livestock nutrition.

5. Some biotechnological and allied applications employed in livestock nutrition

Modern biotechnology has the potential to provide new methods for achieving enhanced livestock productivity in ways that could alleviate poverty, promote food security and nutrition, and also promote sustainable use of natural resources [4]. The applications of biotechnology in animal nutrition were reported [29] and are as summarized in **Table 7**. The author mentioned that there could be the formation of new ingredients such as single-cell protein and yeast protein, and the aim is to manufacture microbial proteins as new feed sources for animal feeding. These could also be included in the ration of livestock in order to upgrade the crude protein content of the ration.

Secondly, as outlined in **Table 7**, there could be the application of designer ingredients that could be applied in designing genetically engineered plants and forage crops, which are genetically modified using recombinant DNA technology with the objective of introducing or enhancing a desirable characteristic in the plant or seed used. This author [4] explained that transgenic forage crops are aimed at bringing about some benefits to consumers. Thus, when transgenic forage crops are first fed to ruminants, then the animal products to be consumed by humans from these ruminants are not themselves transgenic. This implies that food products derived from animals fed with transgenic forage crops are safer than when directly modified crops are consumed by humans. Also, in another research [30], it was demonstrated that the inclusion of genetically modified corn silage in dairy cows diets did not affect feed intake or milk production. The corn silage diet fed to the dairy cows was engineered with substantial improvements in their nutrient (proteins, amino acids, oils, fatty acids, starches, sugars, fiber, vitamins, minerals, enzymes) contents. The feed intake or milk production was not negatively affected, and there was absence of transgenic DNA in the milk harvested from these experimental cows. Thus, designer ingredients or plants (e.g., high oil maize) with genetic modification are made to enhance nutrition. There could also be designer ingredients (e.g., low-phytate maize) or forage crops engineered to reduce the level of antinutritive compounds, which occur in livestock feed ingredients. A researcher [5] reported that feeds derived from genetically modified (GM) plants (a quarter of which are now grown in developing countries), such as grain, silage, and hay, have contributed to an increase in livestock growth rates and milk yield. Also, genetically modified crops with improved amino acid profiles can be used to decrease nitrogen excretion in pigs and poultry. The author [5] explained that increasing the levels of amino acids in grains means that the essential amino acid requirements of pigs and poultry can be met by diets that are lower in protein content.

Other biotechnological applications of different classes of feed additives outlined in **Table 7** are the use of crystalline amino acids, antioxidants, antifungals, antibiotics, and different classes of antibiotic replacers. Feed additives may be added to the diet to enhance the effectiveness of nutrients, and they also exert their effects in the gut or on the gut cell walls of the animal [31]. They are used for the purpose of promoting animal growth through their effect in increasing feed quality and palatability. Besides, they are mixed with the feed in nontherapeutic quantities and thus protecting the animal against all sorts of harmful environmental stresses. Low levels of additives in animal feed may contribute to increased production of animal protein for human consumption and thereby decrease the cost of animal product. The use of avoparcin, zinc bacitracin, spiramycin, virginiamycin, and tylosin phosphate as animal feed additives was banned in the European Union in 1998 and in 2006 [29]. The US, starting January, 2017, also enforced a ban on the use of antimicrobials (antibiotics and antifungals) to promote food animal growth [32]. Envisaging a total ban on in-feed antibiotic use, a multitude of compounds (individually and in combinations) are being tested to serve as alternatives [29].

Probiotics are defined as feed supplements that are added to the diet of farm animals to improve intestinal microbial balance [33]. Thus, in contrast to the use of antibiotics as nutritional modifiers, which destroy bacteria, the inclusion of probiotics in feeds is designed to encourage certain strains of bacteria in the gut at the expense of less desirable gut microorganisms [4]. This researcher [4] also mentioned that probiotics could produce vitamins of the B complex and digestive enzymes, and the stimulation of intestinal mucosa immunity, by increasing protection against toxins produced by pathogenic microorganisms. Thus in ruminants, probiotics are effective in controlling the diseases of the gastrointestinal tract of young animals. It was found that in adult ruminants, yeasts could be used as probiotics to improve rumen fermentation [33]. The use of these feed additives may help to make animal products to be more homogenous and of better quality.

6. Practical application of biotechnology in monogastrics (poultry, pigs, and fish) and ruminants (cattle, sheep, and goats)

Biotechnology is offering a lot of opportunities for increasing agricultural productivity and for protecting the environment through the reduced use of agrochemicals [34]. Techniques of modern biology such as genetic manipulation of rumen microbes, and chemical and biological treatment of low-quality animal feeds for improved nutritive value among others have become a reality in the past few decades and are finding their ways into present research and development programs. These go along side with fleeting coverage of issues concerning the potential environmental hazards of genetic engineering and other biotechnologies, and the need for their ethical evaluation and for an international regulatory mechanism [34]. Practical application of biotechnology in monogastrics (poultry, pigs, and fish) and in ruminants (cattle, sheep, and goats) is hereby discussed below.

6.1. Practical application of biotechnology in poultry feeding

Nonnutritive feed additives such as the enzymes xylanases, β-glucanases, and phytates are used to overcome antinutritional effects in some grains and to improve overall nutrient availability and feed value. Antioxidants such as butylated hydroxyl toluene (BHT), butylated hydroxyl anisole (BHA), and ethoxyquin are used in poultry feeds to prevent auto-oxidation of fats and oils in poultry diets. Antifungals such as aflatoxins are added to poultry feed ingredients such as grains, groundnut cake, and cottonseed cake to control fungi growth in feed and to bind and reduce the negative effects of mycotoxins. Probiotics are used in poultry to encourage the growth of certain strains of bacteria in the gut at the expense of other less desirable microorganisms. Prebiotics (oligosaccharides) may function to bind harmful bacteria in the digestive system of poultry. In laying hens and broilers, research findings [35] showed that feeding recombinant DNA-produced crops and newly expressed proteins in genetically modified plants did not show chemical and physical properties different from those fed with native plants.

6.2. Practical application of biotechnology in pig feeding

In a research review article [36], it was reported that the quest to widen the narrow range of feed ingredients available to pig producers has prompted research on the use of low cost, unconventional feedstuffs, which are typically fibrous and abundant. Maize cob, a by-product of a major cereal grown worldwide, has potential to be used as a pig feed ingredient. Maize cob is usually either dumped or burnt for fuel. However, the major hindrance in the use of maize cobs in pig diets is their lignocellulosic nature (45–55% cellulose, 25–35% hemicellulose, and 20–30% lignin), which is not easily digestible by pigs' digestive enzymes. These researchers [36] explained that the high fiber in maize cobs (930 g neutral detergent fiber/kg DM; 573 g acid detergent fiber/kg DM) increases the rate of passage and sequestration of nutrients in the fiber, thereby reducing their digestion. The application of simple techniques such as grinding, heat treatment such as sun-drying, and fermentation can modify the structure of the fibrous components in the maize cobs and improve their utilization. Pigs could extract up to 25% of energy maintenance requirements from fermentation products. Also, dietary fiber improves pig intestinal health by promoting the growth of lactic acid bacteria, which suppress proliferation of pathogenic bacteria in the intestines.

In another journal article [37], it was reported that in growing pigs, the effects of four dietary levels of microbial phytase (Natuphos) enzyme on the apparent and true digestibility of Ca, P, CP, and AA in dehulled soybean meal were assessed. In the study, the researchers observed that supplemental microbial phytase did not improve the utilization of amino acid provided by soybean meal but was an effective means of improving calcium and phosphorus utilization by the growing swine fed soybean meal-based diets.

It was observed that in pigs, feeding recombinant DNA produced crops and newly expressed proteins in genetically modified (GM) plants showed no biologically relevant effects on feed intake, digestibility, or animal health [35]. Also, there were no unintended effects on the performance and fertility of animals. The food products obtained from the pigs fed with GM plants were of good chemical composition and quality.

6.3. Practical application of biotechnology in fish feeding

In a journal review article [38], it was reported that the use of probiotics in feed for fish and its inclusion in intensive aquaculture to promote healthy gut is growing. These researchers stated the need for alternative measures that will perform closely and effectively to the use of antibiotics after it was banned in the European Union (EU) in 2006. They stated that several definitions of probiotics mainly for aquaculture were considered. Among them is the definition that probiotics is described as “any microbial cell provided via the diet or rearing water that benefits the host fish, fish farmer, and fish consumer, which is achieved, in part at least, by improving the microbial balance of the fish.” The authors regarded the direct benefits to the host fish as immunostimulants, improved disease resistance, reduced stress response, and improved gastrointestinal morphology. The benefits to the fish farmers and consumers include improved fish appetite, growth performance, feed utilization, improvement of carcass quality, flesh quality, and reduced malformations. It was explained that combining probiotics with prebiotics could improve the survival of the bacteria and enhance their effects in the large intestine [38]. Thus, probiotic and prebiotic effects might be additive or even synergistic (prebiotic is a nondigestible carbohydrate that helps to render harmful bacteria inactive).

6.4. Practical application of biotechnology in ruminant feeding

Globally, food-producing animals consume 70–90% of genetically engineered (GE) crop biomass. Furthermore, many experimental studies have revealed that the performance and health of GE-fed animals are comparable with those fed isogenic non-GE crop lines [39].

In a mini review article [40], it was reported that probiotic live cells with different beneficial characteristics have been extensively studied and explored commercially in many different products in the world. Their benefits to young ruminants have been supported in several scientific articles. These benefits include enhanced development of the rumen microflora, improved digestion, and nitrogen flow toward lower digestive tract and improved meat and milk production during the adult stage of the ruminant. The author reported that in order to attain higher profit margin in intensive small ruminant production, farmers are now shifting from traditional to high input feeding systems. He explained that in order to harvest real benefits from small ruminants, which are raised on nutrient-rich diets, feed additives like probiotics are needed to be used to enhance the efficiencies of nutrient utilization in growing ruminants. Thus, the more feed an animal consumes each day, the greater would be the opportunity for increasing its daily production. Probiotic supplementation was found to increase feed intake and to influence performance of ruminants [40]. Also, the use of probiotics in a healthy animal stimulated nonspecific immune response and enhanced the system of immune protection. The probiotic that enhanced immunoglobulin level may have more positive effect on growth performance, production, and ability to resist diseases. Examples of probiotics suggested were those containing *Lactobacillus plantarum* (which breakdown carbohydrates into glucose) and *Aspergillus oryzae* (which produce enzymes that are involved in the digestion of carbohydrates and fiber) [40]. Some other researchers [41] observed that the addition of probiotic containing yeast in supplemental diet enhanced growth performance and immune response of Zandi lambs. Another study was conducted that involved a 765-day trial [42]. This trial included two lactations, using nine primiparous, and nine multiparous dairy cows. The experimental cows were fed diets containing whole crop silage, kernels, and whole crop cobs from GE corn and its isogenic non-GE counterpart. There were no significant differences in the gene expression profiles of the cows fed either the transgenic or the near-isogenic rations [42]. Similarly, dairy cows, beef cattle, and other ruminants were fed recombinant DNA-produced crops and newly expressed proteins in genetically modified plants (GMP) [35]. There were no unintended effects in composition and contamination of genetically modified plants compared with isogenic counterparts. Rather, there were lower mycotoxin concentrations in GMP with *Bacillus thuringiensis* (Bt) [35].

6.5. The European Union requirements for the assessment of probiotics or microbial feed additive usage

The following guidelines of usage should be followed: the identity of the product (proposed proprietary name) should be stated. There should be characterization of the active agents (nomenclature, biological origin, genetic modification, compliance with released directive for genetically modified organisms (GMOs), toxin production, virulence factors, antibiotic production and antibiotic resistance, and other relevant properties). Then, the conditions for the usage of the microbial feed additive should be given [43].

Safety guidelines under the conditions for use: there should be performed a detailed safety assessment.

Studies on target species: studies should be carried out on target species or animals of different categories to determine the safety margin for each species. The aim of this trial is to evaluate for the target animal the risk of an accidental overdosing that could originate during feed production (mixing heterogeneity). This trial shall be conducted at a dosage being at least

10-fold the maximum recommended dosage. Studies on the effect of the microbial additive on the microflora of the digestive tract are also required when claim is made concerning an effect on the intestinal microflora.

Consumer safety assessment: certain toxicological tests are required to be performed to exclude the possibility that when the probiotic product or microbial additive is accumulated in the target animal, it will not form a consumer risk. The test includes both genotoxicity studies (a metaphase cytogenetic assay and other *in vivo* and *in vitro* studies) and oral toxicity test (a 90-day in-feed or drinking water).

7. The application of nanotechnology in livestock nutrition and feeding

Nanotechnology is described as the study of materials at the nanoscale, with at least one dimension generally ranging between 1 and 100 nm (10^{-9} to 10^{-7} m) [7]. Nanomaterials are best referred to as particles. There are three basic systems of nanoparticles in their applications; that is, nanoparticles can serve as a whole functional unit, or as a delivery vehicle for materials conjugated to their surface, or as encapsulated within. The application of nanotechnology in animal production is new as production in livestock industry has been centered on the use of antibiotics as growth promoters [7]. However, there has been much anxiety globally over microbial antibiotic resistance, and laws and regulations are being updated to ban in-feed antibiotic use in the livestock production industry. This has thus set in motion the search for alternatives for animal growth promoters and antimicrobials for inclusion in animal diets. Nanoparticles may present a feasible alternative to antibiotics and may help bar pathogens from entering animal production sites. Metal nanoparticles with net positive charges are drawn to negatively charged bacterial membranes, resulting in leakage and bacterial lysis [44]. There has been the discovery of the use of nanoparticles for nutrient delivery into livestock feeds. Copper is regularly added to feeds for its ability to promote animal growth and performance in addition to its antimicrobial properties [45]. In another research [46], it was demonstrated that nanoform copper could better improve piglet energy and crude fat digestion through the augmentation of lipase and phospholipase A activity in the small intestine compared to a basal diet supplemented with copper sulfate ($CuSo_4$). However, further investigations need to be done to ascertain whether antibiotics in feed can be completely replaced by nano-antimicrobials. Also, despite the expansion of antibiotic resistance in bacteria, antibiotics have not yet been rendered totally ineffective. However, their delivery and efficacy may be enhanced by nanoparticle carriers, and thus substantially decreasing the dosage of antibiotics required for treatment. Thus, it was stated that the inclusion of nutrient supplements in livestock feed, regardless of particle size, may benefit the producer if there is still consumer demand for the final product [7]. These authors [7] further explained that if for example, meat and eggs obtained from an animal fed nanoparticle supplements are enhanced and are indiscernible from the original product, then they are likely to still be favorable to consumers. These researchers mentioned that it is, however, important to understand the role of the nanoparticle as an additive in a given biological system and the by-products from that system and to ensure that it is safe for consumption before its application in livestock production.

7.1. Future prospects

As nanotechnology continues to develop and gain more attention, its application would grow wider in the livestock industry [7]. Thus, nanoparticles may have to be used alongside the use of antibiotics until it gains more understanding and global acceptance.

8. Conclusion

In conclusion, continuous provision of adequate quantity and quality of nutritious feeds for livestock is necessary to sustain the livestock industry. This is not negotiable now that human population is growing exponentially in the twenty-first century. The adoption of new biotechnological applications and biosafety in livestock nutrition and feeding systems is necessary in order to promote improvements in current and future global livestock production. The main cost of livestock production is on the production of concentrate feeds. Alternative feed resources should be properly utilized, and low nutrient quality feeds should be improved upon by the use of various technologies, for better utilization by livestock. There could be the optimizing of production of high-quality forages such as genetically engineered forages with high nutrient contents and genetically manipulated for more digestible cell wall components. Generally, focus could be directed at meeting the nutritional requirements of livestock through biotechnological applications. In the developing countries, particularly during the dry season when forage is scarce, there could be the substitution of forage with nutrient detergent fiber (NDF-)rich feeds and feedstuffs. These may include crop residues, agroindustrial by-products and other feedstuffs that are of little or no value in human feeding. There could be the development of carefully balanced partial or total mixed rations.

Meeting the nutritional need and varied dietary preferences of the growing global population is also needed. This could be addressed through continuous development of better quality feeds for quality livestock products and by-products. The adoption of new biotechnological applications and bio-safety in livestock nutrition and feeding systems is necessary in order to promote improvements in current and future global livestock production. There should be the development and use of biologically safe animal feeds for the production of economically viable and safe animal products. Therefore, the production of feed ingredients that would be affordable for livestock producers with minimum use of chemical additives and use of locally available feed resources is paramount.

Future improvements in livestock feed resources could be based on the application of biotechnology such as use of safe antibiotic replacers. Probiotics and prebiotics could be employed to improve animal performance. The risks that may be involved in the use of antibiotics and the development of antibiotic resistance in livestock and in humans should be kept at minimum levels. These could be checked through continuous enforcement of guidelines in the use of feed additives and microbials. Further expectations about the future improvement in livestock feeding could involve the application of nanoparticles in livestock feeds and feeding to enhance animal nutrition, growth, and performance. The biosafety of the use of nanotechnology, however, needs to be ascertained. Possible risk control in the application of microbials and nanotechnology could include continuous monitoring and control of biological and environmental safety, in terms of guarding against the re-emergence of livestock and human diseases and antibiotic resistance through the livestock feed industry.

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Chapter 8

Respirometry and Ruminant Nutrition

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Abstract

The gaseous exchange between an organism and the environment is measured by respirometry or indirect calorimetry. Once the oxygen consumption (O_2) and the production of carbon dioxide (CO_2) and methane (CH_4) are known, the energy losses by gas and heat can be calculated. Energy metabolism and methane production have been studied in the Calorimetry and Metabolism Laboratory of the Federal University of Minas Gerais, located in Belo Horizonte, Minas Gerais, Brazil. Animals used are mainly Zebu cattle and their crossbreeds that represent most beef and dairy cattle breed grazed on tropical pastures. System calibration and routine work are addressed in this text. The results obtained on respirometric chambers are expressed in net energy (NE), which can be net energy for maintenance (NE_m), lactation (NE_L), weight gain (NE_g), and pregnancy (NE_p). NE is, in fact, what is used by the animal for maintenance and each productive function. The values of k (conversion efficiency of ME into NE) for maintenance (k_m), milk (k_L), weight gain or growth (k_g), and pregnancy (k_p) are determined. Thanks to the peculiarity of the respirometric technique, the same animal can be evaluated several times, in different physiological states and planes of nutrition.

Keywords: bovine, calorimetry, energy metabolism, gases, nutrient requirements

1. Introduction

Calorimetry is the process of measuring heat production in the body; it can be direct or indirect. In the first case, produced heat is measured by increasing ambient temperatures. Indirect calorimetry measures heat produced by the animal through the quantification of metabolism products, for example, the gas exchanges with the environment [2].

The Animal Metabolism and Calorimetry Laboratory (LAMACA), located at the Veterinary School of Federal University of Minas Gerais, Belo Horizonte, Minas Gerais, Brazil, is a pioneer in the construction of respirometric chambers in Latin America (**Figure 1**). The first experiment started in 2006 with small ruminants and since 2008, this kind of research has been carried out to evaluate the energy metabolism and the production of methane by cattle. The results obtained are expressed in net energy (NE), which can be net energy for maintenance (NE_m), net energy for milk production (NEL), net energy for weight gain (NE_g), and net energy for gestation (NEp). We can determine what was truly used by the animal in described productive functions. Conversion factors of total digestible nutrients (TDN) for digestible energy (DE) and metabolizable energy (ME) are calculated and the latter for each physiological function or NE. The *k* values are determined (conversion efficiency of ME in NE) for maintenance (k_m), milk yield (k_L), weight gain or growth (k_g) and gestation (k_p).

In this chapter, basic concepts of indirect calorimetry or respirometry are presented; some notes about the use of this methodology in the research into metabolism and nutrition of cattle in the laboratory are also included.

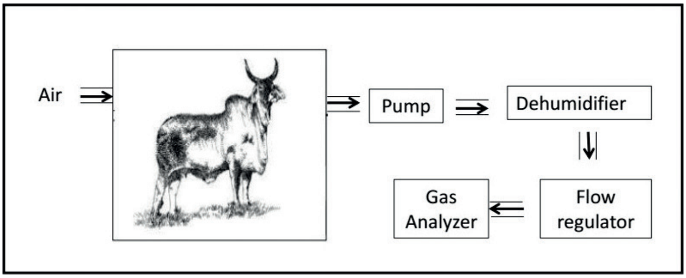

Figure 1. Respirometric chamber's design at LAMACA.

2. Calorimetry: concepts and basic principals

Several researches throughout history have energy as the focus of their study. In one of the first works, Leonardo Da Vinci, in his publication "Codex Atlanticus" postulated that where flame does not live no animal that breathes cannot live. Subsequently, Robert Boyle (1627–1691) concluded that both combustion and life necessitated a substance present in the air. The same observation relating "fire x life" was made by his contemporary, the scientist John Mayow (1643–1691), who built the first semi-quantitative "respirometer" and observed that by placing a candle and a mouse under a single flask, soon after the candle flame went out, the animal died. In the next century, John Priestly (1733–1804) found evidence of the diversity of gases that compose atmospheric air (such as carbon dioxide and nitrogen) and observed that different chemical reactions could produce gases capable of sustaining life [3].Although such researchers have contributed brilliantly to the understanding of bioenergetics, the scientist Antonie Lavoisier (1743–1794) deserves special attention for the great importance of his discoveries. He discovered the existence and importance of the gas he named "*oxigène*" (oxygen). For Lavoisier, breathing was defined as a slow combustion process. His studies led to the creation of indirect calorimetry (which allows the evaluation of metabolic rates through oxygen consumption, changes according to exercise and diet), as well as direct calorimetry: when a mouse is surrounded by ice, heat production of the animal can be evaluated by the formation of water in the liquid state [4].

A fundamental advance in calorimetry development was the postulation of the first law of thermodynamics by the German Julius Robert von Mayer (1814–1878) in 1842, based on observations made by the Swiss chemist Germain Henry Hess (1802–1850). The first law, known as the "mass preservation law," tells us that energy can be transferred or transformed, but it cannot be destroyed or created. Later, in his work on the equivalence between work and heat, James Prescott Joule (1818–1889) eventually corroborated the concept proposed by Mayer in relation to energy conservation [5].

Still, in the nineteenth century, Berthelot (1827–1907) developed the adiabatic calorimetric pump. Its creation obeyed the principle of thermodynamics that energy is only transferred; therefore, the energy released in heat form during the combustion of an organic substance would be equivalent to the available gross energy in case of a food or loss by the organism, in case of excreta.

The development of bioenergetics concepts exploring the interrelationship between gas exchange and heat production had a significant advance with the work of Carl Von Voit, who used an open circuit respirometry apparatus developed by Max Von Pettenkofer (1818–1901). Other researchers (all Von Voit students) such as Henry Armsby, Wilbur Atwater, Oskar Kellner, and Max Rubner, using similar equipment, have developed work on energy metabolism [5].

Kellner and Köhler (1900), cited by [6], developed the "starch equivalent" concept, using a system based on foods net energy, in which foods energy value presented a relation to starch energy content, which has been used for many years in Europe and Russia, also serving as the basis for the development of later feeding systems. At the same time, Atwater and Bryant developed the physiological fuel values system to determine the metabolizable energy values of carbohydrates, fats and proteins—this energy value is corrected for the energy value of the excreted urea. Armsby (1903, 1907), also using respirometric calorimetry, developed the concept of net energy and defined the metabolizable energy (ME) as the net energy (or retained energy, RE) plus the food heat increment (HI) (ME = RE + HI).

It is noteworthy that the system proposed by Armsby at the beginning of the twentieth contains many of the principles used for the development of current net energy systems, such as [7, 6].

Another important advance in modern calorimetry, however, would only occur in 1965, with the publication of Brouwer's equation [8]. The equation (Eq. 1) allowed the calculation of the heat production.

Heat production

$$HP = (3.866 \times O_2) + (1.2 \times CO_2) - (0.518 \times CH_4) - (1.431 \times N) \quad (1)$$

where HP is the heat production; O_2 is the O_2 volume, L; CO_2 is the CO_2 volume, L; CH_4 is the CH_4 volume, L; N is the urinary nitrogen.

The food, feces, and urine crude energy are determined by caloric pump. Brouwer's equation allows the calculation of heat production by an animal, after evaluation of produced gases over time. A range of possibilities open up in the study of energy metabolism of animals, including food assessment and determination of nutrient requirements.

3. Open circuit respirometry system

LAMACA's respirometric chambers operate in open circuit system (**Figure 2**). The animal is housed in a chamber with a sealing that does not allow any gas exchange with the outside air, except by a proper air circulation system. Air tubing is coupled to a pump, which performs the renewal of air inside the chamber in a constant flow during the measurement, regulated by a mass flow meter, which corrects the airflow as a function of temperature, pressure, and humidity. According to [8], the flow control system represents a major limitation of this method, since the accuracy of this measurement is indispensable for the proper functioning of the system.

The air inside the chamber is continuously renewed by the constant input of external air. The input of fresh air into the chamber is possible due to the negative pressure created by the pump that promotes the suction of the internal air, thus allowing the entrance of external air. There is a renewal of the inside air that can be used for sampling and later evaluation by the gas analyzers. The internal negative pressure guarantees safety in the data acquisition because it prevents leakage of the air, which could constitute a source of errors in the analysis of the sampled gas.

Figure 2. Respirometric chambers for large animal (left) and small animal (right), presented by its designer, professor Norberto Mário Rodriguez.

Air temperature and circulation inside the chamber are controlled. Air renewal is regulated by a mass flowmeter (model SABLE Flow-kit 500H). The flow rate is between 0.5 and 1 L/kg body weight/minute. The air leaving the chamber is piped to an outside area, and samples are pumped to gas analyzers. These are in the bypass system, that is, all are interconnected, allowing the passage of a single sample through all the analyzers. The gas analyzers used in this experiment come from the company SABLE SYSTEMS®, with the following models being used: TA-1B O_2 analyzer, CA-2A CO_2 analyzer, and MA-1 CH_4 analyzer.

Gas reading in the analyzers occurs in 5 min cycles. At the beginning of each cycle, the circuit is automatically moved by the equipment to a piping, which is connected to an outside area outside and an air sample is collected. The external air sample (atmospheric), called "baseline," circulates throughout the circuit until the gaseous material is analyzed. The system is then shifted to a closed sampling loop and the air is sampled from the chamber interior and analyzed. The baseline and the gas sample pass continuously through the system for 5 min. The data reading occurs in the last 30 s (the first 4 min 30 s were for ensuring that there were no residuals from the samples). Animal oxygen consumption, methane, and carbon dioxide production are calculated by the difference between external air concentrations and the chamber air. Due to the gaseous nature of the material, the control of temperature, pressure, and humidity of the system is very important, since these factors are responsible for changes in the volumes of each gas evaluated in relation to the temperature and pressure normal conditions. The chamber is constructed of steel and has two opposing openings, one that allows the entrance and exit of the animal (larger door, 2 m length and 2.2 m height) and one for feeding, with minimum air displacement, in the front part, with an area of 0.75 m^2 (1 m long and 0.75 m high). On the sides, there are acrylic windows, sealed, which allow the visualization of the animal and the interior of the chamber, as well as another animal, placed parallel to the chamber, in a cage. The internal volume of the camera is 22.391 L.

Due to the complexity of this system, it is necessary to determine a correction factor for the whole system [9], in order to have a correlation between reading and actual gas concentrations.

4. Daily analyzer calibration

Gas analyzer calibration shall be performed whenever the equipment is used. Gases are injected in a constant flow and known concentrations. After stabilization, the read value is an adjustment to the actual value. Pure nitrogen is used to calibrate the analyzer for zero concentration, while atmospheric air is used to calibrate the O_2, CO_2, and methane analyzers. Atmospheric air O_2 concentration is 20.946%. The CO_2 and CH_4 have a known concentration because they are diluted in nitrogen (5 and 1%, respectively). Stabilization is inversely proportional to the gas aliquot directed to the devices. LAMACA uses 0.2 L/min flow [10], which requires approximately 5 min for values stabilization.

Atmospheric air or standard gas (21% diluted O_2 in nitrogen) were evaluated to carry out the O_2 analyzer calibration. The results for methane, carbon dioxide production, and oxygen consumption, as well as the animal heat production, were compared. All tests had best results with atmospheric air; then, we chose it for all analyses, with O_2 air concentration as constant.

5. Correct factor determination

Before starting any work, a correct factor must be determined to eliminate CO_2 and O_2 concentration effect, according to [8]. To determine the correction factors, the first activity to be performed is to check the chamber's sealing conditions, ensuring that no air is exchanged with the outside, except by the pump system.

The correct factor determination and use of the large animal chamber at LAMACA is described here. In this system, the pump that performs the air renewal was later allocated to the chamber generating a slight pressure inside the chamber, so that the external environment is well ventilated.

A negative pressure will be generated inside the chamber, which can be verified using a differential column manometer. This should be connected one point to the chamber at the endpoint and the other at an outside point. After a short time of operation of the flow, a gap can be seen between the two columns, indicating a considerable resistance for the external air to enter the chamber through another path than the pipe itself for its renewal. The total displacement of the water column (WC) is given by the sum of the elevation (*E*) of this on the side connected to the chamber and the lowering (L) on the side open to the environment. Usually, in a well-planned system, this total displacement reaches 0.5 cm.

After verification of the system seal, the quantity of each injected gas is calculated. The gases used were CH_4, CO_2, and N_2, with purity higher than 99.99%. These three gases were injected simultaneously, and the injection of methane and carbon dioxide resulted in an increase in their concentration inside the chamber, simulating what happens when the animal is housed. In turn, nitrogen injection resulted in all gases dilution, such as oxygen, which was reduced inside the chamber simulating the consumption by the animal. An important point of this step is determining the injected gas flow and air renewal flow. The determination of these values considers the achieved standard value. The established value was 200 L/min. Injected flow used for each gas (CH_4, CO_2, and N_2) aim to reach 0.04, 0.50, and 20.50% to CH_4, CO_2, and O_2, respectively. Calculations are as follows:

Methane and carbon dioxide flow

$$Fi = ((Cd \times Fr) - (Ca \times Fr))/(P/100) \tag{2}$$

where Fi is the injection flow (L/min); Cd is the desired gas concentration (%); Fr is the renewed air flow used (L/min); Ca is the atmospheric air concentration (%); P is the gas purity (%).

Nitrogen flow

$$Fi = \left(\left((Ca\,O_2 \times Fr\right)/Cd\,O_2\right) - Fr\Big)/(P/100) \tag{3}$$

where Fi is the injection flow (L/min); CaO_2 is the oxygen atmospheric concentration (%); CdO_2 is the oxygen concentration desired (%); Fr is the renewed air flow used (L/min); P is the gas purity (%).

After the injection flow determination, the manometers are assembled to the cylinders that are weighted in a 0.1 g accuracy balance. After this, all the cylinders are connected to the chamber by specific piping. Each one contains a flow meter for injection flows determination. The calibration process is started. When all the analyzers are calibrated, the readings are started. Desired injection flow for each gas is reached after the first reading cycle. The used injection time is approximately 4 h. The cylinder registers are closed and temperature and pressure inside the chamber are recorded hourly, after gas injection time is completed. All cylinders are weighed again. The cylinders with water condensation should be weighed the next day. After the initial and final cylinders weighing, we know how much gas was injected (g). One mole of any gas has 22.4 liters volume in normal temperature and pressure conditions. Each injected gas volume (L) can be calculated by dividing the weight (g) of the injected values of 1.2506, 1.9647, and 0.7162, respectively, for nitrogen, carbon dioxide, and methane.

The next step is the evaluation of CO_2 concentration inside the chamber after the complete injection process. At the beginning of the injection, gas concentration will increase. At the end of the injection, gas concentration reaches maximum value. Then, the CO_2 value starts to reduce. Further values are discarded after CO_2 concentration stabilizes at minimum values. Time from the beginning of gas injection and CO_2 stabilization is considered for the correction factor calculation.

The first point for measuring injected volumes of each gas by the analyzer is the determination of the initial, final, and average concentrations of methane, carbon dioxide, and oxygen in atmospheric air and in the air leaving the chamber. The air volume present inside the humidity-free chamber and in normal conditions is determined. Dry air volume in the initial normal conditions (Vsi) and the dry air volume in final normal conditions (Vsf), according to [9], are calculated as follows:

Vsi and Vsf

$$VSi \text{ or } Vsf = (VC) \times (273/(273 + T)) \times \left((P - P_{\mathrm{H_2O}})/760\right) \tag{4}$$

where Vs is the dry air size inside the chamber at normal conditions in the beginning or by the end of measurement (L); V is the inside chamber size; T is the beginning or end temperature (°C); P is the beginning or end environment pressure (mmHg); P_{H_2O} is the beginning or end partial pressure (mmHg); the correction factor for methane and CO_2 was calculated according to Eq. (4).

CH_4 and CO_2 correct factor.

$$F = \left(V_{inj}\right)/[(Cs \times Vt/100) - \{(Ce/100) \times [Vt - \left(V_{\mathrm{CH}_{4i}} + V_{\mathrm{CO}_{2i}} + V_{\mathrm{N}_{2i}}\right)]\} + \{[Cf \times Vsf/100] - [Ci \times Vsi/100]\}] \tag{5}$$

where F is the correct factor for CH_4 or CO_2; V_{inj} is the injected gas size (L); Cs is the average gas concentration in air leaving the chamber (%); Vt is the total size in air through in the system (flow L × minutes); Ce is the gas average concentration at atmospheric air that is entering the chamber (%); $V_{CH_{4i}}$ is the injected CH_4 (L); $V_{CO_{2i}}$ is the injected CO_2 (L); $V_{N_{2i}}$ is the injected N_2 (L); Cf is the gas final concentration at last reading (%); Vsf is the gas final size inside chamber corrected for normal conditions (L); Ci is the gas initial concentration at first reading (%); Vsi is the initial air size in chamber corrected for normal conditions (L).

Then, the calculations are performed to determine the correction factor for oxygen. The oxygen correction factor is a function of the carbon dioxide concentration ($FO_2 \times CO_2$). In the analysis systems used—paramagnetic sensor for oxygen and infrared for methane and carbon dioxide—there is interference of the concentration of CO_2 in the reading of O_2 concentration (Eq. 6). A gas mixture containing known CO_2, O_2, and N_2 concentrations has its concentrations measured several times in normal conditions and with the use of the CO_2 absorber, located before the analyzers. Several repetitions are observed with the CO_2 concentrations, so the effect of CO_2 (present or not) on O_2 concentration (with and without the use of absorber) can be known.

O_2 and CO_2 correction factor

$$FO_2 \times CO_2 = (CO_2 ab - CO_2 sab)/C_{CO_2} \tag{6}$$

where $FO_2 \times CO_2$ is the O_2 correction factor in function of CO_2; $CO_{2\,\mathrm{ab}}$ is the O_2 concentration with absorber (%); $CO_{2\,\mathrm{sab}}$ is the O_2 concentration without absorber (%); C_{CO_2} is the CO_2 concentration utilized (%).

Eq. 7 determines the correct factor for oxygen.

$$\begin{aligned} F = {} & \big((Ca/100) \times Vt - \big(V_{CH_{4i}} + VCO_2\, O_2\, i + V_{N_{2i}}\big)\big)\Big) - \big(\big(\big(Cf + \big(FO_2 \\ & \times CO_2 \times CfCO_2\big)\big) \times Vsf\big)/100 - \big(\big(Ci + \big(FO_2 \times CO_2 \times CiCO_2\big)\big) \times Vsi\big)/100\Big) \end{aligned} \tag{7}$$

where F is the O_2 correction factor; Ca is the O_2 average concentration at atmospheric air coming inside the chamber (%); Vt is the air total size through the system (flow, L × min); $V_{CH_{4i}}$ is the CH_4 (L) injected; V_{CO2i} is the CO_2 (L) injected; $V_{N_{2i}}$ is the N_2 (L) injected; Cf is the O_2 final concentration, at last reading (%); $FO_2 \times CO_2$ is the O_2 concentration correct factor in function of CO_2; $CfCO_2$ is the CO_2 final concentration, at last reading (%); Vsf is the chamber air size correction for normal conditions (L); Ci is the O_2 initial concentration, at first reading (%); $CiCO_2$ is the CO_2 initial concentration, at first reading (%); Vsi is the chamber air initial size correction for normal conditions (L).

6. Animal adaptation and taming

After system calibration, measures can begin. Small ruminant respirometric chambers methodology in LAMACA was published by [9]. Working with bovines, the system calibration process is hard since the chamber is big and so air circulation is complicated. Besides this, the species peculiarities have showed us that the adaption period must be longer, until the animal appears so calm that its behavior is similar inside and outside of the chamber. Since 2008, when investigations with bovines began on this lab, procedures have been adopted in order to get a similar inside and outside chamber dry matter intake, under normal conditions. This work is based on animal welfare assurance, with animal behavioral assessments and

Figure 3. Animals used in experiments during rational taming (source: Personal archive).

monitoring of blood parameters that may indicate if something is wrong. Zebu and their crossbreeds—the focus of our research line—are more temperamental than taurine animals. Sometimes, they get angry and they always stay alert to external movements and sounds. The training we adopt is based on the principles of rational taming [10]. All animals are gradually presented to the experimental conditions that they will be subjected to. isolation, pain, sudden noise or fear situations make them stressed and should be avoided. Observation is done on each individual animal, and daily behavior is assessed as experimentation methodologies are introduced. Daily baths and brushings are used; and there is daily contact with undergraduate and graduate students, teachers and employees (**Figure 3**), always with a lot of care and patience. The basic principles are respect and communication in a language that the animal can understand. Fear, intimidation, or pain is never used. Nelore, Guzerá, Gyr and F1 – Holstein × Gyr animals were very afraid at the beginning of the work, but when they were presented to daily management, facilities and devices, they became calm and quiet.

7. Experimental routine

An apparent digestibility assay is performed immediately before every measurement in the respirometry chamber. Total stool is collected for 5 days and urine for 24 h. Then, the animal is confined for 24 h in the respirometry chamber. Temperature, pressure, and humidity are constant, with an automatic air conditioning. This way, the chamber is subjected to a continuous flow of air so that the inlet points of the atmospheric air and the internal air outlet of the chamber are located on opposite sides. This results in a constant renewal of internal air, avoiding CO_2 concentration greater than 1% [11], cited by [9]. During the 24 h of measurements, analyzers (Sable brand) monitor carbon dioxide, oxygen, and methane concentrations every 5 min, alternately. Total air circulating throughout the chamber, air flow (in L/min) used, multiplied by the total measurement time (min) gives gas quantities entering and leaving the chamber. Therefore, by difference, carbon dioxide and methane output and consumed oxygen are used to determine animal heat production. The analyzers used in these experiments require a daily calibration to ensure read reliability. Calibration consists of adjusting the analyzer reading at the end of each 5 min cycle for each gas concentration range. At the end of each cycle, analyzers of each gas shows gas concentration similar to the cylinder concentration. In the CO_2 case, the concentration should range from 4.990 to 5.007 and for CH_4, the allowed range is from 0.997 to 1.003. In the case of N_2, all devices must have close to zero values with at least two decimal places. They can differ from each other only in the third decimal. For O_2, the reading indicated by the analyzer should be between 20.9450 and 20.9510. If the analyzers have performed right readings after three rounds (each round corresponds to the four 5 min cycles for each gas—N_2, CO_2, CH_4, and O_2) without adjustments, the equipment is calibrated.

Measurements start immediately after calibration. Mass flowmeter flow is adjusted according to the animal's live weight, as well as after ensuring air circulation and cooling systems are operating normally. Residual gas present inside the chamber must be added to the total volume of produced gases (carbon and methane) and consumed oxygen. Vsi and Vsf are determined by discounting animal volume multiplied by gases concentration at the beginning and at the end of the measurement, respectively. By subtracting the final and initial values, gas accumulated in the chamber (for carbon and methane) and consumed oxygen are obtained. These values are added to the values obtained previously, resulting in the final values of produced carbon dioxide, methane, and consumed oxygen, which are used to determine the animal heat production. Heat production measurements are carried out with fed animals at production levels in accordance with the established treatment (weight maintenance, intermediate and *ad libitum*), at the various physiological stages or after 48-h solid food fasting. The difference between the values of fed and fasting animal will be the caloric increment. Diet net and metabolizable energy content can be found [4].

Fasting heat production (FHP, kcal) corresponds to net energy requirements for maintenance. In the fed animal, it corresponds to the sum of the energy necessary for maintenance plus the caloric increment of feed consumed. PC is calculated by using an equation (Eq. 1) of [7]. Some authors mention high values for the estimation of the NE_m requirement from heat production in fasting.

8. Chamber measurements

At the first time, the animals pass through the chamber receiving the same diet provided in the digestibility assay. The power supply must only be provided when the equipment is ready to start reading. The chamber door will be closed and the reading will begin. Next day, we stop readings and the animal is removed from the chamber. Sorts are weighed. Knowing dry matter intake inside the chamber allows the calculation of the caloric increment required for energy partition. It is essential that the animals maintain the feed intake observed in the apparent digestibility assay.

The second measurement is with a fasting animal. The animal is placed in the chamber after 48 h of fasting solid food and staying there until the next day (72 h). Water must be *ad libitum* all the time.

9. Energy partition, net energy requirement, and energy efficiency

Gross energy intake and feces gross energy are determined in an adiabatic calorimetric pump for digestible energy calculation. Metabolizable energy is calculated considering urine and methane. The quantification of energy losses in the form of methane will be done in the respirometric chamber. For each liter of methane, a value corresponding to 9.47 kcal should be attributed [7]. The metabolizability (q) of the diet will be calculated by the relation between metabolizable energy and gross energy ingested [7]. The efficiency of using metabolizable energy for different functions (k_m, k_g, k_l, and k_p) is the relation between the net energy and metabolizable energy.

In one study with cross-breed milk cattle, [12] evaluated heat production in fasting bulls fed different diets corresponding to 1, 1.5, and 2 times (1×, 1.5×, and 2×) the dry matter intake (DMI) for weight maintenance. O_2 consumption (L/kg $LW^{0.75}$) under fasted and fed conditions did not differ between animals at 1× and 1.5× the maintenance diet, providing mean values of 22.25 and 30.35 L/kg $LW^{0.75}$, which represented a 36.4% increase in O_2 consumption as a function of eating. The 2× treatment provided the greatest ($P < 0.001$) O_2 consumption with values of 26.77 and 39.03 L/kg $PV^{0.75}$ for the animals under fasted and fed conditions, respectively. CO_2 production, similar to O_2 consumption, was greater for the 2× animals, which showed 21.2% and 37.6% higher production ($P < 0.001$) than the animals in the 1× group, under fasted and fed conditions.

Fasting heat production (FHP) was greater ($P < 0.001$) for the two × group (133.3 kcal/kg $LW^{0.75}$), compared with the other groups (112.1 and 107.9 kcal/kg $LW^{0.75}$, respectively), among those in which the FHP did not differ. The lowest O_2 consumption and CO_2 production that occurred with reduced intake are in line with the results obtained by [13], who indicated that the rates of oxygen consumption by organs like the liver and kidneys, per gram of tissue or as a function of their mass, decreased in response to feeding at the maintenance level. The effect of diet on maintenance metabolism has been associated with variations in the tissue metabolic rate. The causes of these variations are associated with changes in the energy rates and costs of blood flow, of the entrance of oxygen into the liver and in nutrient transference in the intestinal lumen [14].

A linear increase ($P < 0.001$) in FHP was seen in the present study with increased intake of DM. The highest values of FHP found, for the highest levels of feeding, reflect the increase in energy demands as a function of the productive condition of the animal. Calculating how much of this increase is due to the maintenance or weight-gain diet becomes an issue of semantics, as [15] reports, as the curvilinear relationship between retained energy and food intake may be explained by considering a decrease in the efficiency of use of the food supplied above the constant maintenance level. It may also be explained by considering a constant efficiency and a progressive increase in the components analogous to the maintenance diet.

Some author's report increased NE_m values when using the FHP [16, 12] constructed the regression equation obtained by the logarithm for heat production (HP) measured in the respirometry chamber, on different diets, as a function of MEI. The values found by the extrapolation for metabolizable energy intake equal to zero corresponded to the "NE_m^3" values described in **Figure 6**. It is noted that these "NE_m^3" values are less than those obtained by the FHP (NE_m^2) and closer to those obtained in experiments with comparative slaughter. The studies are in an initial phase and need to be expanded since they may indicate the change of methodology adopted in the experiments using respirometry. Similar to NE_m, the k_m found using the "NE_m^3" is different from the value obtained using the "NE_m^2."

10. Basal metabolism and maintenance

The metabolizable energy for maintenance is composed of two main components. The first is the basal metabolism, which corresponds to the minimum energy required to support the vital processes in a fasting healthy animal, in the post-absorptive state (48–144 h of fasting after feeding), performing the activity in the thermoneutral environment [17]. The second component associated with the requirement of metabolizable energy for maintenance involves several factors associated with the production of heat originated by the maintenance level, that is, by the heat increment, such as body temperature regulation, voluntary activity, digestion, nutrient absorption and assimilation, fermentation [19, 21].

The difference between basal metabolism and maintenance is that when in maintenance, the animal is not fasting [17]. The metabolizable energy requirement for maintenance (EMm) is defined as metabolizable energy intake (MEI), which corresponds exactly to the heat production, without any loss or gain of body reserves [19, 21]. This will occur when the retained energy equals zero (RE = 0) and the net energy for maintenance, although fundamentally important in net energy systems, cannot be directly determined by experimental techniques. So, it was stipulated that the net energy requirement for maintenance could be obtained by measuring the energy requirements of basal metabolism (EBM), which corresponds to the fasting heat production. At first, the net energy determination through the animal fasting heat production would not be appropriate, since this represents the requirements of ATP at the cellular level added to the heat produced in the formation of ATP by the mobilization of the body reserves. The most appropriate way to obtain the net energy for maintenance would be through the ratio $ELm = EMB \times k_b$, where k_b is the conversion efficiency of body reserves to useful energy in the form of ATP. However, the k_b has minimal variation (as the contribution of body reserves to ATP generation varies very little in fasting animals with similar nutritional plains), thus making the energy required for basal metabolism and fasting heat production have a strong relationship [20, 22]. This justifies the use of fasting heat production as the value adopted for net maintenance energy.

11. Energy efficiency use: relationship between metabolizable and net energy

From energy partition in the animal, we can obtain values that indicate the efficiency of the animal in using the energy for maintenance and/or production. The terms that make this evaluation possible are known as the metabolizability (q) and energy efficiency of use (*k*). [7] defines "q" (the quality factor) as the portion of metabolizable energy contained in the gross energy ingested, and the constant "*k*", as the portion of the metabolizable energy retained as net energy directed to maintenance, weight gain, fetus and fetal attachments and milk. When the animal is fed at maintenance level, the letter "m" (q_m and k_m) is added to such constants. Likewise, the terms k_g are used for growth and weight gain, k_l for milk production and k_f for gestation.

k_m was defined by [23] cited by [5], as the linear regression slope between negative energy retention, that is, energy loss, and ingested metabolizable energy. The efficiency of the use of metabolizable energy for gain (k_g), according to the same author, was defined as the slope of the linear regression between positive retained energy and metabolizable energy intake. When evaluating the nutritional requirements through the respirometric technique, the efficiencies of retention of the metabolizable energy are calculated as a function of the relation between the retained energy, that is, net energy, and the metabolizable energy, being $k_m = 1 - (PC_{alimentado} - PC_{jejum})/MEI$, where MEI corresponds to the ingested metabolizable energy [24].

The efficiency of using the metabolizable energy for maintenance is greater than that directed to the productive processes [1]. The various body functions of mammalian animals of the same species are more efficient in retention of metabolizable energy for maintenance, followed by lactation, weight gains, and reproduction functions. When comparing different species, the ruminant is known as the holder of the lowest net energy efficiency [25], which makes this field of research promising in the identification of components of the management of production systems that have a greater impact on the nutritional efficiency of these animals.

It is important to determine the energy efficiency use since several factors can influence them. The variable "q", for example, changes as a function of intake levels, and there are larger fecal losses with highest intake due to a higher passage rate and potentially digestible material escape. The digestible energy can decrease from 2.1 to 6.2% as energy consumption increases in relation to the maintenance level [26]. Urine energy losses tend to be constant, as well as losses due to methane production, ranging from about 5 to 12% in urine and 3 to 5% for methane [27].

12. Some results obtained with respirometry

Gyr, Nelore, Guzerá, Holstein, and F1 Holstein × Gyr animals (**Figure 4**) were evaluated at different physiological stages (growth, adult animal, weight gain, gestation, and lactation) and different nutritional levels (maintenance, intermediate, *ad libitum*). Animal breed, sex, and physiological state were evaluated and presented no significant effect on methane production. Dry matter intake (DMI) explained 87.7% of the variation in methane production;

Figure 4. F1 – Holstein × Gyr (left) and Gyr (right) heifers inside the respirometric chamber of the Metabolism and Calorimetry Laboratory of the Veterinary School of UFMG.

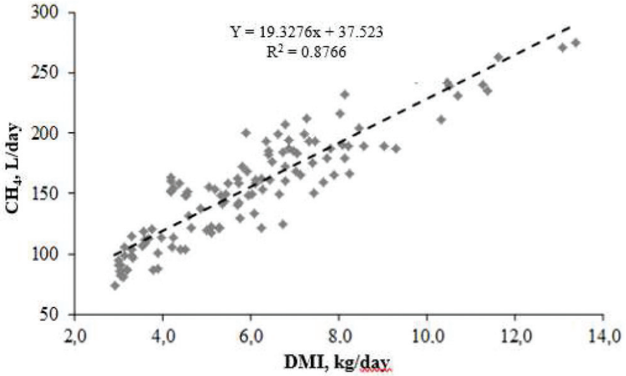

Figure 5. Relationship between daily production methane (CH_4) and dry matter intake (DMI). The points represent the evaluations considered for the development model (n = 125).

there is no improvement in the predictive model with the inclusion of other predictive variables (**Figure 5**). The same occurred with the GE intake (GEI). These data are published [1].

Several studies have shown that when animal productivity is increased, there is a reduction in the proportion of methane produced per unit of product. According to the United States' Environmental Protection Agency [28], increasing livestock productivity to achieve lower methane emissions per unit of product is the most promising and cost-effective way to reduce emissions. Moderate correlations were obtained (−0.49; $P = 0.03$) in the study by [12], showing that the level of intake relative to maintenance was inversely related to methane production. Increasing the intake by one unit above maintenance resulted in a decrease of 0.73 percentage units of methane production (%GEI).

In low-quality fodder, the addition of nutrients for microorganisms increases the efficiency of microbial growth because it increases the efficiency of the fermenting process in the rumen with a decrease in the methanogenic activity per unit of degraded carbohydrates [29]. However, there is an increase in methane production per animal ranging from 8.4 to 12.3% of the GEI because it is organic.

In one study with cross-bred milk cattle, [12] evaluated heat production in fasting bulls fed different diets corresponding to 1, 1.5, and 2 times (1×, 1.5×, and 2×) the DMI for weight maintenance. O_2 consumption (L/kg $LW^{0.75}$) under fasted and fed conditions did not differ between animals at 1× and 1.5× the maintenance diet, providing mean values of 22.25 and 30.35 L/kg $LW^{0.75}$, which represented a 36.4% increase in O_2 consumption as a function of eating. The 2× treatment provided the greatest ($P < 0.001$) O_2 consumption with values of 26.77 and 39.03 L/kg $PV^{0.75}$ for the animals under fasted and fed conditions, respectively. CO_2 production, similar to O_2 consumption, was greater for the 2× animals, which showed 21.2% and 37.6% higher production ($P < 0.001$) than the animals in the 1× group, under fasted and fed conditions.

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A linear increase ($P < 0.001$) in FHP was seen in the present study with the increased intake of DM. The highest values of FHP found, for the highest levels of feeding, reflect the increase in energy demands as a function of the productive condition of the animal. Calculating how much of this increase is due to the maintenance or weight-gain diet becomes an issue of semantics. [15] reports that the curvilinear relationship between retained energy and food intake may be explained by considering a decrease in the efficiency of use of the food supplied above maintenance level.

Some authors report increased NE_m values when using the FHP. [16, 13] constructed the regression equation obtained by the logarithm for heat production (HP) measured in the respirometry chamber, on different diets, as a function of MEI. It is noted that the "$NE_m{}^3$" values obtained by this regression are smaller than those obtained by the FHP ($NE_m{}^2$), and closer to those obtained in experiments with comparative slaughter. The studies are in an initial phase, and need to be expanded, since they may indicate the change of methodology adopted in the experiments using respirometry. Similar to the NE_m, the k_m by using the "$NE_m{}^3$" is different from the value obtained by using the "$NE_m{}^2$."

The efficiency of converting DE to ME is influenced by several factors, such as the rate of microbial growth in the rumen, production of methane, relationship between energy and protein in the diet, and efficiency of the use of metabolizable protein, among others. [15] reports that the ME/DE relationship is approximately 0.82. [14, 18] suggest a value between 0.81 and 0.80, respectively; whereas [7] uses values from 0.81 to 0.86. Higher relationships, from 0.89 to 0.92, were found by [30]. An analysis of the relationship between DE intake (DEI)

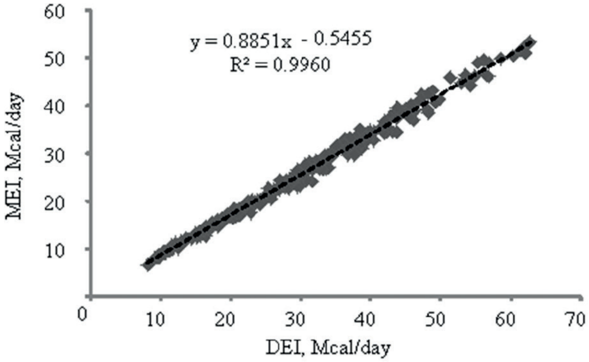

Figure 6. Relationship between digestible energy intake (DEI) and metabolizable energy intake (MEI) expressed as Mcal/day.

and ME intake (MEI), determined from the metabolism trials in respirometry chambers, was conducted (**Figure 6**).

The data presented show the high dependence of the MEI variable as a function of DEI. It is important to stress that, considering that in all experiments studied, the methane losses were measured in the respirometry chamber and were not estimated, the ME/DE ratio was always greater than 0.82.

13. Maintenance and production nutrient requirements

Many experiments were already carried out at LAMACA. Nutrient requirements data are still scarce, but some observations can be done. When milk production increases, maintenance requirements in relation to total energy requirement decrease. Energy requirements for maintenance in relation to total energy requirement are 50:50, 32:68, 24:76 on 15, 30, and 45 L of milk/day cows, respectively, according to NRC. Zebu cows (like Gyr) and F1 cows have low to medium milk production. Maintenance requirements can mean a good part of total requirements of these cows. Some papers compared animals with different production potential (milk or weight gain) and showed that there is a positive correlation between production ability and maintenance. Dairy Zebu cows' data is still scarce. [13] compared slaughter technique and respirometry in male F1 – Holstein × Gyr on maintenance, intermediate and *ad libitum* energy intake or 1×, 1.5×, or 2× NEm. *Ad libitum* group had higher NEm (+29%). In this group, the heart, liver, kidneys, and gastrointestinal tract weight were 25, 22, 22, 31% bigger, respectively.

Energy requirement of Gyr, F1 – Holstein × Gyr, and Holstein heifers were studied. Gyr had lower maintenance requirement than Holstein, and F1 was intermediate. Gyr heifers were selected for milk production, but maintenance requirement did not increase at the same proportion. It showed us that Zebu cows require less energy for maintenance, so they can be more economic. We also noticed that younger animals have higher maintenance requirements.

Energy requirements for maintenance increased during lactation. It was expected since organs and visceral tissues are adapted to metabolize many nutrients during lactation. Dairy Gyr heifer had lower dry matter intake than the Holstein, probably because Gyr gastrointestinal tract is smaller. In this way, their NE_m is smaller too.

14. Conclusions

Respirometry is an excellent technique that allows the evaluation of the same animal many times, from birth through life, at different physiological status.

Animal nutrition knowledge can be improved by using the respirometric technique that is presented as a technology complementary to comparative slaughter, since it allows the determination of both methane production as well as the efficiencies of energy use.

The determination of the nutritional energy requirements for bovines of different genetic groups and under different feeding conditions allows the appropriate adjustment of the formulation of feeds for each animal category.

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