ABSTRACT

GERNAT, ASHLEY ALEXANDRA. Evaluation of Dietary Plasma Fed to Turkeys During Brooding on Subsequent Performance to Market Age. (Under the direction of Dr. Jesse Grimes).

The turkey industry, especially commercial production, faces economic loss due to the different types of exposure to stress. Turkeys can experience various levels of stress during periods in their production life including, but not limited to; hatching, brooding/growing,

and transport. Factors such as environment, climate, transportation, social interactions, sub-optimal management practices, nutritional deficiencies and many more can have an impact on production (Huff et al., 2008). Temperature and climate are two important issues of concern for poultry producers and scientists. Both heat and cold stress are known as major livestock problems accompanied by economic losses. In 2008, China's winter conditions and low temperatures caused almost 20 million poultry deaths and an economic loss of 100 million Yuan ($16,000,000 USD) (Nguyen et al.,2016; Chen et al, 2012). Poultry exposed to acute cold stress have shown clear suppression in survival, development, and egg production (Sagher, 1975; Renwick et al.,1985). Stress exposure also causes increased probability of infections and diseases that also have a negative economic impact in production. The animal production industry is in constant analysis of nutritional products that could benefit or alleviate stress impacts in animals and as alternatives to antibiotic use. Consumers with different preferences have a higher awareness of animal welfare and food safety that come into the equation.

In this research project, Large White commercial turkey hens were reared to 12 weeks to evaluate their stress responses and performance alterations due to induced stress to mimic brooder house to grow out transition. Parameters for performance, blood, bone, and meat yield were recorded. Spray Dried Bovine plasma (SDBP) (AP920, APC, Europe S.L.U) was formulated iso-nutritionally into the diets. AP920 has shown to be an ingredient in animal diets that may help

support immune health and have a positive effect on performance. This product was used for a total of 6 weeks in the early feed phases (starter 1 and grower 2) at different percentages of inclusion. Treatments included a control diet (0% plasma), a 1.0% (AP1) plasma inclusion and 2.0%(AP2) plasma inclusion. At 6 weeks, common diets were fed (grower 2 and finisher 1). Management stressors were applied for 24 hours, with feed and water restraints and cold temperatures. In addition, previously used pine shavings were used for bedding throughout the trial. No statistical differences due to feed treatments were observed for body weight, body weight gain, or feed intake throughout the trial. Feed conversion ratio (FCR) showed an improvement at 6 weeks where birds fed with SDP, AP1(1.90) and AP2(1.97) had a lower value than birds fed the control diet (2.041). However, no difference in FCR was found at 12 weeks. No differences were observed for meat yield %, mortality%, bone ash% or bone parameters. Blood analysis resulted in no effects for immunoglobulin levels, but a significant difference was observed for corticosterone levels post stress where AP1(23.81ng/mL) and AP2 (19.17ng/mL) had a higher level than control (16.40 ng/mL).

Although SDBP has been reported to benefit other species when exposed to extreme environmental or infectious challenges, further research will be needed to analyze and study the effects of this product at different inclusion levels to benefit the production and immune system in turkeys.

Evaluation of Dietary Plasma Fed to Turkeys During Brooding on Subsequent Performance to Market Age

by
Ashley Alexandra Gernat

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Master of Science

Poultry Science

Raleigh, North Carolina
2022

APPROVED BY:

Dr. Jesse L. Grimes
Committee Chair

Dr. Fernanda Santos

Dr. Frank Edens

DEDICATION

To my beloved mother, Carolina Soto and my sisters, Andrea Gernat, and Clarissa Gernat for their outmost support throughout this journey. To my family in Honduras, who has encouraged me with love throughout my life. To my aunt Lisa Gernat and uncle Mark Gernat for never letting me quit. To my best friends Ambar Lobo, Virginia Garcia and Yolibeth Munguia for the constant support and words of encouragement. To my grandmother who watches over me, in heaven, Olimpia Crespo. To Dr. Jesse L. Grimes and Mrs. Ruth Ann Grimes, who have been unconditional in my journey and could not have come this far without them.

BIOGRAPHY

Ashley Alexandra Gernat, daughter to Abel Gernat and Carolina Soto, was born in Tegucigalpa, Honduras on April 20th, 1995. She grew up on the outsides of the city with her family. Her love for animals and agriculture started from a young age. After completing high school, Ashley applied to the university of El Zamorano located in Honduras. She completed her bachelor’s degree in agricultural sciences and production. As a requirement to graduate with her bachelor’s degree, Ashley had to fulfill an internship abroad, which led her to North Carolina State University in the Prestage Department of Poultry Science. She spent a semester working under Dr. Grimes at the Talley Turkey Educational Unit and later returned to Zamorano to graduate. After graduating, Ashley worked seven months in CADECA, one of the three main poultry companies in Honduras. As her interest in poultry grew, Ashley enrolled to start graduate school in August 2017 under the direction of Dr. Grimes. Ashley plans to continue her education in becoming a Doctor of Philosophy in poultry science with a minor in Food Safety after she completes her Master of Science degree. Ashley enjoys reading and spending time with her friends.

ACKNOWLEDGMENTS

I would like to show an enormous gratitude to every person involved in the process. I would like to express great appreciation to my advisor, Dr. Grimes, for his support, patience, and guidance in every step of my program. Dr. Adam Fahrenholz in his support for the completion of my Feed Mill Certificate, as well as all the feed manufacturing experience. Dr. Frank Edens and Dr. Fernada Santos whom both supported and encouraged me as part of my committee.

All my research projects would not have been possible without the help of the staff from the Talley Turkey Educational Unit as well as the Feed Mill Education Unit. Thank you to Stephen Hocutt, Mike Mann, Brooke Griffith and Adam Gross for their hard work and constant support in the Turkey Education Unit. I also want to thank Lynn Strother, Marissa Cohen and Dannica Wall for their help and kindness. Thank you to Dellila Hodgson, Vicky Hedgepeth and Christina Sigmon for their laboratory help and knowledge. My lab colleagues, Karlinton Flores and Brooke Bartz thank you for teaching me and always assisting me. To my graduate student colleagues, Elle Chadwick, Ben Alig, Madison Spangle, Katherine Cupo, Andrea Rubio, and Danny Patino for their friendship, support and assistance throughout projects and different subjects. Thank you to every person that helped me in this time.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1

LITERATURE REVIEW

History of Poultry Consumption

As poultry products consumption has changed over time, so has poultry production. Historically, poultry consumption was considered a luxury because chicken was significantly more expensive than beef or pork (Moody, 2018). The science and practice of poultry science and nutrition (including protein, carbohydrates, and fats) has evolved greatly over the past 100 years moving from a back yard enterprise to the modern computer-controlled production of whole diets formulated to specific nutrition compositions (Elwinger, 2019). As global populations increased, global meat (protein) consumption per person also increased, especially in the last 20 years as more affluent peoples could afford more meat protein in their diets (Whitenall, 2019). With meat protein preference shifting toward higher consumption of fish and poultry and less consumption of beef and to a lesser degree for pork, the poultry industry became the major producer of animal protein using safe and healthy procedures. Nutritionally, people eat poultry meat for its high content of high-quality protein and its low-fat content (Scanes, 2019). Thus, when the word poultry is mentioned, most consumers immediately think only of chicken and eggs.

Turkeys *(Meleagris gallopavo)* were domesticated over 2000 years ago by the pre-Columbian Pre-Aztec and Aztec civilizations of present-day Mexico and Central America (Thornton, 2012). Turkeys were not only a source of food for the ancient tribes, but they were also important for sacrificial offerings. Their bones, feathers and other byproducts were used to produce medicines, fans, tools, musical instruments, and even personal ornaments (Thornton, 2012). Today, turkey is mainly used for a meat protein source for humans. The growth of turkey meat consumption is due to various reasons possibly based the many ways to prepare it for consumption.

The turkey is a year-round bird, meaning that it can be produced all year and not just for the holiday meals. Turkey meat is made into sausages, ham and delicacy products for retail and food services. The preferences among the more affluent populations are trending toward more turkey consumption each day to maintain healthier eating habits. Individuals looking for healthier options also have expectations of sensory and nutritional quality. However, consumers are concerned about the environmental impact of poultry and turkey production which has brought focus on their welfare (Bir et al, 2019).

Importance of Poultry Health

To meet the increasing demand for affordable high quality animal proteins, the Food and Agriculture of the United Nations (FAO) estimated that world poultry production needed to grow 2-3% per year to meet world demand, which will require more intense production systems (FAO,2017). There are numerous risks associated with more intense production facilities which would facilitate higher risk of animal disease transmission. Improving food animal intestinal health and the efficiency of the immune system should have a positive impact on overall poultry performance and health (Campbell, 2019). Poultry health can be attributed to a combination of factors that enhance successful production of commercial poultry and turkeys. Therefore, poultry and turkey producers must optimize the relationships among nutrition, physiology, management, and health to optimize the relationship between performance and productivity. Similar to all other animals, the first days of life of the turkey poult are crucial. With turkeys, proper incubation and hatching are critical to enhance healthier poult hatchlings which leads to healthier growing flocks. Adequate brooding conditions are critical to provide young poults with proper temperature, water, ventilation, maintenance of a disease and pest free environment and proper litter management

(Grimes, 2015). Key management factors such as these are becoming more and more critical as consumers lean toward healthier safer food products that are provided via proper animal production methodology.

Over the last decade, the expression “gut health” has entered the collective consciousness of animal industries and researchers alike (Kogut, 2017). Gut health can be hard to describe, given the fact that a ‘healthy gut’ is easier observed than described. The most basic function of the gut is regulating homeostasis that provides the host the ability to withstand infectious and noninfectious stressors (Kogut, 2017). In turkeys, the intestinal health can be directly related to the growth, performance, and productivity of the flock (Grimes, 2015). Overall, intestinal health is important in a bird, as well as a good immune system, but this status evolves as a result of a good farm management program. As producers and scientists develop solutions for poultry health-related issues to meet consumers demands for healthier products, producers cannot leave body stress related issues unattended.

Stress Factors

Stress can be defined in different ways depending on the situation; however, it is commonly known as the state of real or perceived threat to homeostasis- the stability of bodily physiological systems (term coined by W. B. Cannon in 1926; (Smith and Vale, 2006). Though it was not until later in the 1930’s, stress became a physiological/psychological term referring to mental strain and/or biological challenge (Seyle,1956). Stress can also be defined in various scenarios; however, it is described in this case as an adaptive response by an animal to any threat to homeostasis (Dohms and Metz, 1991). Stress can have a broad spectrum, can be described as Eustress (good stress) or Distress (bad stress) and result in different kinds of responses. Birds show stress responses when exposed to stressors of all types. The first is “Fight-or-Flight” described by stress physiologists as the neurogenic response that involves the immediate response of the sympathoadrenal system and the adrenal medulla. In this response, the sympathetic nervous system responds immediately followed closely by massive release of epinephrine and norepinephrine from the adrenal medulla. These immediate responses govern the sequestration of energy substrates that allow the target of a stressor to withstand the stressor or to allow the animal sufficient energy to escape the stressor and find an environment in which the animal can be sheltered from the stressor (Koutsos and Klasing, 2014). The second is the activation of the hypothalamic-pituitary-adrenal (HPA) axis, the long-term response to a stressor, that results in the secretion of the of corticosterone from the adrenal cortex (Koutsos and Klasing, 2014). In general, stressors can induce two types of responses- nonspecific and specific. Any kind of general stress can be noted to have non-specific effects, such as peripheral vasoconstriction if the animal is exposed to a cold stressor or vasodilation if the stressor is heat. These responses are deemed to be stimulus dependent. On the other hand, regardless of the type of stressor, in both heat and cold, long term exposure will induce the hypothalamic-anterior pituitary-adrenal cortical axis (HPA), which results in hypothalamic release of corticotropin releasing hormone (CRH) that stimulates anterior pituitary corticotropes to first synthesize a protein called proopiomelanocortin, which has 11 cleavage products among which is adrenal corticotropin, which activates the adrenal cortex to synthesize and secrete corticosterone, which then facilitates the adaptive responses of the stressed animal, allowing it to adapt to the environmental stressor (Bartz, 2016). In poultry, corticosterone is considered to be the main avian adrenal glucocorticoid (Scanes, 2016), that when exposed to intensive stressor(s) induces high output of corticosterone, which in very long-term stressor exposure will cause increased adrenal corticosterone output that will ultimately cause decreased performance of the stressed animal. Although the HPA is certainly involved in the ultimate decreased performance of stressed animals, it is not without benefit to the animal. For instance, a breeding flock may be faced with a situation where there is very little food available. This might continue for days and then the food is gone. In a situation such as this, it makes no biological sense to continue to use available energy to keep all systems running at maximum energy usage. Thus, the body begins to shut down systems which are not essential for life-sustaining processes. Reproduction can be shut down; the immune system can be shut down; the digestives system can be shut down for a short period of time. During this process, body energy is conserved for use by the brain, the heart and respiratory system, the renal system, and the skeletomuscular system - all of which are essential for life sustaining processes. From the animal's point of view, the shutdown process is reasonable. When resources become available again, all those shut-down systems will regain their ability to be integrated back into the overall homeostatic process as if nothing ever happened (Tsigos et al.,2020).

There are many kinds of distressors in the environs of a poultry house that could cause negative effects within the body's physiological systems. In poultry, during commercial production, the animals can be exposed to a variety of stressors related to environmental conditions and husbandry practices (Akinyemi, and Adewole., 2021). Some of these stressors can be attributed to transportation processes (Huff et al.,2008), social interactions, restricting feeding schedules, environmental factors, or sub-optimal management practices to elucidate only a few potential stressors, which can induce within a short time some level of stress that later can lead to decreased growth performance, alterations in the function of the immune system, decreased reproductive performance as well as decreased livability. In food animals, distress can result in a much higher financial burden on producers for the food industry.

Turkeys can experience various periods of exposure to extreme temperatures. One of them being transferred from a brooder house to a grow-out house, which, depending on the season, extreme heat or cold can cause stress in them. In the case of cold exposure, it has been observed that it can influence the function of neuroendocrine system, antioxidation system, and immune system (Hangalapura et al., 2006; Onderci et al. 2003; Flehsner et al.1998; Helmreich et al.2005). Hagalapura et al. (2003) indicated that the effect of cold stress on the immune system can depend on stressor time and stressor intensity. Important factors that enhance the development of diseases has been determined by Huff et al. (2009) when psychological stressors are experienced during production and transportation. This opens opportunities for infections such as *E. coli*, that can cause severe respiratory diseases in poultry, cellulitis, arthritis, and soft tissue abscesses, which can all enhance the colonization of foodborne pathogens (Huff et al., 2013). Foodborne pathogens along with animal welfare have become very worrisome among producers and consumers alike.

The concern for animal welfare and wellbeing started as a small activist movement called : The Royal Society for the Prevention of Cruelty to Animals (RSPCA) in England in 1824 and spread around the world with development of similar organizations, which in turn have grown unchecked due to their popularity among people of all nations. Governments also began to listen to the populace and Federal and state legislative acts have been passed governing the care and use of animals of all kinds in laboratories. In the United States, the first bill passed was called the (Laboratory) Animal Welfare Act (Public Law 89-544) and this has been expanded many times since its passage. Animal welfare and wellbeing movements continue to expand and now are so powerful that those organizations dictate what animal products and quality of product that can be delivered to the consumer of animal products. It is a force that must be respected because it dictates to all animal industries and food purveyors alike. Much of the cause for such a large movement can be attributed to lack of concern of workers in animal industries having little to no concern for their animal charges' welfare. Public concern, about production standards for food animals over the years, has had some very important impacts in animal production practices. Many of the production changes have been costly to implement; however, in many instances, safer animal food products were the benefit to the consumer, which then is justification for production of a healthier more productive food animal. As a result of the public's concern for animal welfare, numerous auditing systems have been developed to assure producer compliance of laws and implementation of production standards incorporating provisions for improved animal welfare. Through the animal welfare legislation, producers are required to improve production practices which include modern husbandry practices, biosecurity elements, environmental standards, litter management, management of mortality losses, etc.

Over a period of about six decades animal producers used antimicrobials and antibiotics to aid birds during stress and other health issues (National Academies Press, US, 1980) to maintain growth potential and decrease mortality. However, beginning in the early 2000's a trend developed in which the consuming populations around the world began to demand antibiotic free (ABF) poultry and other livestock protein sources. To maintain ABF flocks and herds, elaborate testing by FDA, grocers and many other private enterprises do routine testing to assure that the food supply is ABF compliant. In line with consumer demands, turkey producers subscribe to the ABF standards promulgated by Federal and State Health Departments assuring consumers that they have safe and reliable turkey food products.

Cold Stress

As awareness of animal welfare and food safety has risen, ABF production is more common. It is not always feasible to have an ABF flock because so many factors can come into confluence to exacerbate diseases or infections. One of these factors is temperature stress, both heat and cold. Both heat and cold stress are known as major livestock problems which can result in great economic losses. In 2008, China's winter conditions and low temperatures caused almost 20 million poultry deaths and an economic loss of 100 million Yuan ($16 million USD) (Nguyen et al.,2016; Chen et al, 2012). Poultry exposed to acute cold stress suffer increased mortality, depressed development, and decreased egg production (Sagher,1975; Renwick et al.,1985). It has been recorded that temperature that decreases below 18 °C resulted in permanent tissue damage, cold-related illnesses, and death due to loss of the ability to induce increased body heat (Dhanalakshmi et al. ,2007).

Adenosine monophosphate-activated protein kinase (AMPK), a central regulator of the body and cellular energy homeostasis, is a key energy sensor that can regulate energy balance homeostasis of broiler chickens (Song et al., 2012). Geraer et al., (1988) reported that cold exposure is associated with increased energy expenditure. Zhao et al., (2013) reported that the cellular phosphorylation of AMPK is significantly increased under cold stress to regulate the energy distribution in response to stress (Roman et al., 2005). AMPK was shown to play an important role in determining gut epithelial health. Birds that were exposed to cold had acutely injured livers and an increased gene expression of AMPKα– PPARα pathway (Zhang et al.,2014). There is clear evidence (Su et al., 2018) that cold stimulation at 12 °C lower than the regular temperature led to cold stress responses of birds, which was then followed by inflammation. Two important hormones, triiodothyronine (T3) and thyroxine (T4), play a crucial role in the endocrine system as well as the immune system. These hormones travel through the blood to reach almost every body cell, and these regulate the speed of metabolism. T3 and T4 regulate and permit body functions, like heart rate, processing of food, and body temperature. Since the thyroid hormones are of vital importance in the immune system, they are also important in stress. There is evidence that cold stress affects thyroid hormones (T3 and T4), that play a role in energy expenditure and body temperature homeostasis (Collin et al., 2013; Sahir et al., 2012). This is evidenced by the fact that the thyroid hormones are seasonally expressed in higher concentrations during the cold weather and lower concentrations in warm weather. It is key to have a healthy immune system and avoid extreme temperature changes or exposures to avoid stress and diseases and exclude antibiotic use.

Antibiotics in Turkeys

With trends and regulations changing over time, poultry production practices have made major adjustments regarding the use of antibiotics and antimicrobials. Producers and researchers are working closely to meet the needs and demands of consumers all the while adhering to variable regulations. To be compliant with consumer demands, poultry producers and scientists must continually seek alternatives for antibiotic usage as prophylactic growth promoters as a sole means to improve performance and production success. The US is the largest turkey producer in the world, with 7.5 billion pounds of turkey meat produced in 2019 (ERS-USDA, 2021; NASS/USDA, 2021). Similar to several livestock production systems, turkey production has been affected by the changing consumer demands. Since the production cycle of turkeys is significantly longer than that of broilers (Caucci et al., 2019), turkeys experience a higher risk for development of disease before they are marketed (Tumpey et al., 2004). Chronic infections of the joints, bones, and soft tissues with opportunistic bacterial pathogens are some of the problems the turkey industry faces (Huff et al, 2006). Thus, finding reliable alternatives to antibiotic usage in turkey production that is acceptable to the ultimate demands of consumers is becoming a greater challenge. Antibiotic resistance is of paramount concern in the poultry industry. The very real potential for development of antibiotic resistance in livestock and poultry, which could impact human health is another reason why antibiotic usage in poultry should be curtailed as suitable alternatives are developed (Landers et al., 2012).

In the U.S., turkey is consumed primarily during the Thanksgiving and Christmas seasons; however, the market for turkey is much larger and is expanding. According to the Agricultural Marketing Resource Center (2021), the consumer demand for turkey products is increasing as consumers see turkey products as a lean alternative for pork and beef. Therefore, turkey producers strive to provide optimal environmental conditions for growing turkeys in an effort to guarantee a profitable safe food production chain. In efforts to meet consumer demands, researchers and turkey producers are working cooperatively to improve every facet of turkey production systems. Every element of turkey production systems, including assurance of proper nutrition to enhance the health and wellbeing of the turkey. Over the past two decades, poultry scientists and producers have been investigating numerous alternatives to antibiotic usage that would provide, ostensibly, acceptable control of a broad spectrum of health issues experienced by growing turkeys (Mehdi et al., 2018; Aziz Mousavi et al., 2018; Gadde et al., 2017; Teillant and Laxminarayan, 2015).

Feed Additives

Turkey nutritional requirements are dynamic and change in accordance with bird age, gender, and purpose of production. In the poultry industry, the feed accounts for 70% of the production cost and is the largest challenge facing producers today. If the world population continues to expand at its current rate, in a few decades farmers will be faced with production challenges that have never been seen as they attempt to provide sustainable, affordable, low environmental impact practices to feed the human populations and food animal populations. Feed additives have been used for many years in livestock and poultry industries to improve nutrient availability through improved digestion. The European Feed Standard Agency (EFSA) describes feed additives as products used in animal nutrition for purposes of improving the quality of feed and the quality of food from animal origin, or to improve the animals' performance and health, e.g., providing enhanced digestibility of the feed materials. Feed additives can be used for food safety reasons, environmental issues, antibiotics ban, gut health, high efficiency of production, preventing diseases, standardizing welfare standards, and in some cases cost purposes (Pirgozliev, et al., 2019). The industry has seen a shift in preferences as to the origin of their food and the use of feed additives in livestock production. Many consumers prefer less synthetic and animal product feed additives (antimicrobials, animal by-products, etc.) and more plant or natural based products (prebiotics, probiotics, essential oils, spices, enzymes) (Abd El- Hack Me et al., 2022). Certain feed additives may be described as immunomodulators. Nutritional immunomodulators can be defined as diet supplementation with certain nutrients that affect the aspects of the immune functionality to achieve an intended goal (Swiatkiewicz et al., 2014). Diets do not stimulate the immune system, instead dietary ingredients nourish immune cells and also modulate their function to facilitate the establishment of commensal microflora (Abo-Al-Ela et al., 2021). Nutrition is a way of promoting healthy birds and enhancing the immune system for optimum production.

Although the FDA/ USDA have no official definition for the term "Animal By-Product" (ABP), the American Meat Science Association (AMSA) defines animal by-products, which are sometimes called offal, as the parts of an animal that are left over after a butcher or slaughterhouse has harvested meat. The term plant-based is popular in the feed industry, especially with plant extracts and plant by-products, but these are not always as favorable as animal by-products, which are more readily digested, when it comes to nutrition.

Certain diets, composed mainly of grains and soybean meal, are deficient in some vitamins (such as vitamin B12) that can be supplemented with animal protein (Ellis and Bird, 1950). For diets of nonruminants, the proteins of soybean meal have been thought to be less effective than those of animal by-products (Ellis and Bird 1950). The ABP are an economical source of highly important nutrients for livestock and poultry that are digested easily (Jędrejek et al., 2016). These APB provide high quality protein with all the needed essential amino acids, energy in the form of fats and carbohydrates, vitamins, and minerals (phosphorus and calcium) (Jędrejek et al., 2016).

These products are beneficial to livestock for more reasons than nutrition because they offer a sustainable solution by producer use of value added to former waste products and ingredients in the animal agriculture industry (Tyler, 2021). Additionally, use of by-products from animal and plant sources will assist in reduction of greenhouse gas (GHG) emissions, repurposed water, reduced animal fat, protein, and byproduct waste and provide nutritious ingredients that can be used in formulation of improved feed for food animal species to name a few benefits of using animal and plant byproducts (Tyler, 2021). Some of the most important animal by products that are used today in the feed industry are tankage, meat meals, blood meal, bone meal of different types, meat and bone meal, liver meal, processed animal protein, fish meal, SDP, etc. (Ellis and Bird, 1950; Castro-Munez and Ruby-Figueroa., 2019).

Spray dried plasma as a feed additive

Spray dried plasma (SDP), first proposed in the late 1980's as a protein source for use in pig diets, is a protein rich by product that is obtained from the industrial fractionation of swine and bovine blood plasma (Perez- Bosque et al., 2016). To obtain SDP, blood is collected with an anticoagulant and then centrifuged to separate the blood cells. The plasma is later concentrated, and spray dried under high pressure to achieve a minimum of 80 °C throughout its substance. With this process, proteins preserve most of their biological activity as well as albumin, growth factors, and peptides, which can be utilized as a feed additive (Gatnau et al., 1989; Borg et al., 2002). SDP can be found in different forms including powder, granules or in water soluble forms. The different forms of SDP are still under investigation to determine its effects in various food animal species (Campbell et al., 2006). SDP, which contains high levels of antibodies in the form of activated immunoglobulins, is used as a feed additive to “boost” the gastrointestinal tract immune system in livestock such as swine, cattle, and poultry, and can serve as an alternative for antibiotics. Based on collected data, SDP enhances early intestinal health and supports an efficient immune system response locally in the intestine and systemically in the body. These results are encouraging in that SDP can benefit growth, improve feed efficiency, and increase survival of young food animals in conventional, commercial production even with inherent, hostile conditions associated with many potential disease-causing pathogens and parasites and a large variety of environmental stressors (Campbell et al., 2019). The SDP associated improvements shown in livestock production are more pronounced under commercial production conditions compared to ‘cleaner’ research facilities (Campbell et al., 2019). SDP is described as having a mode of action that can support the intestinal barrier, facilitate adequate and normal nutrient absorption while potentially excluding toxins and microorganisms (Zhang et al.,2016). The part of the SDP that is responsible for beneficial effects is the immunoglobulin-rich fraction in the plasma (Pierce et al., 2005). SDP can be enhanced if feeds are formulated to have a low moisture content, which is protective of the SDP via prevention of exposure to high temperatures and pressures during storage. These minimal procedures provide nutritional stability (favors protein levels) and is a fairly simple process compared to drum drying and freeze drying, which represents potential for lower cost of production.

Spray Dried Plasma in Turkey Production

Starting a turkey flock properly is critical. The health and, therefore, economic risks associated with early livability issues and those toward the very end of the production period are increased compared to most of the growing period. Therefore, poults require proper brooding conditions since they have a more difficult time regulating their body temperature in comparison to chicks and must have at least a 35°C at floor level (Grimes, 2015). The requirements for the best nutrition and management of poults are an economic necessity as this sets the stage for improved performance during the growing period and increases numbers of healthy, high-grade turkeys going to market. With this in mind, it may be beneficial to utilize animal byproducts such as SDP that provide numerous enhancements and benefits especially to young poults.

Marketing trends for turkeys are also changing. Therefore, the food industry must set new standards that affect the production of food animals that are in compliance with marketing trends. Marketing trend changes can influence production of growing poultry. Some of the changing marketing trends have resulted in increased production cost balanced by increased pounds of poultry sent to the market. However, changing trends can sometimes seem to be unreasonable and can remain a point of contention due to production costs increases without added market weighs. Use of animal by-products in feeding regimens can also be a contentious subject and even strongly disapproved by many consumers. Oddly, many of the disapproving consumers are not fully aware of the benefits provided to the food animals via addition of ABP to feed or the decreased environmental impact of the feeding program with certain feed additives in addition to the economic benefits derived from the use of APB. The profit margin per bird sent to market can be low, although the large the number of birds marketed improves producer profit. As market turkey flocks' production cycles advance for longer times, they become increasingly exposed to risks for development of disease in high density production facilities (Tumpey et al., 2004; Caucci et al., 2019). Additionally, feed costs for each week of the production cycle become greater, inducing economic losses as they go past a market age and optimal body weight. This would be an example of how a feed additive that increased body weight gain and reduced production cost would be beneficial. With feed being the element with the highest cost in production, the producer would want to make sure their birds get the appropriate nutrients. Therefore, feed and its quality are essential during production and critical during brooding (Grimes, 2015).

Brooding is extremely important in young poults' development because it has not yet developed its own gut microbiota and its GI tract is more easily penetrated by potentially pathogenic bacteria. The gut microbiota develops in stages and until it reaches a climax population, the gut will be susceptible to development of bacterial and viral infections. This problem is exacerbated because of inherent litter pecking in all turkeys. Young poults then acquire potentially pathogenic bacteria from the litter without having developed a defensive gut microbiota (Mailyan, 2019). Providing the proper, optimum environmental conditions for poults when placed in the brooder house are critical for proper development. Strong stressors continue to impact young turkey poults as they are moved to grow out houses when they are between five and seven weeks of age. The level of the stress response is dependent on climate and age, which can result in a long-term stressor as the poults begin to compete for feeder space as well as personal space as they mature through the growth phase to market age

Soybean meal (SBM) is usually the greatest plant-based protein source in turkey diets. However, SBM has a low methionine content that is met with additional supplements of the amino acid to the diet. The SBM also has high levels of indigestible carbohydrates, called oligosaccharides, that are difficult for monogastrics to digest and reduces metabolizable energy values (Boling and Firma, 1997). Natural soybeans contain high levels of trypsin inhibitors, which reduce the protein digestibility. Phosphorus in SBM also is digested poorly because phosphorus could be bound to phytate making it unavailable for digestion. For these reasons alone, plant-based protein might not be the best source of protein in the turkey diet, but until a suitable replacement source of protein is found, turkey nutritionists must rely on enzymes to increase protein digestion along with carbohydrate digestion.

Diet ingredient substitutions are frequently used in formulation of turkey diets. Wheat inclusion in the diet can improve pellet quality; however, feeding wheat may reduce yield of breast meat (Amerah and Ravindran, 2008). SDP improved growth in swine, poultry, and dairy cattle. Henrich et al. (2021) showed SDP improved growth and intestinal functional in young calves when included in milk replacers (MR) fed at conventional rates. (DSDP) was shown to be effective in the improvement of growth performance of pigs raised in unsanitary conditions (Weaver et al., 2014). Various studies show that piglets fed SDP perform equally or better than piglets that were fed antibiotics (Balan et al., 2021) or alternative products such as organic acids, plant extracts or other types of immunoglobulins. With studies being performed in other food animals showing promising results with SDP, turkey farmers can learn more about the many potential solutions and options to today's challenges in turkey production, and SDP may be an option to consider. Turkeys face many challenges from hatchery to harvest and this cost the turkey industry large amounts of money due to diseases, feed, climate, stress factors, to consumer preferences that lead to bias perceptions of the industry.

With regard to all the factors mentioned including gut health, stress, animal welfare, management, nutrition, one must keep in mind that optimal turkey production is impacted by all these many factors. Thus, continuing research is necessary to promote more efficient and economical turkey production.

REFERENCES

Abd El-Hack, M. E., El-Saadony, M. T., Salem, H. M., El-Tahan, A. M., Soliman, M. M., Youssef, G. B. A., Taha, A. E., Soliman, S. M., Ahmed, A. E., El-Kott, A. F., Al Syaad, K. M., & Swelum, A. A. (2022). Alternatives to antibiotics for organic poultry production: types, modes of action and impacts on bird's health and production. *Poultry Science*, *101*(4), 101696.

Abo-Al-Ela, H. G., El-Kassas, S., El-Naggar, K., Abdo, S. E., Jahejo, A. R., & Al Wakeel, R. A. (2021). Stress and immunity in poultry: light management and nanotechnology as effective immune enhancers to fight stress. *Cell Stress & Chaperones, 26*(3), 457–472.

Akinyemi, F., & Adewole, D. (2021). Environmental Stress in Chickens and the Potential Effectiveness of Dietary Vitamin Supplementation. *Frontiers in Animal Science, 2*. https://doi.org/10.3389/fanim.2021.775311

Amerah, A. M., & Ravindran, V. (2008). Influence of method of whole-wheat feeding on the performance, digestive tract development and carcass traits of broiler chickens. *Animal Feed Science and Technology*, *147*(4), 326–339.

Ancient Maya Domesticated Wild Turkey 2300 Years Ago. (n.d.). Breaking Science News | Sci-News.com. Retrieved March 10, 2022, from http://www.sci-news.com/archaeology/article00522.html

Aziz Mousavi, S. M. A., Mahmoodzadeh Hosseini, H., & Mirhosseini, S. A. (2018). A review of dietary probiotics in poultry. *Applied biotechnology reports*, *5*(1), 48–54.

Bartz, B. M., & Others. (2016). *Effects of Induced Stress on Turkey Hens Supplemented with Yeast Derived Fermentation Products*. https://repository.lib.ncsu.edu/bitstream/handle/1840.16/11343/etd.pdf?sequence=2

Bir, C., Davis, M., Widmar, N., Zuelly, S., & Erasmus, M. (2019). Perceptions of Animal Welfare with a Special Focus on Turkeys. *Frontiers in Veterinary Science*, *6*, 413.

Boling, S. D., & Firma, J. D. (1997). Rendered By-Products as Soybean Meal Replacement in Turkey Rations. *The Journal of Applied Poultry Research*, *6*(2). https://doi.org/10.1093/japr/6.2.210

Borg, B. S., Campbell, J. M., Polo, J., Russell, L. E., Rodríguez, C., & Ródenas, J. (2002). Evaluation of the chemical and biological characteristics of spray-dried plasma protein collected from various locations around the world. *Am Assoc Swine Vet*, *33*, 97–100.

Campbell, J. M., Crenshaw, J. D., González-Esquerra, R., & Polo, J. (2019). Impact of Spray-Dried Plasma on Intestinal Health and Broiler Performance. *Microorganisms*, *7*(8). https://doi.org/10.3390/microorganisms7080219

Castro-Muñoz, R. and Ruby-Figueroa, R. (2019) Membrane Technology for the Recovery of High-Added Value Compounds From Meat Processing Coproducts. Pp 127-143. In: Sustainable Meat Production and Processing, Ed. C. M. Galanakis. Academic Press, New York.

Caucci, C., Di Martino, G., Dalla Costa, A., Santagiuliana, M., Lorenzetto, M., Capello, K., Mughini-Gras, L., Gavazzi, L., & Bonfanti, L. (2019). Trends and correlates of antimicrobial use in broiler and turkey farms: a poultry company registry-based study in Italy. *The Journal of Antimicrobial Chemotherapy*, *74*(9), 2784–2787.

Chen, X., Jiang, R., & Geng, Z. (2012). Cold stress in broiler: global gene expression analyses suggest a major role of CYP genes in cold responses. *Molecular Biology Reports*, *39*(1), 425–429.

Collin, A., Buyse, J., van As, P., Darras, V. M., Malheiros, R. D., Moraes, V. M. B., Reyns, G. E., Taouis, M., & Decuypere, E. (2003). Cold-induced enhancement of avian uncoupling protein expression, heat production, and triiodothyronine concentrations in broiler chicks. *General and Comparative Endocrinology*, *130*(1), 70–77.

Dhanalakshmi, S., Devi, R. S., Srikumar, R., Manikandan, S., & Thangaraj, R. (2007). Protective effect of Triphala on cold stress-induced behavioral and biochemical abnormalities in rats. *Yakugaku Zasshi: Journal of the Pharmaceutical Society of Japan*, *127*(11), 1863–1867.

Dixon, L. M., Sparks, N. H. C., & Rutherford, K. M. D. (2016). Early experiences matter: a review of the effects of prenatal environment on offspring characteristics in poultry. *Poultry Science*, *95*(3), 489–499.d

Dohms, J. E., & Metz, A. (1991). Stress--mechanisms of immunosuppression. *Veterinary Immunology and Immunopathology*, *30*(1), 89–109.

Ellis, N. R., & Bird, H. R. (1950). *Byproducts as Feed for Livestock*. https://naldc.nal.usda.gov/catalog/IND43894177

Elwinger, K., Fisher, C., Jeroch, H., Sauveur, B., Tiller, H., & Whitehead, C. C. (2016). A brief history of poultry nutrition over the last hundred years. *World's Poultry Science Journal*, *72*(4), 701–720.

Feed additives. (n.d.). Food Safety. Retrieved March 13, 2022, from https://ec.europa.eu/food/safety/animal-feed/feed-additives_en

Fleshner, M., Nguyen, K. T., Cotter, C. S., Watkins, L. R., & Maier, S. F. (1998). Acute stressor exposure both suppresses acquired immunity and potentiates innate immunity. *The American Journal of Physiology*, *275*(3), R870–R878.

Food and Agriculture Organization of the United Nations. (2018). *The future of food and agriculture: Trends and challenges*. Food & Agriculture Org.

Gadde, U., Kim, W. H., Oh, S. T., & Lillehoj, H. S. (2017). Alternatives to antibiotics for maximizing growth performance and feed efficiency in poultry: a review. *Animal Health Research Reviews / Conference of Research Workers in Animal Diseases*, *18*(1), 26–45.

Gatnau, R., Paul, P. S., & Zimmerman, D. R. (1989). Spray dried porcine plasma as a source of immunoglobulins for newborn piglets. *Journal of Animal Science*, *67*(Suppl 1), 244.

Geraert, P. A., MacLeod, M. G., & Leclercq, B. (1988). Energy metabolism in genetically fat and lean chickens: diet- and cold-induced thermogenesis. *The Journal of Nutrition*, *118*(10), 1232–1239.

Grimes, J. L. (n.d.). Nutritional Determinants for Gut Health and Litter Characteristics in Turkeys. *20th European Symposium on Poultry Nutrition*, 115.

Hangalapura, B. N., Kaiser, M. G., Poel, J. J. van der, Parmentier, H. K., & Lamont, S. J. (2006). Cold stress equally enhances in vivo pro-inflammatory cytokine gene expression in chicken lines divergently selected for antibody responses. *Developmental and Comparative Immunology*, *30*(5), 503–511.

Hangalapura, B. N., Nieuwland, M. G. B., de Vries Reilingh, G., Heetkamp, M. J. W., van den Brand, H., Kemp, B., & Parmentier, H. K. (2003). Effects of cold stress on immune responses and body weight of chicken lines divergently selected for antibody responses to sheep red blood cells. *Poultry Science*, *82*(11), 1692–1700.

Helmreich, D. L., Parfitt, D. B., Lu, X.-Y., Akil, H., & Watson, S. J. (2005). Relation between the hypothalamic-pituitary-thyroid (HPT) axis and the hypothalamic-pituitary-adrenal (HPA) axis during repeated stress. *Neuroendocrinology*, *81*(3), 183–192.

Henrichs, B. S., Brost, K. N., Hayes, C. A., Campbell, J. M., & Drackley, J. K. (2021). Effects of spray-dried bovine plasma protein in milk replacers fed at a high plane of nutrition on performance, intestinal permeability, and morbidity of Holstein calves. *Journal of Dairy Science*, *104*(7), 7856–7870.

Huff, G. R., Huff, W. E., Wesley, I. V., Anthony, N. B., & Satterlee, D. G. (2013). Response of restraint stress-selected lines of Japanese quail to heat stress and Escherichia coli challenge. *Poultry Science*, *92*(3), 603–611.

Huff, G., Huff, W., Rath, N., Balog, J., Anthony, N. B., & Nestor, K. (2006). Stress-induced colibacillosis and turkey osteomyelitis complex in turkeys selected for increased body weight. *Poultry Science*, *85*(2), 266–272.

Jędrejek, D., Levic, J., Wallace, J., & Oleszek, W. (2016). Animal by-products for feed: characteristics, European regulatory framework, and potential impacts on human and animal health and the environment. *Journal of Animal and Feed Sciences*, *25*(3), 189–202.

Kogut, M. H. (2022). Role of diet-microbiota interactions in precision nutrition of the chicken: facts, gaps, and new concepts. *Poultry Science*, *101*(3), 101673.

Koutsos, E. A., & Klasing, K. C. (2014). Chapter 17 - Factors Modulating the Avian Immune System. In K. A. Schat, B. Kaspers, & P. Kaiser (Eds.), *Avian Immunology (Second Edition)* (pp. 299–313). Academic Press.

Landers, T. F., Cohen, B., Wittum, T. E., & Larson, E. L. (2012). A review of antibiotic use in food animals: perspective, policy, and potential. *Public Health Reports*, *127*(1), 4–22.

Mehdi, Y., Létourneau-Montminy, M.-P., Gaucher, M.-L., Chorfi, Y., Suresh, G., Rouissi, T., Brar, S. K., Côté, C., Ramirez, A. A., & Godbout, S. (2018). Use of antibiotics in broiler production: Global impacts and alternatives. *Animal Nutrition (Zhongguo Xu Mu Shou Yi Xue Hui)*, *4*(2), 170–178.

Moody, J. (2018, January 23). *The Chicken: A Brief History of America's Most Consumed Meat*. The Weston A. Price Foundation. https://www.westonaprice.org/health-topics/farm-ranch/chicken-brief-history-americas-consumed-meat/

National Research Council (US) Committee to Study the Human Health Effects of Subtherapeutic Antibiotic Use. (1980). *Antibiotics In Animal Feeds*. National Academies Press (US).

Onderci, M., Sahin, N., Sahin, K., and Kilic, N. (2003). Antioxidant properties of chromium and zinc: in vivo effects on digestibility, lipid peroxidation, antioxidant vitamins, and some minerals under a low ambient temperature. *Biological Trace Element Research*, *92*(2), 139–150.

Pérez-Bosque, A., Amat, C., Polo, J., Campbell, J. M., Crenshaw, J., Russell, L., & Moretó, M. (2006). Spray-dried animal plasma prevents the effects of Staphylococcus aureus enterotoxin B on intestinal barrier function in weaned rats. *The Journal of Nutrition*, *136*(11), 2838–2843.

Pérez-Bosque, A., Polo, J., and Torrallardona, D. (2016). Spray dried plasma as an alternative to antibiotics in piglet feeds, mode of action and biosafety. *Porcine Health Management*, *2*, 16.

Pirgozliev, V., Rose, S. P., and Ivanova, S. (n.d.). *Feed additives in poultry nutrition*. Retrieved March 11, 2022, from https://www.agrojournal.org/25/01s-02.pdf

Roman, E. A., Cesquini, M., Stoppa, G. R., Carvalheira, J. B., Torsoni, M. A., and Velloso, L. A. (2005). Activation of AMPK in rat hypothalamus participates in cold-induced resistance to nutrient-dependent anorexigenic signals. *The Journal of Physiology*, *568*(Pt 3), 993–1001.

Scanes, C. G. (2016). Biology of stress in poultry with emphasis on glucocorticoids and the heterophil to lymphocyte ratio. *Poultry Science*, *95*(9), 2208–2215.

Selye, H. (1956**).** The Stress of Life. McGraw-Hill Book Company, New York.

Selye, H. (1959). Perspectives in stress research. *Perspectives in Biology and Medicine*, *2*(4), 403–416.

Shahir, M. H., Dilmagani, S., & Tzschentke, B. (2012). Early-age cold conditioning of broilers: effects of timing and temperature. *British Poultry Science*, *53*(4), 538–544.

Smith, S. M., & Vale, W. W. (2006). The role of the hypothalamic-pituitary-adrenal axis in neuroendocrine responses to stress. *Dialogues in Clinical Neuroscience*, *8*(4), 383–395.

Song, Z., Liu, L., Yue, Y., Jiao, H., Lin, H., Sheikhahmadi, A., Everaert, N., Decuypere, E., & Buyse, J. (2012). Fasting alters protein expression of AMP-activated protein kinase in the hypothalamus of broiler chicks (Gallus gallus domesticus). *General and Comparative Endocrinology*, *178*(3), 546–555.

Świątkiewicz, S., Arczewska-Włosek, A., & Józefiak, D. (2014). *Immunomodulatory efficacy of yeast cell products in poultry: a current review*. *70*(1), 57–68.

Teillant, A., & Laxminarayan, R. (n.d.). *Economics of antibiotic use in U.s. swine and poultry production*. Retrieved March 11, 2022, from https://www.cddep.org/wp-content/uploads/2017/06/choices_1.15-1.pdf

Tsigos, C., Kyrou, I., Kassi, E., & Chrousos, G. P. (2020). Stress: Endocrine Physiology and Pathophysiology. In K. R. Feingold, B. Anawalt, A. Boyce, G. Chrousos, W. W. de Herder, K. Dhatariya, K. Dungan, J. M. Hershman, J. Hofland, S. Kalra, G. Kaltsas, C. Koch, P. Kopp, M. Korbonits, C. S. Kovacs, W. Kuohung, B. Laferrère, M. Levy, E. A. McGee, … D. P. Wilson (Eds.), *Endotext*. MDText.com, Inc.

Tumpey, T. M., Kapczynski, D. R., & Swayne, D. E. (2004). Comparative susceptibility of chickens and turkeys to avian influenza A H7N2 virus infection and protective efficacy of a commercial avian influenza H7N2 virus vaccine. *Avian Diseases*, *48*(1), 167–176.

Turkey Profile. (n.d.). Retrieved March 10, 2022, from https://www.agmrc.org/commodities-products/livestock/poultry/turkey-profile

Turkey Sector: Background & Statistics. (n.d.). Retrieved March 10, 2022, from https://www.ers.usda.gov/newsroom/trending-topics/turkey-sector-background-statistics/

Tyler, G. (n.d.). *[No title]*. Retrieved March 10, 2022, from https://socialeurope.eu/getting-to-zero-whats-the-beef

W.B. Cannon, W. B. (1926). Physiological regulation of normal states: some tentative postulates concerning biological homeostatics. A. Pettit (Ed.), A Charles Richet: ses amis, ses collègues, ses élèves, Les Éditions Médicales (1926), p. 91. Paris

Weaver, A. C., Campbell, J. M., Crenshaw, J. D., Polo, J., & Kim, S. W. (2014). Efficacy of dietary spray dried plasma protein to mitigate the negative effects on performance of pigs fed diets with corn naturally contaminated with multiple mycotoxins. *Journal of Animal Science*, *92*(9), 3878–3886.

Whitnall Tim, & Pitts Nathan. (n.d.). Global trends in meat consumption. *Agricultural Commodities*, *9*(1), 96–99. *Molecular Biology Reports*, *39*(1), 425–429.

Zhang, Y., Zheng, P., Yu, B., He, J., Yu, J., Mao, X. B., Wang, J. X., Luo, J. Q., Huang, Z. Q., Cheng, G. X., & Chen, D. W. (2016). Dietary spray-dried chicken plasma improves intestinal barrier function and modulates immune status in weaning piglets. *Journal of Animal Science*, *94*(1), 173–184.

Zhao, F.-Q., Zhang, Z.-W., Wang, C., Zhang, B., Yao, H.-D., Li, S., & Xu, S.-W. (2013). The role of heat shock proteins in inflammatory injury induced by cold stress in chicken hearts. *Cell Stress & Chaperones*, *18*(6), 773–783.

INTRODUCTION

As an industry with a large economic impact in many countries, the poultry industry has enjoyed continuous growth and innovation, not just for consumers and producers but also for the welfare of the animals. With consumers having preferences towards healthier, “friendlier” food, producers are required to meet or keep up with these preferences. Consumers have become more aware of what they eat, and they are also more aware of what the food animals they consume are being fed and how they are raised. Animal welfare and well-being have become a major target issue in the industry. Since turkey is considered a lean meat, consumption is increasing (Singh et al., 2004), as well as production to provide quality products. Consumers are increasingly concerned about antibiotic usage in food animal production. Thus, the market for birds reared with no antibiotic growth promotors (AGP), antibiotic free programs (ABF), or no antibiotics ever (NAE) (Gould, 2012; Rubin, 2014; Olenjik, 2016) is rising, and, therefore, creating opportunities for producers to develop substitutions for antibiotics or solutions for consumer concerns. Although the use of antibiotics has never been ideal, the industry faces health issues that need to be addressed when it comes to production of safe food products. Diseases, caused by poor management, non-optimum environmental conditions, transportation, and more appear to cause not only stress but economic loss for the poultry industry (Kabir, 2009). Having a low stress environment is considered desirable for general livestock production, and this is especially desirable, given the economic impact, to the poultry industry in several countries.

Stress responses are perceived in various ways and are described differently within individual growing conditions. The physiological response(s) to a stressor is defined as a state of real or perceived threat to homeostasis (Smith and Kale, 2006; Koutsus and Klasing, 2014). It has been acknowledged that optimum production in animals is reduced by many stressors, such as the environment (heat and cold, increased population density, ammonia, wet litter), pathology (bacterial, viral, and parasitic infections), nutrition (unbalanced feeds, no feed, oxidized feed ingredients), and many other factors (increased noise levels, strange animal invasions, etc.). The resultant physiological alterations called stress indicate the continued need for improvements in the science of animal management and housing technology to meet the needs of genetically improved flocks.

While there is an array of factors that can affect production, the environment in which poultry is maintained, in this case turkeys, may be the most important factor that affects productivity. In the case of the turkey's environment, one must be conversant in factors such as methods of confinement, management system, bird surroundings and their relationship, and of course thermodynamics within the barns housing the turkeys. Maintaining proper conditions such as air movement, humidity, light levels, and access to feed and water can reduce stress related responses such as decreased appetite, which can directly affect performance and production. Factors such as cold, heat, stocking density, diseases or other types of stressors can affect feed intake and growth, which can negatively impact the birds' immune system (Abo-Al-Ela, 2021). External and internal stimuli, perceived through the central nervous system, mediate subsequent stress type reactions in the birds. Additionally, the character of the stress response can be categorized as being specific or non-specific. Specific responses are related to such things as increased heart rate, altered body temperature, elevated respiratory rate, decreased feed intake when a bird experiences a physical stressor either via internally or externally delivered stimulus. Alternatively, non-specific stress response is characterized by such classical responses associated with elevated glucocorticoid levels, elevated cholesterol levels, increased rates of gluconeogenesis to meet increased metabolic needs and induction of a rapid sympathoadrenal response with increased secretion of epinephrine from the adrenal cortex. The non-specific stress responses are mediated in response to all stressors and often are associated with stressors that generate specific stress reactions. Obviously, the induced stress responses cause different levels of stress within individual affected animals. The general level of stress in those individuals will be related to the severity and duration of the inducing stressor and will be buffered or exacerbated by prevailing the physiological state of the affected animal (Savino et al, 2016; Abo- Al- Ela, 2021). During severe stress reactions, the immune system becomes compromised by all the adaptive physiological changes occurring in the birds' bodies. Immunosuppression can occur because of either acute (short-term) or chronic (long-term) stress. The difference between acute (short-term) and chronic (long-term) stress is the duration of that stress and both specific and non-specific stress responses can be observed in each condition. In poultry, acute stress can have long term effects, not just in production but also economically. Stress can cause disruption in certain physiological roles that can cause a high disease susceptibility (Graczyk et al.,2006; Pierson et al, 1996; Boa-Amponsem et al., 1999; Rautenschlein and Sharma,1999).

The exposure time to stressors can also harm the immune system due to interactions with the stress hormone corticosterone (Dixon et al.,2016). Corticosterone, the avian stress hormone, acts on cardiovascular, immune, behavioral, and metabolic regulations in birds (Smith and Vale, 2006). Responses to stressors can be either non-specific or specific that involve the endocrine, immune, and nervous system (Smith and Vale,2006). There are certain organs that receive direct impact from stressor such as, the bursa of Fabricius, thymus, and the spleen, reducing their proper growth (Liu et al., 2014). The consequences of these stress responses encumber the immune cell population and reduces the counts of blood leukocytes and lymphocyte and serum immunoglobins (IgM, IgG [IgY], IgA) (Roushdy et al., 2020). These blood cells and components have important rolls in the immune system. Leukocytes are part of the immune system of an animal or human that help the body fight infections and diseases, whereas lymphocytes are a type of blood cell that is made in bone marrow and can be found in the lymph tissue and blood. Two types of lymphocytes (T cells and B cells) can make antibodies that can attack different types of viruses, bacteria, and toxins.

There is a very broad spectrum of literature that addresses how the immune system functions and how SDP reacts in chickens. A significant portion of the immunological data were obtained as the result of testing the immune system of birds given a variety of pharmaceutical products and how those products might have affected or improved poultry production. Food animal production is more than just giving food and water to the animals and observing their growth. From hatchery to the processing plant, it is important to document critical periods in development to develop management protocols to deal with the weak periods. Prophylactic management has proved to be a better management procedure than therapeutic management.

One of the many products receiving considerable attentions in the livestock and poultry industry is Spray Dried Plasma (SDP) obtained from bovine or swine plasma. The SDP is a highly digestible protein ingredient that is rich in functional molecules which is manufactured from animal blood collected from federally inspected slaughter facilities (Coffey and Cromwell ,2001; APC,2019). This is later spray dried to preserver the proper functionality of its components. Some of the proteins, peptides, and some nutrients contained in SDP include albumen, globulins, immunoglobulins, transferrin, amino acids, cytokines, growth factors, and other nutritional components that are reportedly beneficial to animals (APC, 2019; Tujimoto-Silva et al., 2021). Dietary constituents usually neither directly stimulate the immune system nor interfere with its functions. However, many dietary ingredients appear to modulate or enhance faster and more efficient responses (Abo-Al-Ela 2021; APC, 2019). Although SDP has been tested primarily in pigs, mice, and rats, chickens apparently respond positively to SDP (Campbell et al., 2019; Campbell et al.,2006; Song M et al., 2015; Zhang et al., 2016; Weaver et al.,2016). This supplementary protein in SDP appears to mitigate intestinal inflammation (Moreto and Perez-Bosque, 2009). The effects of SDP are not limited to the gastrointestinal system, but also enhance the respiratory and reproductive systems (Song et al, 2015; Lui et al., 2014). Nutrition is a key factor in all phases of animal development. It affects all phase of the actions of the immune system modulating cell proliferation and activation, phagocytosis, primary and secondary lymphoid tissue development, mucus production, and synthesis of immune modulators, basically exerting a very strong influence on the overall functioning of the immune system. (Abo- Al-Ela et al.,2021). Therefore, certain nutritional alternatives are used. Immunomodulation can be defined as any manipulation of the immune system using exogenous means to control the infections and other adverse health effects (Petrovsky and Aguilar, 2004). Nutritional immunomodulation can be defined as the supplementation of a specific dietary nutrient or feed additive that can cause an alteration in the immune system's function to achieve a certain goal (Korver, 2012). Each species has its own nutritional requirements to develop properly in a specific time, and it is important that those requirements are met for the benefit of the animal leading to economic benefit for the producer. If a bird experiences nutritional deficiencies, the bird's ability to develop an effective immune system will be severely limited (Kidd, 2004). Turkeys and chickens, although very dissimilar in many aspects of their development and physiological capabilities, do share some physical characteristics. One of the greatest physical differences resides in their growth to a market age related to body size. Turkey production has an inherently higher economical risk associated with many aspects of their daily lives. As they age and grow heavier, the potential costs of daily losses increase significantly. Thus, turkey flock management is very demanding requiring close observation to intervene in developing problems associated with growth, including the functioning of the immune system. Turkeys grow through critical stress periods, one being associated with early poult mortality during 1 to10 and 10 to 20 days post hatch, and a second associated with the transfer from brooding to grow-out houses at 4 to 7 weeks of age, and a third time being associated with load out for transportation to the processing plant. When being transferred to grow out houses, turkeys can be exposed to heat or cold stressors, depending on the season, and exposure to potential pathogens. Thus, considering those three vital periods during the development of marketable birds, it is vitally important that the birds possess a strong immune system.

Broiler chickens, fed SDP, have shown important post-hatch developmental responses; however, little is known about SDP effects in turkeys. Thus, the objective of this thesis was to test different levels of dietary SDP fed to turkeys during the brooder period, and document their performance and development as influenced by management under a standard protocol at the NC State University Talley Turkey Educational Field Laboratory.

MATERIALS AND METHODS

Housing and Brooding

A total of 1440 Large White commercial turkey hen poults (Nicholas Select, Aviagen Turkeys, Lewisburg, WV) were obtained from a commercial hatchery (Prestage Family Farms, Clinton, NC) and transported to the NC State university Talley Turkey Education Unit (Raleigh, NC). All birds were beak and toe conditioned. The birds were then placed in a curtain-sided house with power ventilation. The house consisted of 48 pens (8 x 11.5 feet) organized in 4 blocks of 12 pens each. There were a total of 3 treatments with 16 replicate pens of birds per treatment with equal representation in each of the 4 blocks (4 replicates of each treatment in each block). Each pen housed 30 birds which were reduced to 28 birds per pen at 6 weeks of age due to sampling. During the brooding period supplemental drinkers and feeders were provided along with the feeder and the bell drinker already inside the pen. The poults were reared in brooder rings inside each pen. The rings as well as the supplemental feeders and drinkers were removed after 7 days of age. Heat lamps, fitted with thermostats for temperature control, were placed in each ring and were used according to bird comfort. Hallways on both ends of the house were sprayed with water daily for 6 weeks to increase house humidity and to suppress dust accumulation. Fresh pine wood shavings, mixed with old litter from a previous flock, as the source of the bedding for birds.

Temperature & Lighting

House temperature was started at 90˚F for 2 days, 88˚F for 2 days and 85˚F for 10 days. Beginning at week 3, house temperature was decreased by 5˚F each week until ambient temperature was reached. As per the lighting program photo phase was set at 14 hours per day using LED lights. House temperature was decreased to 55˚F at 5 weeks of age for 24 hours to simulate a winter move from brooding to growing house.

Feed manufacturing and programming

All feed phases and treatments were manufactured at the North Carolina State University Feed Mill Educational Unit. Bovine spray dried plasma (SDBP) (APC, Europe S.L.U.) was formulated iso-nutritionally into the diets. This product was used for a total of 6 weeks in the early feed phases (starter 1 and grower 1) at different percentages of inclusion. Treatments included a control diet (0% plasma), 1.0% plasma inclusion (AP1) and 2.0% plasma inclusion (AP2). After 6 weeks, common diets were fed (grower 2 and finisher 1). This study included four feed phases: starter1 (S1), grower1 (G1), grower 2 (G2) and finisher 1(F1). The S1 and G1 were crumble while the G2 and F1 diets were fed as pellets (Tables 1, 2, and 3).

Feed was made available on an *ad libitum* basis. Feed phases were provided by age- meaning that feed was dumped after weigh back (feeder and feed were weighed) on each weigh day changing from one feed phase to the next. Weights of feed added were recorded on pen sheets to generate calculations of different parameters. Feed was removed at 5 weeks for a period of 24 hours (to induce stress and simulate the end of the brooding period in the field).

Table 1. Starter ingredient and nutrient composition of dietary treatments fed to turkey hens for the first 3 weeks of the trial.

Ingredient, % "as-fed"	Control	AP1%	AP2%
Age fed (weeks)	0 to 3	0 to 3	0 to 3
Form	Crumble	Crumble	Crumble
Corn	23.60	25.0	26.10
Soybean Meal, 46 % Crude Protein	33.40	31.60	30.00
Poultry by Product Meal	10.00	10.00	10.00
Wheat	20.0	20.0	20.0
Poultry Fat	6.765	6.265	5.865
Monocalcium phosphate, 21% P	2.500	2.475	2.450
Limestone	1.800	1.825	1.850
L-Lysine-HCl (78%)	0.460	0.440	0.410
D-L Methionine	0.425	0.425	0.430
Sodium Bicarbonate	0.15	0.15	0.15
Choline Chloride (60%)	0.20	0.20	0.20
Vitamin Premix[2]	0.20	0.20	0.20
Trace mineral premix[1]	0.20	0.20	0.20
Salt	0.20	0.14	0.08
L-Threonine	0.05	0.03	0.015
Selenium Mix, 0.06%[3]	0.05	0.05	0.05
AP920[4]	0	1.000	2.000
Total %	100.00	100.00	100.00
Calculated analysis, % (unless otherwise noted)			
AMEn, kcal/lb	1,377	1,377	1,377
Crude Protein	28.1	28.1	28.1
Digestible Lysine	1.61	1.61	1.61
Calcium	1.51	1.51	1.51
Sodium	0.18	0.18	0.18
Fat	9.94	9.47	9.10

Abbreviation: AME_n, apparent metabolizable energy

[1]Mineral premix include per kg of diet: Mn (manganese sulfate), 120 mg; Zn (zinc sulfate), 120 mg; Fe (iron sulfate monohydrate), 80 mg; Cu (tri-basic copper chloride), 10 mg; I (ethylenediamine dihydriodide), 2.5 mg; and Co (cobalt), 1 mg.

[2]Vitamin premix includes per kg of diet: Vitamin A (Vitamin A acetate), 6600 IU; Vitamin D (cholecalciferol), 1980 IU; Vitamin E (DL-alpha tocopherol acetate), 33 IU; menadione (menadione sodium bisulfate complex), 2 mg; Vitamin B12 (cyanocobalamin), 0.02 mg; folacin (folic acid), 1.1 mg: D-pantothenic acid (calcium pantothenate), 11 mg; riboflavin (riboflavin), 6.6 mg; niacin (niacinamide), 55 mg; thiamin (thiamin mononitrate), 2 mg; D-biotin (biotin), 0.13 mg; and pyridoxine (pyridoxine hydrochloride), 4 mg.

[3]Selenium premix provided Se at 0.3 mg/kg of feed.

[4] AP920, animal plasma feed ingredient (AP 920, APC Inc., Ankeny, IA).

Table 2. Grower 1 ingredient and nutrient composition of dietary treatments fed to turkey hens from week 3 to 6 weeks of age.

Ingredient, % "as-fed"	Control	AP1%	AP2%
Age fed (weeks)	3 to 6	3 to 6	3 to 6
Form	Crumble	Crumble	Crumble
Corn	32.10	33.40	34.55
Soybean Meal, 46 % Crude Protein	26.30	24.60	23.00
Poultry by Product Meal	10.0	10.0	10.0
Wheat	20.0	20.0	20.0
Poultry Fat	5.845	5.373	4.935
Monocalcium phosphate, 21% P	2.300	2.250	2.225
Limestone	1.600	1.625	1.650
L-Lysine-HCl (78%)	0.445	0.415	0.380
D-L Methionine	0.355	0.357	0.3600
Sodium Bicarbonate	0.15	0.15	0.15
Choline Chloride (60%)	0.20	0.20	0.20
Vitamin Premix[2]	0.20	0.20	0.20
Trace mineral premix[1]	0.20	0.20	0.20
Salt	0.20	0.14	0.08
L-Threonine	0.055	0.040	0.020
Selenium Mix, 0.06%[3]	0.05	0.05	0.05
AP920[4]	0	1.000	2.000
Total %	100.00	100.00	100.00
Calculated analysis, % (unless otherwise noted)			
AME_n, kcal/lb	1,406	1,406	1,406
Crude Protein	25.1	25.1	25.1
Digestible Lysine	1.43	1.43	1.43
Calcium	1.38	1.38	1.38
Sodium	0.18	0.18	0.18
Fat	9.23	8.78	8.37

Abbreviation: AME_n, apparent metabolizable energy

[1]Mineral premix include per kg of diet: Mn (manganese sulfate), 120 mg; Zn (zinc sulfate), 120 mg; Fe (iron sulfate monohydrate), 80 mg; Cu (tri-basic copper chloride), 10 mg; I (ethylenediamine dihydriodide), 2.5 mg; and Co (cobalt), 1 mg.

[2]Vitamin premix includes per kg of diet: Vitamin A (Vitamin A acetate), 6600 IU; Vitamin D (cholecalciferol), 1980 IU; Vitamin E (DL-alpha tocopherol acetate), 33 IU; menadione (menadione sodium bisulfate complex), 2 mg; Vitamin B12 (cyanocobalamin), 0.02 mg; folacin (folic acid), 1.1 mg: D-pantothenic acid (calcium pantothenate), 11 mg; riboflavin (riboflavin), 6.6 mg; niacin (niacinamide), 55 mg; thiamin (thiamin mononitrate), 2 mg; D-biotin (biotin), 0.13 mg; and pyridoxine (pyridoxine hydrochloride), 4 mg.

[3]Selenium premix provided Se at 0.3 mg/kg of feed.

[4] AP920, animal plasma feed ingredient (AP 920, APC Inc., Ankeny, IA).

Table 3. Common Grower 2 and Finisher 1ingredient and nutrient composition of dietary treatments fed to turkey hens from 6 to 12 weeks of age.

Ingredient, % "as-fed"	Common Grower 2	Common Finisher 1
Age fed (weeks)	6 to 9	9 to 12
Form	Pellets	Pellets
Corn	38.80	43.30
Soybean Meal, 46 % Crude Protein	20.0	15.50
Poultry by Product Meal	10.0	10.0
Wheat	20.0	20.0
Poultry Fat	5.920	6.590
Monocalcium phosphate, 21% P	1.950	1.800
Limestone	1.450	1.250
L-Lysine-HCl (78%)	0.460	0.275
D-L Methionine	0.350	0.210
Sodium Bicarbonate	0.15	0.15
Choline Chloride (60%)	0.20	0.20
Vitamin Premix[2]	0.20	0.20
Trace mineral premix[1]	0.20	0.20
Salt	0.20	0.20
L-Threonine	0.070	0.075
Selenium Mix, 0.06%[3]	0.05	0.05
AP920[4]	0	0
Total %	100.0	100.0
Calculated analysis, % (unless otherwise noted)		
AME_n, kcal/kg	1,450	1,500
Crude Protein	22.4	20.2
Digestible Lys	1.29	1.04
Calcium	1.25	1.14
Sodium	0.18	0.18
Fat	9.43	10.17

Abbreviation: AME_n, apparent metabolizable energy

[1]Mineral premix include per kg of diet: Mn (manganese sulfate), 120 mg; Zn (zinc sulfate), 120 mg; Fe (iron sulfate monohydrate), 80 mg; Cu (tri-basic copper chloride), 10 mg; I (ethylenediamine dihydriodide), 2.5 mg; and Co (cobalt), 1 mg.

[2]Vitamin premix includes per kg of diet: Vitamin A (Vitamin A acetate), 6600 IU; Vitamin D (cholecalciferol), 1980 IU; Vitamin E (DL-alpha tocopherol acetate), 33 IU; menadione (menadione sodium bisulfate complex), 2 mg; Vitamin B12 (cyanocobalamin), 0.02 mg; folacin (folic acid), 1.1 mg: D-pantothenic acid (calcium pantothenate), 11 mg; riboflavin (riboflavin), 6.6 mg; niacin (niacinamide), 55 mg; thiamin (thiamin mononitrate), 2 mg; D-biotin (biotin), 0.13 mg; and pyridoxine (pyridoxine hydrochloride), 4 mg.

[3]Selenium premix provided Se at 0.3 mg/kg of feed.

[4] AP920, animal plasma feed ingredient (AP 920, APC Inc., Ankeny, IA).

Water Water was provided on an ad libitum basis. At 5 weeks of age, water was removed for a period of 24 hours (to simulate the end of the brooding period in the field-).

Turkey management*:* Turkeys were weighed individually at placement, 3, 6, 9, and 12 weeks of age. Weights were recorded and used to calculate feed intake, weight gain and feed conversion ratio.

Animal Ethics*:* Turkeys were observed at least twice a day, in the morning and afternoon. Any mortalities were removed, weighed, and recorded as well as feeder weigh back. Birds that needed to be culled due to injuries, leg issues, or any type of health issue were removed and properly euthanized. Employees and students that participated in this project were all trained properly for the handling of animals. The handling of birds and any required procedure was approved by the NCSU Institutional Animal Care and Use Committee.

Carcass and meat yield at the end of the trial: At 12 weeks, two birds per pen were selected by average weight. Birds were humanely stunned and slaughtered. During processing, hen carcass and breast weight were measured to calculate carcass yield (in relation to the body weight at slaughter) and breast yield (in relation to eviscerated carcass).

Meat Yield Analysis*:* Per performance data, for cold and hot carcass percentages the statistical model was based on diet treatments and house block. For meat yield the statistical model also included the cutter (person who cut the bird) as a blocking factor.

Bone measurements*:* The right tibia from each bird that was processed and collected to measure ash content. Cartilaginous caps were manually removed. Samples were dried at 105ºC for 12 hours and then defatted for 72 hours using Soxhlet petroleum ether in a glass container. Bones were dried again in a drying oven for 24 hours. Then they were weighed and ashed in muffle furnace at 600ºC for 18 hours. Bone ash (bone mineral content) was expressed as percent of the dry defatted bone weight and as the absolute weigh of the tibia in grams.

Before bones were ashed, they were weighed and measured utilizing the 3-point bend method where different measurements were taken utilizing a digital 12” caliper (iGAGING) that was connected to the computer by a data logger. This generated the diameter and length of the bones. Bone breaking strength was measured by applying a force perpendicular to the bone’s diaphysis, where bones were placed on 2 support points measuring 3 cm apart. Using a 250 kg load cell and a crosshead speed of 100mm/min, the force of a shear plate measuring 8cm x 1mm was applied to the midpoint of each bone.

Blood Analysis: Blood was collected from two (2) birds per pen via the brachial wing vein on the day before stress at 5 weeks, the day after stress, and three weeks post stress (8 weeks). Blood plasma was analyzed to determine the stress steroid hormone, corticosterone (CORT). A volume of 3 mL of blood was collected in heparinized needles and syringes from different birds each sampling day by trained individuals. Samples then were placed in individual borosilicate glass culture tubes containing heparin. Samples were later centrifuged at 500 X g for 1 hour to ensure proper plasma separation. Plasma was collected into individual plastic vials that were frozen and then stored in a -80°C freezer until corticosterone analysis could be completed. A corticosterone EIA assay kit (Cayman Chemical, Ann Arbor, MI, USA) was used.

Statistical Analysis: The data in this study were analyzed using a complete randomized block design using ANOVA in JMP® 15, SAS Institute Inc., Cary, NC. Means were separated using Tukey’s HSD procedure within JMP and significance was recognized at $P \leq 0.05$ for all performance and blood data.

RESULTS AND DISCUSSION

Performance data

In other studies, SDP was found to improve body weight (BW), body weight gain (BWG), feed conversion (FC), reduce mortality, gut inflammation as well as other important growth and production parameters. Most experiments were performed on different animals such as swine, broilers, layers, or mice, and there is very little that is reported on SDP in turkeys. Different environments and stressors/challenges were involved in these experiments; however, based on previous research and reported data, the severity of test challenges was correlated with the beneficial effects of SDP in the feed (Campbell et al., 2019). In this specific cold induced stress model, promising results were recorded in the different measured parameters. The corticosterone concentrations increased post stress, feed conversion ratio showed an advantage in the treatments with added product, and birds underperformed in body weight when compared to commercial standards.

Table 4. Mean Body Weight (kg/bird)

Diet	0 d	3 wk	5 wk Pre-Stress(d0)	5 wk Post stress (d1) after stress	6 wk	9 wk	12 wk
AP1[1]	0.052	0.519	1.225	1.138	1.710	3.964	6.555
AP2[2]	0.052	0.499	1.217	1.141	1.738	3.962	6.577
Control	0.052	0.496	1.215	1.137	1.700	3.949	6.575
SEM	0.000	0.009	0.020	0.017	0.021	0.041	0.055
P-value	0.453	0.204	0.922	0.983	0.441	0.958	0.952

[1] Bovine spray dried plasma at 1%
[2] Bovine spray dried plasma at 2%

Body weight

No significant differences due to diet were observed throughout the trial for body weight either at placement or at 12 weeks of age (Table 4). This agrees with the experimental results investigating different sources of added SDP in pigs. The investigators found that both porcine and bovine SDP were effective in increasing BW at 1 week post treatment and that the IgG fraction of each source of SDP was the key fraction in improving weight gain (Pierce et al., 2005). Continuous feeding to chicks with granular SDP was more effective than powder SDP from d 0 to 14. The results of this experiment confirmed that SDP improved broiler growth rate, feed intake, feed efficiency, and minimized enteric challenge associated with necrotic enteritis with maximal protection afforded by continuous feeding (Campbell et al., 2006). The results herein with continuous feeding of SDP to turkey poults to 6 weeks are in contrast with the results of Campbell et al. (2006). Beski et al. (2016) also found a higher body weight in broilers fed with SDP than those fed the control diets. Bregendahl et al. (2005) reported 2 SDP experiments associated with body weight gain in broilers in which the first had an unsanitary environment that produced unconvincing results yet there was increased starter phase feed intake in those broilers. They concluded that the reason for such poor results was attributed to the fact that the environment was not unsanitary enough. Therefore, a second experiment was conducted in which the investigators provided additional challenges to the broilers. The results from the second experiment resulted in increased feed consumption in all phases with the exception of the grower phase and increased body weight in all growth phases (Bregendahl et al., 2005). SDP is used extensively in swine. In an experiment performed on weaned piglets, different treatments and types of SDP were fed. There were SDP related increased average daily gain and average daily feed intake (Balan et al., 2020). Swine consuming SDP have better efficiency and growth rates when they are housed in a challenging environment compared to swine that are housed in a sanitized environment (Coffey and Cromwell, 1995). Improvement in the performance of SDP fed Holstein bull calves challenged with *Escherichia coli* was reported by Quigley et al. (2000). Campbell et al. (2004b) added spray dried bovine serum (SDBS; fibrin removed from plasma) to turkeys' drinking water and subjected the turkeys to two different environmental challenges. Turkeys housed in floor pens with old litter compared to turkeys housed in floor pens with new litter were analyzed for growth response to the SDBP. Turkeys on old litter given the SDBP had a greater growth response than turkeys given SDBP on new litter Campbell et al. (2004b). In another experiment Campbell et al. (2004a) challenged turkeys given SDBP in drinking with *Pasteurella multocida* resulted in increased average daily gain and decreased mortality up to day 35 of 49.

Table 5. Mean Body weight gain (Kg/birds) of turkey poults given dietary supplements of spray dried plasma.

Diet	3-6 wk	6-9 wk	9-12 wk
[1]AP1	1.191	2.254	2.590
[2]AP2	1.238	2.224	2.614
Control	1.204	2.248	2.262
SEM	0.0193	0.333	0.023
P-value	0.2149	0.7989	0.5608

[1] Bovine spray dried plasma at 1%
[2] Bovine spray dried plasma at 2%

Body Weight Gain

There was no significant difference observed for body weight gain due to diet throughout the trial for each period or at 12 weeks of age. Various researchers have noted the positive effects of feeding SDP, from either bovine or swine sources, on body weight gain. It appears that SDP, depending on the food animal species, has critical phases in which the SDP is more effective than in others (van Dijk et al., 2001). SDAP fed to piglets was more effective in the first week rather than the second week; however, body weight and body weight gain was improved in both week 1 and week 2 (van Dijk et al., 2001). Campbell et al. (2006) noted an advantage in average daily gain in SDP fed broilers with necrotic enteritis. Others working with different food animal species have confirmed that SDP has a positive effect on average daily body weight gain (Jamroz et al., 2012; Henn et al., 2013; Walters et al., 2019; Campbell et al., 2004; Coffey and Cromwell, 1995).

Table 6. Feed Intake per bird (Kg/bird*)* given diets supplemented with spray dried plasma.

Diet	0-3 wk	3-6 wk	0-6 wk	6-9 wk	0-9 wk	9-12 wk	0-12 wk
AP1[1]	0.794	2.611	3.398	4.880	7.892	6.834	14.229
AP2[2]	0.783	2.619	3.403	4.965	7.966	6.971	14.536
Control	0.764	2.644	3.408	5.015	7.970	6.891	14.324
SEM	0.019	0.054	0.069	0.074	0.106	0.108	0.163
P-value	0.533	0.910	0.994	0.459	0.842	0.672	0.402

[1] Bovine spray dried plasma at 1%
[2] Bovine spray dried plasma at 2%

Feed Intake

There were no significant differences in feed intake during feeding periods and at 12 weeks among the three treatment groups. These results are in contrast with other published results in food animals fed SDP, which did result in positive growth and feed intake advantages. The nutritional requirements for an animal must be properly formulated according to what each animal needs, as well as proper quantities to be ingested and absorbed properly. Since body weight and feed efficiency are directly affected by feed intake, it is important to properly manage a flock and keep an optimum environment for preservation of health of the birds (Ferket and Gernat, 2006). Feeding SDP to early weaned pigs showed an increase in feed intake in the first 3 weeks (Kats et al., 1994). Feed intake was improved in broilers facing a necrotic enteritis challenge on either continuous or discontinued feed containing SDP (Campbell et al., 2006). Henn et al. (2013) noted improved feed intake in SDP-fed broilers subjected to challenging health conditions. SDPP-fed mice had increased daily feed intake over a 3-week trial (Thomson et al., 1994). Furthermore, SDBS added to the drinking water of turkeys resulted in increased water intake, which is normally positively correlated with increased feed intake (Campbell et al., 2004a). Given the number of observations of increased feed intake when animals are fed SDP, one must wonder why a similar observation was not made in the study herein. Nevertheless, it has been noted that when there have been no health challenges in trials where SDP has been given, positive performance indices have not been found. Thus, it is possible that the turkey barn in which this study was conducted was too clean to elicit improved performance data.

Table 7. Cumulative Feed Conversion Ratio of turkey poults given a dietary supplement of spray dried plasma.

Diet	3 wk	6wk	9wk	12wk
AP1[1]	1.317	1.901[b]	2.038	2.182
AP2[2]	1.278	1.975[ab]	2.110	2.217
Control	1.363	2.041[a]	2.109	2.181
SEM	0.039	0.031	0.032	0.030
P-value	0.317	0.010	0.214	0.638

[a, b] Means within a column lacking a common superscript differ ($P \leq 0.05$).
[1] Bovine spray dried plasma at 1%
[2] Bovine spray dried plasma at 2%

Feed Conversion Ratio

Feed costs can range from 60%-70% of total costs for a turkey commercial grower, and feed efficiency has a large economic impact in the turkey industry and poultry industries in general. Turkey production periods are longer than that of chickens, meaning the economic risk is higher. For this trial, it was decided that mortality would not be included in the calculations for FCR, mimicking the industry. Improvement was found at 6 weeks where the birds fed with SDP had a lower FCR, AP1(1.901) and AP2 (1.975) than birds in the control treatment (2.041). These results benefit the product (AP920) used, however that benefit disappeared once the product was no longer included in the diets throughout the remaining growing period. No differences were found at 12 weeks of age. Campbell et al, (2006) reported effects on feed efficiency in broiler performance where birds were in a challenged environment. The inclusion of 2% SDP showed an improvement in FCR in broilers' starter feed, but it showed no impact in grower and finisher treatments when compared to control (Walters et al., 2019). Continuous provision of SDP feed to the birds herein resulted in the improvement in feed efficiency then those that were fed SDP for the first two weeks and discontinued. Feeding broilers with SDP in the first days of their life has proven to be effective for performance at the end of the cycle (Belote, et al., 2021). Earlier, Walters et al. (2019) added SDP in the broiler starter phase, which resulted in improved overall FCR. Beski et al. (2016) has reported similar results. Turkeys given SDBS in their water had improved FCR at the end of the trial (Campbell et al., 2004b). Broilers fed SDP in battery cages, showed improved FCR (Jamroz et al., 2012) but (Campbell et al., 2003) reported battery cage housing resulted in small performance differences in comparison with floor-pen housing when using SDP. The FCR was also reported to improve in weanling piglets when fed SDP at an early age (van Dijk et al., 2001).

Table 8. Effect of feeding spray dried plasma on 12 weeks old female turkey carcass and parts yield.

Diet	Live Weight (kg)	Hot Carcass %	Cold Carcass %	Thigh %	Drums %	Wings %	Breast Skin %	Breast Major %	Minor Breast %	Breast Rack %
AP1[1]	6.75	78.17	80.01	16.23	13.01	12.41	2.08	20.66	5.81	29.44
AP2[2]	6.77	77.85	79.60	16.47	13.02	12.6	2.04	19.94	5.48	29.80
Control	6.80	78.02	80.08	16.47	12.96	12.35	1.98	20.37	5.83	29.47
SEM	0.07	0.64	0.29	0.17	0.13	0.12	0.73	0.34	0.17	0.54
P value	0.91	0.24	0.47	0.30	0.94	0.35	0.33	0.33	0.33	0.87

[1]Bovine spray dried plasma at 1%
[2] Bovine spray dried plasma at 2%

Meat Yield (%)

Stress of any type such as suboptimal management and/or environment can cause a negative economic impact in body weight, feed intake and feed conversion, but also carcass yield and meat quality are frequently affected negatively by even small stressful events (Campbell et al., 2019). For meat yield, no significant differences. Bregendahl et al. (2005) performed two experiments with SDP-fed broilers with different levels of stress. The first experiment showed no improvements in performance or carcass measurements, whereas the second experiment showed improvement in performance data and breast meat yield. In experiments conducted by Hann et al. (2013), there was no effect due to inclusion of SDP in starter and grower diets regarding carcass or cut yields in 42-day old broilers.

Different kinds of blood plasma can be used as a protein source for animal diets. The results of Longo et al. (2007) are in line with results from a turkey trial where SDP supplement to feed did not differ among treatments. Early manipulation of nutrients can affect the deposition of meat and fat in the carcass of chickens, but proper protein availability in the prestart phase has not increased muscle development in later phases.

Table 9. Influence of supplemented dietary spray dried plasma on poult mortality.

Diet	3 wk	6 wk	9 wk	12 wk
AP1[1]	3.40	4.44	6.10	10.27
AP2[2]	3.54	6.25	9.79	11.88
Control	3.75	5.83	7.92	10.62
SEM	0.864	1.023	1.454	1.691
P-value	0.96	0.43	0.21	0.78

[1] Bovine spray dried plasma at 1%
[2] Bovine spray dried plasma at 2%

Mortality (%)

Feed based SDP has shown beneficial effects when provided in the first phases of production diets with a prolonged effect in performance and overall health of animals. Mortality in any livestock production system represents an economic loss that affects the industry negatively; however, this can be addressed with proper handling, management, and adequate nutritional provision. Campbell et al. (2006) observed a large decrease in mortality in an experiment where broilers were exposed to a severely challenged by necrotic enteritis where the survival of broilers given the control diet was only 56%. However, SDP-fed broilers had a 90% survival rate. Supplementing SDBS in drinking water for turkey poults challenged by *Pasteurella multocida*, improved survivability (94%) in SDBS-treated poults, but poults given untreated drinking water had only a 63% survival rate (Campbell et al., 2004a). Cherian et al. (2019) reported that chickens with a history of inclusion body hepatitis and fed SDP reduced mortality from 6.5% to 3.9% when compared to the control diets. In broilers Gonzalez- Esquerra et al. (2019), reported lower mortality rates due to *E. coli* and *Streptococcus* (14%) in SDP-fed broilers compared to control-fed broilers

(84%). In a comparison of nursery pigs with different feed programs (with and without SDP), pig mortality did not differ throughout feeding phases (Crenshaw et al., 2019).

Blood Analysis

Table 10. Blood Analysis Pre-stress

Diet	ALT (units/liter)	Protein (g/dl)	AST (units/liter)	Albumin (g/dl)	IgA (mg/dl)	IgG (mg/dl)	IgM (mg/dl)
0998AP1[1]	1.42	1.15	199.0	1.51	10.79	12.03	21.30
AP2[2]	2.36	1.53	204.4	1.54	14.58	20.73	29.35
Control	4.77	1.65	211.6	1.54	13.96	31.33	35.91
SEM	1.143	0.218	9.268	0.038	1.725	7.189	6.091
P-value	0.114	0.254	0.632	0.836	0.261	0.176	0.247

[1] Bovine spray dried plasma at 1%
[2] Bovine spray dried plasma at 2%

Table 11. Blood Analysis Post Stress

Diet	ALT (units/liter)	Protein (g/dl)	AST (units/liter)	Albumin (g/dl)	IgA (mg/dl)	IgG (mg/dl)	IgM (mg/dl)
AP1[1]	2.23	1.10	268.6	1.61	13.73	74.28	23.25
AP2[2]	3.75	1.50	257.5	1.61	12.83	67.48	27.08
Control	4.90	1.62	282.7	1.61	12.48	68.15	31.11
SEM	1.372	0.217	10.06	0.025	0.611	6.105	3.558
P-value	0.394	0.219	0.220	0.990	0.336	0.688	0.306

[1]Bovine spray dried plasma at 1%
[2] Bovine spray dried plasma at 2%

Table 12. Blood Analysis 3 weeks post stress.

Diet	ALT (units/liter)	Protein (g/dl)	AST (units/liter)	Albumin (g/dl)	IgA (mg/dl)	IgG (mg/dl)	IgM (mg/dl)
[1]AP1	2.49	1.26	219.7	1.63	10.95	104.37	44.51
[2]AP2	3.00	1.58	234.3	1.63	12.00	104.03	50.06
Control	3.37	1.86	229.3	1.67	12.26	101.83	50.51
SEM	0.824	0.191	6.535	0.027	1.325	0.904	2.779
P-value	0.752	0.097	0.289	0.424	0.763	0.111	0.246

[1] Bovine spray dried plasma at 1%
[2] Bovine spray dried plasma at 2%

Blood Chemistries

Immunoglobulins, also known as antibodies, are glycoprotein molecules produced by stimulated B cells that transform into plasma cells which produce antibodies that are specific for specific antigens. The antibodies are an integral part of the humoral immune response that recognize and bind to antigens like bacteria and viruses. The immunoglobulins are classified into IgG, IgM, IgA, IgD and IgE. In this case IgA, IgM, IgG were analyzed, and no significance differences were found due to SDP treatment. The analysis of these is important to diagnose abnormal protein metabolism and the body's lack of ability to resist infectious agents. IgM, found in blood, is thought to be largest amongst all the Ig's and is the first to act when there is an infection in the body. IgG, found in blood and tissue, also responds to infections. An experiment in owls indicated that stressors, known to elevate corticosterone levels, can cause a long-lasting effect on IgG antibody levels (Stier et al., 2009). IgA, found in fluid and mucus membranes is of high importance in the gut and respiratory organs, since these are the main disease involving systems that are prominent in poultry. High levels of Aspartate Aminotransferase (AST) and Alanine Aminotransferase (ALT) can indicate organ damage, certain liver diseases, muscular dystrophy, and other diseases. AST can be found in the liver, heart, skeletal muscle, brain, and kidney. This enzyme also helps metabolize amino acids. There were no differences among the values for plasma AST and ALT due to the use of SDP. In a study done by Maroufyan et al., (2010) with dietary supplementation of methionine and threonine, no significant differences were found between treatments for blood parameters and liver enzymes at day 28. However, 14 days after being challenged, levels of serum concentrations of ALT and AST significantly increased (Ehsani et al., 2010). Albumin and Protein were also measured, and no significant difference was found due to SDP treatment. Protein assists in oxygen transportation, water regulation and blood clotting, as well as other biological, metabolic, and chemical processes in the body that are of high importance in the survival of birds. Albumin, produced by the liver and the largest protein fraction in birds, helps vitamins, enzymes, hormones, and other substances circulate throughout the body. However, the values presented for both plasma albumin and protein are much lower than expected in turkeys in the age range of the birds herein. Beski et al. (2016) found lower levels of IgG and IgM in broilers that were fed SDP compared to broilers with other treatments. No differences were found in blood analyses for the immunoglobulins at prestress, post stress or 3 weeks after stress.

Table 13. Effect of exposure to a cold episode along with feed and water withholding for a period of 24 hours in turkey poults fed spray-dried bovine plasma (ng/mL)

Diet		Pre-Stress	Post Stress	3 weeks Post Stress
AP1[1]		6.642	23.815 [a]	3.071
AP2[2]		6.436	19.17 [ab]	2.942
Control		8.224	16.402 [b]	2.915
SEM		1.247	2.000	0.498
	P-value	0.545	0.039	0.972
Diet	0.199			
Timepoint	<.0001			
Diet*timepoint	0.0302			

[a, b] Means within a column lacking a common superscript differ ($P \leq 0.05$).
[1] Bovine spray dried plasma at 1%
[2] Bovine spray dried plasma at 2%

Plasma Corticosterone: The Stress Hormone

Corticosterone is the primary glucocorticoid that is involved in the regulation of energy, immune reactions and especially in stress responses. This corticosteroid is established as the free principal corticosteroid found in turkey plasma (Brown, 1961). Stressors such as water deprivation and cold significantly elevate the plasma corticosterone, which was observed in this trial. The turkeys were exposed acutely for 24 hours to cold temperature at 12.8°C and were simultaneously challenged with feed and water restriction.

Corticosterone levels were measured prestress, post stress, and 3 weeks post stress. No differences among treatments were found in association with the prestress blood sampling. However, an increased CORT level from pre to post stress was observed and differences ($p < 0.05$) in the corticosterone levels by treatment was observed post stress. The turkeys in the AP1 (23.815 ng/mL) treatment with 1% SDP had a nearly a 3.5-fold increase in plasma corticosterone after the stressful exposures (Table 13). Similarly, turkeys fed the AP2 diet with 2% SDBP expressed a threefold increase in plasma corticosterone (19.17 ng/mL), but this group's corticosterone levels were not different from the corticosterone levels (16.402 ng/mL) in the control group. It is interesting to note that the turkeys among the three treatment groups at the 3 weeks post-stress sampling time had plasma corticosterone levels that were significantly lower than the corticosterone levels found in the prestress turkeys. It has been reported that plasma corticosterone levels are elevated in young poults, and those higher levels decline over time followed by a rebounding of levels (McCorkle et al., 1985). Since the adrenal glucocorticoids are associated with adaptive responses in animals exposed to stressors, it stands to reason that the supplementary SDBP had imparted some protective advantage to those turkeys compared to the controls. Stress has long been acknowledged to cause adaptive and maladaptive changes to body and behavior (McEwan et al., 2015). It is suggestive, based on these data, that SDBP promotes adaptive actions when turkeys are subjected to a strong stressor. It has been noted above that strong stressor appear to be necessary to maximize the adaptive responses of birds, cattle, and swine, which have been supplemented with SDP. Because the stressor placed on the turkeys herein was acute and of short duration, the induced adrenal cortical response was short lived. Consequently, the full effect of the long-term adaptive response was not activated, which may partially answer why post stress perturbations in development were not observed. Weaned pigs that were fed with SDP showed an increase in the activation of the pituitary-adrenal axis after being exposed to a lipopolysaccharide (LPS) challenge, in comparison to pigs fed a diet that did not contain SDP (Carrol et al., 2002).

Table 14. Influence of supplemented dietary spray dried plasma on 12 weeks old female turkey organ weights (g).

Diet	Bursa	Spleen	Thymus
AP1[1]	0.124	0.138	0.059
AP2[2]	0.120	0.127	0.059
Control	0.130	0.128	0.052
SEM	0.005	0.007	0.003
P-value	0.439	0.524	0.235

[1] Bovine spray dried plasma at 1%
[2] Bovine spray dried plasma at 2%

Organ Weights

Weights of internal organs of poultry, including turkeys, can yield important information relative growth and development of that bird. Any kind of stressor can serve as a starting point for any malfunction in the bird's multiple organ systems, including the bird's whole body (Maiylan, 2016). There was no change in organ weights of 12 weeks old female turkeys among SDP-fed and control fed (Table 14). This observation is in agreement with Beski et al. (2016) 6) who fed SDP to broilers fed SDP and found no differences in liver, spleen, and thymus weights among treatment groups, but SDP-fed broilers had significantly larger bursa of Fabricius weights compared to control fed broilers. There is only one instance where the data in this trial might be confounded, and that is due to the possibility that the thymus and bursa of Fabricius might have begun to involute along with increasing age in these turkeys.

Table 15. Effect of feeding spray dried bovine plasma to female turkeys until 12 weeks of age**.**

Diet	Ash%
AP1[1]	19.766
AP2[2]	19.821
Control	19.592
SEM	0.253
P-value	0.802

[1] Bovine spray dried plasma at 1%
[2] Bovine spray dried plasma at 2%

Bone Ash Percentage

Bone ash% was measured using the initial weight of the bone and comparing it to the final weight of ash content. For bone ash percentages no statistical differences were found among diet treatments. The lack of differences in bone ash suggests that there were no deleterious effects on skeletal growth and development due to feeding SDP to turkeys (Table 15).

Table 16. Bone Measurements for Tibia.

Diet	Bone Strength (Newtons)	Bone Strength Pound-force	Elasticity (g/sec)	Bone (mm)	Length	Bone (mm)	Diameter
AP1	789.549	177.498	3590.562	182.789		13.610	
AP2	809.430	181.967	3495.675	178.629		13.490	
Control	778.000	174.901	3353.968	180.902		13.350	
SEM	35.810		155.330	2.729		0.292	
P-value	0.822		0.560	0.563		0.811	

[1] Bovine spray dried plasma at 1%
[2] Bovine spray dried plasma at 2%

The right tibia was used for all the morphometric measures in this investigation. Overall, the measures of the tibia, there were no differences due to SDP treatment in bone breaking strength, or the Newton/pound-force needed to break the bone. Neither was there a difference in bone elasticity which is a measure of the elastic modulus of the bone. The elastic modulus of the bone gives the measure of resistance offered by the bone to elastic deformations when exposed to external stress such as the Newtons of force exerted to break the bone. The elastic modulus, measured as g/second, for a bone can be calculated using the following formula:

$$\text{Elastic Modulus} = \frac{\text{stress}}{\text{strain}}$$

There were no differences among treatments for bone elasticity (Table 16). Finally, there were no differences among treatments for bone length and bone diameter (Table 16).

Bones represent one of the most dynamic tissues (organs) in the body. Bone consists of 70% mineral, 20% organic matter and 10% water. It has the tensile strength of cast iron but weighs much less. Bone is constantly being remodeled as animals age or as damage is done to the bone. Birds kept in confinement where they get little opportunity for exertion and exercise may display a high incidence of bone issues that can lead to bone weakness, breakage, deformity, infection, and osteoporosis-related mortalities (Rath et al., 2000; Huff et el., 2006). These issues cause major economic losses in the industry as well as welfare concerns for the turkey industry. Bone strength is the ability to endure stress or the ultimate load (Newtons or pound-force) at which the bone can break. The load at the breaking point is the sum of all the forces and moments applied to the bone (Nigg and Grimstone,1994) which is the breaking strength of the bone. Bone strength can be related to different physical, architectural, and material properties (Rath et al., 2000). Factors such as gender, aging and growth, have been noted to influence bone growth as well as hormonal differences (Seeman, 1999). Rath et al., (1999) showed differences in diaphyseal diameters in males and females of the same age, where females showed a lower value. Genetics, nutrition, physical activity, infections, antinutrients, and hormones all play a role in the regulation of bones strength. Based on the results of this study, the supplementation of SDP had no negative effects on bone growth of young female turkeys. In fact, the 2% supplementation may be more beneficial in turkeys or production sites where there is a problem associated with bone breakage such as spiral fracture of the thigh, keel bone fracture and other skeletal dysfunctions.

SUMMARY

The induced model used in this study for transportation of birds and cold stress proved to work, mimicking exposure of turkeys to stressors and stressful experiences during rearing and transportation. This was observed with bird behavior and their reaction to the induced stress. Corticosterone levels increased from pre to post stress. While birds gained weight throughout the trial, they underperformed in comparison to field standards. Feeding birds SDP resulted in an improved FCR at 6 weeks. There were no statistical differences due to diet for most other performance parameters as well as blood analysis. Corticosterone levels were increased by SDP which agrees with swine data where cortisol increased when pigs were challenged and fed with SDP. In conclusion, based on this work, there was a beneficial corticosterone response to SDP when included in the feed. However, SDP may need to be fed continuously for full benefit the animal. Further research needs to be done in turkey production under different stress environments and different levels and lengths of SDP inclusion.

REFERENCES

Liu, Y., Choe, J., Lee, J. J., Kim, J., Campbell, J. M., Polo, J., Crenshaw, J. D., Pettigrew, J. E., & Song, M. (2018). Spray-dried plasma attenuates inflammation and lethargic behaviors of pregnant mice caused by lipopolysaccharide. PloS One, 13(9), e0203427.

Abo-Al-Ela, H. G., El-Kassas, S., El-Naggar, K., Abdo, S. E., Jahejo, A. R., & Al Wakeel, R. A. (2021). Stress and immunity in poultry: light management and nanotechnology as effective immune enhancers to fight stress. Cell Stress & Chaperones, 26(3), 457–472.

Balan, P., Staincliffe, M., & Moughan, P. J. (2021). Effects of spray-dried animal plasma on the growth performance of weaned piglets-A review. Journal of Animal Physiology and Animal Nutrition, 105(4), 699–714.

Belote, B. L., Soares, I., Tujimoto-Silva, A., Tirado, A. G. C., Martins, C. M., Carvalho, B., Gonzalez-Esquerra, R., Rangel, L. F. S., & Santin, E. (2021). Field evaluation of feeding spray-dried plasma in the starter period on final performance and overall health of broilers. Poultry Science, 100(5), 101080.

Beski, S. S. M., Swick, R. A., & Iji, P. A. (2016). Effect of dietary inclusion of spray-dried porcine plasma on performance, some physiological and immunological response of broiler chickens challenged with Salmonella sofia. Journal of Animal Physiology and Animal Nutrition, 100(5), 957–966.

Boa-Amponsem, K., Larsen, C. T., Dunnington, E. A., & Siegel, P. B. (1999). Immunocompetence and resistance to marble spleen disease of broiler- and layer-type pure lines of chickens. Avian Pathology: Journal of the W.V.P.A, 28(4), 379–384.

Bregendahl, K., Ahn, D. U., Trampel, D. W., & Campbell, J. M. (2005). Effects of dietary spray-dried bovine plasma protein on broiler growth performance and breast-meat yield. The Journal of Applied Poultry Research, 14(3), 560–568.

Brown, K. I. (1961). The Validity of Using Plasma Corticosterone as a Measure of Stress in Turkey. Proceedings of the Society for Experimental Biology and Medicine. Society for Experimental Biology and Medicine, 107(3), 538–542.

Campbell, J. M., Crenshaw, J. D., González-Esquerra, R., & Polo, J. (2019). Impact of Spray-Dried Plasma on Intestinal Health and Broiler Performance. Microorganisms, 7(8). https://doi.org/10.3390/microorganisms7080219

Campbell, J. M., Quigley III, J. D., Russell, L. E. and Koehnk, L. D. (2004a). Efficacy of spray-dried bovine serum on health and performance of turkeys challenged with Pasteurella multocida. Journal of Applied Poultry Research, 13:388–393.

Campbell, J. M., Quigley, J. D., III, & Russell, L. E. (2004b). Impact of spray-dried bovine serum and environment on turkey performance. Poultry Science, 83(10), 1683–1687.

Campbell, J. M., Russell, L. E., Crenshaw, J. D., and Koehnk, H. J. (2006). Effect of Spray-Dried Plasma Form and Duration of Feeding on Broiler Performance During Natural Necrotic Enteritis Exposure. The Journal of Applied Poultry Research, 15(4), 584–591.

Carroll, J. A., Touchette, K. J., Matteri, R. L., Dyer, C. J., & Allee, G. L. (2002). Effect of spray-dried plasma and lipopolysaccharide exposure on weaned pigs: II. Effects on the hypothalamic-pituitary-adrenal axis of weaned pigs. Journal of Animal Science, 80(2), 502–509.

Chen, X., Jiang, R., & Geng, Z. (2012). Cold stress in broiler: global gene expression analyses suggest a major role of CYP genes in cold responses. Molecular Biology Reports, 39(1), 425–429.

Coffey, R. D., & Cromwell, G. L. (1995). The impact of environment and antimicrobial agents on the growth response of early-weaned pigs to spray-dried porcine plasma. Journal of Animal Science, 73(9), 2532–2539.

Coffey, R. D., & Cromwell, G. L. (2001). Spray-dried animal plasma in diets for weanling pigs. Pigs News Inf, 22, 39–48.

Consumers are demanding antibiotic-free meat, and Big Food is starting to listen. (2014, August 11). The World from PRX. https://theworld.org/stories/2014-08-11/consumers-are-demanding-antibiotic-free-meat-and-big-food-starting-listen

Crenshaw, J. D., Campbell, J. M., & Polo, J. (2019). PSIV-3 Comparison of nursery pig feed programs with or without spray dried plasma. Journal of Animal Science, 97(Suppl 2), 182.

Difference Between Lymphocytes and Leukocytes (With Table). (n.d.). Retrieved March 13, 2022, from https://askanydifference.com/difference-between-lymphocytes-and-leukocytes/

Dixon, L. M., Sparks, N. H. C., & Rutherford, K. M. D. (2016). Early experiences matter: a review of the effects of prenatal environment on offspring characteristics in poultry. Poultry Science, 95(3), 489–499.d

Efficacy of Spray-Dried Bovine Serum on Health and Performance of Turkeys Challenged with Pasteurella multocida. (2004). The Journal of Applied Poultry Research, 13(3), 388–393.

Ehsani, M., Torki, M., & Others. (2010). Effects of dietary inclusion of guar meal supplemented by β-mannanase on performance of laying hens, egg quality characteristics and diacritical count of white blood cells. American Journal of Animal and Veterinary Sciences, 5(4), 237–243.

Ferket, P. R., & Gernat, A. G. (2006). Factors That Affect Feed Intake of Meat Birds: A Review. International Journal of Poultry Science, 5(10), 905–911.

Gonzalez-Esquerra, R., Campbell, J. M., Polo, J., Vieira, S., Kindlein, L., and Favero, A. (2019). Effect of feeding spray-dried plasma in the starter diet for 4, 7 or 10 days at different doses on the overall performance of broilers at 42d of age P295. International Poultry Scientific Forum, Atlanta

Gould, D. (2012, June 26). Survey Reveals Growing Consumer Demand For Antibiotic-Free Meat [Video]. Forbes Magazine. https://www.forbes.com/sites/daniellegould/2012/06/26/survey-reveals-growing-consumer-demand-for-antibiotic-free-meat/

Graczyk, S., Wieliczko, A., Pliszczak-Król, A., & Janaczyk, B. (2006). Humoral and cellular response of pheasants vaccinated against Newcastle disease and haemorrhagic enteritis. Acta Veterinaria, 75(3), 379–386.

Henn, J. D., Bockor, L., Vieira, M. S., Ribeiro, A. M. L., Kessler, A. M., Albino, L., Rostagno, H., Crenshaw, J. D., Campbell, J. M., & Rangel, L. F. S. (2013). Inclusion of porcine spray-dried plasma in broiler diets. The Journal of Applied Poultry Research, 22(2), 229–237.

Huff, G., Huff, W., Rath, N., Balog, J., Anthony, N. B., & Nestor, K. (2006). Stress-induced colibacillosis and turkey osteomyelitis complex in turkeys selected for increased body weight. Poultry Science, 85(2), 266–272.

Jamroz, D., Wiliczkiewicz, A., Orda, J., Kuryszko, J., & Stefaniak, T. (2012). Use of spray-dried porcine blood by-products in diets for young chickens. Journal of Animal Physiology and Animal Nutrition, 96(2), 319–333.

Kats, L. J., Nelssen, J. L., Tokach, M. D., Goodband, R. D., Hansen, J. A., & Laurin, J. L. (1994). The effect of spray-dried porcine plasma on growth performance in the early-weaned pig. Journal of Animal Science, 72(8), 2075–2081.

Kidd, M. T. (2004). Nutritional modulation of immune function in broilers. Poultry Science, 83(4), 650–657.

Korver, D. R. (2012). Implications of changing immune function through nutrition in poultry. Animal Feed Science and Technology, 173(1), 54–64.

Koutsos, E. A., & Klasing, K. C. (2014). Chapter 17 - Factors Modulating the Avian Immune System. In K. A. Schat, B. Kaspers, & P. Kaiser (Eds.), Avian Immunology (Second Edition) (pp. 299–313). Academic Press.

Liu, L. L., He, J. H., Xie, H. B., Yang, Y. S., Li, J. C., & Zou, Y. (2014). Resveratrol induces antioxidant and heat shock protein mRNA expression in response to heat stress in black-boned chickens. Poultry Science, 93(1), 54–62.

Longo, F. A., Menten, J. F. M., Pedroso, A. A., Figueiredo, A. N., Racanicci, A. M. C., Sorbara, J. O. B. (2007). Performance and Carcass Composition of Broilers Fed Different Carbohydrate and Protein Sources in the Prestarter Phase. (2007). The Journal of Applied Poultry Research, 16(2), 171–177.

Lutful Kabir, S. M. (2009). The role of probiotics in the poultry industry. International Journal of Molecular Sciences, 10(8), 3531–3546.

Mailyan, E. (2021). Turkey Signals - a practical guide to turkey focused management. Roodbont Publishers B.V.

McCorkle, F. M., Edens, F. W., and Simmons, D. G. (1985) Alcaligenes faecalis Infection in Turkeys: Effects on Serum Corticosterone and Serum Chemistry. Avian Diseases, 29: 80-89.

McEwen, B.S., Bowles, N. P., Gray, J. D., Hill, M. N., Hunter, R. G., Karatsoreos, I. N., and Nasca, C. (2015). Mechanisms of stress in the brain. Nat Neurosci 18:1353-1363.

Moretó, M., & Pérez-Bosque, A. (2009). Dietary plasma proteins, the intestinal immune system, and the barrier functions of the intestinal mucosa. Journal of Animal Science, 87(14 Suppl), E92–E100.

Nguyen, P. H., Greene, E., Donoghue, A., Huff, G., Clark, F. D., and Dridi, S., (2016). A new insight into cold stress in poultry production. Advanced in Food Technology and Nutritional Sciences - Open Journal, 2(1), 1–2.

Nigg, B. M., and Grimstone, S. K. (1994). Bone. Pages 48–78 in: Biomechanics of Musculoskeletal System. B. M. Nigg and W. Herzog, ed. John Wiley & Sons, New York, NY.

Petrovsky, N., & Aguilar, J. C. (2004). Vaccine adjuvants: current state and future trends. Immunology and Cell Biology, 82(5), 488–496.

Pierce, J. L., Cromwell, G. L., Lindemann, M. D., Russell, L. E., & Weaver, E. M. (2005). Effects of spray-dried animal plasma and immunoglobulins on performance of early weaned pigs. Journal of Animal Science, 83(12), 2876–2885.

Pierson, F. W., Larsen, C. T., & Domermuth, C. H. (1996). The production of colibacillosis in turkeys following sequential exposure to Newcastle disease virus or Bordetella avium, avirulent hemorrhagic enteritis virus, and Escherichia coli. Avian Diseases, 40(4), 837–840.

Products. (2019, December 9). APC. https://apcproteins.com/science/products

Quigley, J. D., III, & Drew, M. D. (2000). Effects of Oral Antibiotics or Bovine Plasma on Survival, Health and Growth in Dairy Calves Challenged with Escherichia coli. Food and Agricultural Immunology, 12(4), 311–318.

Rath, N. C., Balog, J. M., Huff, W. E., Huff, G. R., Kulkarni, G. B., & Tierce, J. F. (1999). Comparative differences in the composition and biomechanical properties of tibiae of seven- and seventy-two-week-old male and female broiler breeder chickens. Poultry Science, 78(8), 1232–1239.

Rath, N. C., Huff, G. R., Huff, W. E., & Balog, J. M. (2000). Factors regulating bone maturity and strength in poultry. Poultry Science, 79(7), 1024–1032.

Rautenschlein, S., & Sharma, J. M. (1999). Response of turkeys to simultaneous vaccination with hemorrhagic enteritis and Newcastle disease viruses. Avian Diseases, 43(2), 286–292.

Renwick, G. M., Washburn, K. W., & Lanza, G. M. (1985). Genetic variability in growth response of chicks to cold brooding temperature. Poultry Science, 64(5), 785–788.

Roushdy, E. M., Zaglool, A. W., & Hassan, F. A. M. (2020). Thermal stress consequences on growth performance, immunological response, antioxidant status, and profitability of finishing broilers: transcriptomic profile change of stress-related genes. Tropical Animal Health and Production, 52(6), 3685–3696.

Sagher, B. M. (1975). The effect of cold stress on muscle growth in young chicks. Growth, 39(2), 281–288.

Scholey, D. V., & Burton, E. J. (2017). The effect of bone choice on quantification of mineralization in broiler chickens up to 6 weeks of age. The Journal of Applied Poultry Research, 26(4), 485–490.

Seeman, E. (1999). The structural basis of bone fragility in men. Bone, 25(1), 143–147.

Singh, N. S., Kumar, S., Majumdar, S., Sivaraman, G. K., & Shivakumar, B. M. (2004). Studies on immunocompetence status in two turkey varieties in India. British Poultry Science, 45(5), 619–623.

Smith, S. M., & Vale, W. W. (2006). The role of the hypothalamic-pituitary-adrenal axis in neuroendocrine responses to stress. Dialogues in Clinical Neuroscience, 8(4), 383–395.

Song, M., Liu, Y., Lee, J. J., Che, T. M., Soares-Almeida, J. A., Chun, J. L., Campbell, J. M., Polo, J., Crenshaw, J. D., Seo, S. W., & Pettigrew, J. E. (2015). Spray-dried plasma attenuates inflammation and improves pregnancy rate of mated female mice. Journal of Animal Science, 93(1), 298–305.

Stier, K. S., Almasi, B., Gasparini, J., Piault, R., Roulin, A., & Jenni, L. (2009). Effects of corticosterone on innate and humoral immune functions and oxidative stress in barn owl nestlings. The Journal of Experimental Biology, 212(Pt 13), 2085–2091.

Stress in poultry: focus on turkeys causes, mechanism, consequences, diagnostics and prevention. (2016). Journal of Dairy, Veterinary & Animal Research, 3(6), 62–65.

Thomson, J. E., Jones, E. E., & Eisen, E. J. (1994). Effect of spray-dried porcine plasma protein on feed intake, growth rate, and efficiency of gain in mice. Journal of Animal Science, 72(10), 2690–2695.

Trend toward antibiotic-free poultry product continues to grow. (2016, September 15). Poultry Times. https://www.poultrytimes.com/poultry_today/article_3ecb96b6-7b45-11e6-b282-ffa0e40429aa.html

Tujimoto-Silva, A., Tirado, A. G. C., Carvalho, B., Esquerra, R., Rangel, L. F. S., Santin, E., & Belote, B. (n.d.). [No title]. Retrieved March 13, 2022, from https://en.engormix.com/poultry-industry/articles/field-evaluation-feeding-spray-t47378.htm

van Dijk, A. J., Everts, H., Nabuurs, M. J. A., Margry, R. J. C. F., & Beynen, A. C. (2001). Growth performance of weanling pigs fed spray-dried animal plasma: a review. Livestock Production Science, 68(2), 263–274.

Walters, H. G., Jasek, A., Campbell, J. M., Coufal, C., & Lee, J. T. (2019). Evaluation of Spray-Dried Plasma in Broiler Diets with or Without Bacitracin Methylene Disalicylate. The Journal of Applied Poultry Research, 28(2), 364–373.

Weaver, A. C., Campbell, J. M., Crenshaw, J. D., Polo, J., & Kim, S. W. (2014). Efficacy of dietary spray dried plasma protein to mitigate the negative effects on performance of pigs fed diets with corn naturally contaminated with multiple mycotoxins. Journal of Animal Science, 92(9), 3878–3886.