HEAT STRESS AND DIET UTILIZATION IN MALE TURKEYS

- THE ROLE OF DIETARY ENERGY AND AMINO ACIDS -

Promotor:	**Prof. Dr. Ir. M. W. A. Verstegen** Hoogleraar in de Diervoeding Wageningen Universiteit
Co-promotor:	**Dr. Ir. R. P. Kwakkel** Universitair docent Departement Dierwetenschappen Wageningen Universiteit
Co-promotor:	**Prof. Dr. P. R. Ferket** Professor in Animal Science Department of Poultry Science North Carolina State University (USA)

Samenstelling Promotiecommissie:

Prof. Dr. E. Decuypere	Katholieke Universiteit Leuven (België)
Prof. Dr. A. Pijpers	Universiteit Utrecht
Prof. Dr. Ir. L. A. den Hartog	Wageningen Universiteit
Dr. M. C. Blok	Centraal Veevoederbureau, Lelystad
Prof. Dr. Ir. B. Kemp	Wageningen Universiteit

HEAT STRESS AND DIET UTILIZATION IN MALE TURKEYS

- THE ROLE OF DIETARY ENERGY AND AMINO ACIDS -

Teun Veldkamp

Proefschrift

ter verkrijging van de graad van doctor
op gezag van de rector magnificus
van Wageningen Universiteit,
Prof. Dr. Ir. L. Speelman,
in het openbaar te verdedigen
op woensdag 13 november 2002
des namiddags te vier uur in de Aula.

Veldkamp, T., 2002. Heat stress and diet utilization in male turkeys: the role of dietary energy and amino acids.
Ph.D. Dissertation, Wageningen Institute of Animal Sciences, Department of Animal Nutrition, Wageningen University, P.O. Box 338, 6700 AH Wageningen, The Netherlands.
With ref. – With summary in Dutch.

ISBN 90-5808-732-8.

Abstract

The commercial turkey industry has changed during the last two or three decades from one that marketed predominantly fresh whole dressed turkeys to one that now markets a large variety of mostly further processed products. Turkey breast meat is the most economically important part that is further processed. The turkey industry improved breast meat yield considerably by selective breeding, and advancements in management and feeding programs. Because breast meat yield is highly correlated with body weight, fast growing strains have been developed, but these strains are more sensitive to high ambient temperatures than earlier strains. This dissertation presents information on how male turkeys deal with chronic heat stress and how dietary amino acid and energy levels may alleviate the adverse effects of heat stress. Turkeys subjected to high ambient temperature will reduce their feed and associated nutrient intake because they need less energy for maintaining body temperature. A beneficial effect of including 10% extra dietary lysine, methionine, and threonine to diets that contained already high amino acid contents relative to NRC (1994), was not observed. Higher arginine to lysine ratios (1.25 vs. 1.00) only improved performance of turkeys when dietary lysine contents were marginal. Different electrolyte balances (164 to 254 meq/kg) did not modulate the effect of dietary arginine to lysine ratios. In an experiment with iso-caloric diets and different levels of dietary lysine (75, 90, 105, and 120% of NRC (1994) recommendations), the lysine requirement for optimum performance was determined to be the same for turkeys raised in either high or low ambient temperature when dietary energy contents met the requirement. In the last experiment, an evaluation was made of the response of male turkeys that were fed different dietary energy contents (NRC (1994) recommendations and ± 10%) and relatively high dietary lysine concentrations (105 and 120% of NRC (1994) recommendations) at high and low ambient temperature. The effect of extra dietary energy in the form of soybean oil had a more pronounced effect on performance at low than at high ambient temperature. High-energy diets resulted in lower breast meat yields.

Keywords: turkeys, heat stress, energy, amino acids.

Voorwoord

Vleeskalkoenen hebben een groot groeipotentieel als gevolg van de verregaande selectie op groeisnelheid. Door negatieve externe factoren, zoals bijvoorbeeld hoge omgevingstemperaturen, produceren de dieren vaak op een lager peil. Via aanpassingen in de aminozuursamenstelling en uiteindelijk het energieniveau in het voer is getracht om de nadelige effecten van een verlaagde nutriëntenopname op met name het percentage borstvlees te verminderen. Om te komen tot een duurzame en economisch concurrerende kalkoenenhouderij is het van het grootste belang dat kalkoenen het gehele jaar optimaal produceren. Dit was de aanleiding waarom ruim vijf jaar geleden een start is gemaakt met het promotieonderzoek om de nadelige effecten van hittestress bij vleeskalkoenen te verminderen.

Promotieonderzoek kan alleen succesvol worden uitgevoerd als een team van mensen wordt gevormd, die het idee zien zitten en er volop aan mee willen werken om alles tot een goed eind te brengen. Hiervoor ben ik aan veel mensen dank verschuldigd.

Allereerst wil ik Piet Simons hartelijk danken voor zijn enthousiasme om het promotieonderzoek van de grond te krijgen. Piet, je hebt Jos Noordhuizen (Universiteit Utrecht, voorheen Wageningen Universiteit) bereid gevonden om promotor te worden, waarna we samen het team hebben uitgebreid met Anton Pijpers (Universiteit Utrecht), René Kwakkel (Wageningen Universiteit) en Peter Ferket (North Carolina State University, USA). De begeleidingscommissie bestond uit vijf mensen van vijf verschillende organisaties. Piet, Jos, Anton, René, en Peter iedereen hartelijk dank voor de ontwikkeling van nieuwe ideeën en het refereren van de manuscripten. Ook Gerrit Heusinkveld wil ik bedanken omdat ik van hem de ruimte kreeg om het promotieonderzoek te starten en uit te voeren. Vijf jaar is een heel lange periode in landbouwkundig onderzoek. In deze periode kondigden organisatieveranderingen zich aan en functiewijzigingen werden doorgevoerd. Jos, verwisselde Wageningen Universiteit voor Universiteit Utrecht. Met deze wijziging verschoof ook zijn aandachtsgebied in de veehouderij. In goed overleg, is Martin Verstegen vanaf eind 1999 bereid gevonden om als promotor op te treden. Anton Pijpers verliet de Universiteit Utrecht en aanvaardde een leidende functie bij de Gezondheidsdienst voor Dieren. Helaas kon Anton vanaf 2000 in zijn nieuwe functie geen tijd meer vrij maken om een bijdrage te leveren in het promotieonderzoek. Ook René Kwakkel aanvaardde een nieuwe functie binnen Wageningen Universiteit. Hij verwisselde de leerstoelgroep

‘Diervoeding’ voor ‘Dierlijke Productie Systemen’ maar was bereid om de promotie verder te begeleiden.
Vanaf 2000 bestond de begeleidingscommissie uit Martin Verstegen (promotor), René Kwakkel (co-promotor), Peter Ferket (co-promotor) en Piet Simons. Heren, allen hartelijk dank voor jullie ideeën en suggesties tijdens lopend onderzoek en bij het opstarten van nieuw onderzoek. Concept manuscripten werden aan jullie voorgelegd en kwamen steeds op korte termijn geredigeerd en gerefereerd terug. Ook kon ik altijd bij jullie aankloppen als een probleem werd gesignaleerd of als de vraag zich voordeed: ‘hoe nu verder?’ Kalkoenen zijn immers bijzondere dieren die vaak net iets anders reageren op een proefbehandeling dan vooraf werd gedacht.

Als onderdeel van het promotieonderzoek is in de eerste vijf maanden van 1999 een sabbatical leave gedaan aan North Carolina State University. In North Carolina worden veel kalkoenen gehouden en ik trof dan ook een grote afdeling Poultry Science aan met daarin veel mensen die onderzoek deden met kalkoenen. Het was een geweldige tijd in Amerika, zowel voor het werk als privé. Peter en Debbie Ferket, both of you made us feeling home during our stay. In deze periode ging het werk bij het Praktijkonderzoek Veehouderij ‘gewoon’ verder en hebben Fridtjof de Buisonjé, Piet Simons en Koos van Middelkoop de lopende zaken goed opgevangen. Nogmaals dank hiervoor.

Promotieonderzoek doen binnen een volledige functie valt niet altijd mee. Alle lopende zaken gaan gewoon door en vaak was er dan te weinig tijd binnen het ‘normale’ werk om aan het proefschrift te kunnen werken. Op vele avonden werd daarom doorgewerkt aan het proefschrift. René en Emmy Kwakkel, een bijzonder woord van dank aan jullie is daarom hier op zijn plaats. Vaak kwam ik zo uit het werk, at ik met jullie mee (Emmy hartelijk dank voor het lekkere eten), om vervolgens met René verder te kunnen werken aan het proefschrift.

De basis van dierexperimenteel onderzoek wordt gelegd in de stal. Onderzoek met kalkoenen is zeer arbeidsintensief en fysiek zwaar. Zeker als kalkoenhanen tot op slachtrijpe leeftijd (18,5 kg) worden gehouden en de dieren regelmatig individueel gewogen moeten worden. Niet alleen de dierwegingen waren zwaar maar ook de grote hoeveelheden voer die verorberd werden. In de meeste proeven werd zo’n 36 ton aan kalkoenvoer verstrekt. Zesendertig ton voer in zakjes van 20 kg betekende dat per proef 1800 zakken voer leeggestort moesten worden in de juiste afdelingen. Hierbij wil ik het team van Johan Pikstra (alle dierverzorgers van Praktijkonderzoek Veehouderij, locatie Beekbergen) hartelijk danken voor de grote inspanning die is geleverd om alles correct te

laten verlopen. Een speciaal woord van dank is verschuldigd aan Gerrit Vunderink, die als proefbegeleider alle proeven, die in dit proefschrift zijn opgenomen, heeft begeleid.
Ik wil ook enkele organisaties bedanken voor hun financiële steun aan het onderzoek. De Productschappen voor Vee, Vlees en Eieren en het Ministerie van Landbouw, Natuurbeheer en Visserij hebben een belangrijke bijdrage geleverd in het onderzoek. Daarnaast werd op projectbasis financiële steun gevonden bij Eurolysine (Parijs, Frankrijk) en British United Turkeys (Chester, Engeland). Allen hartelijk dank. Een woord van dank is ook op zijn plaats voor de Dutch Turkey Company in Boxmeer. Even een telefoontje naar Ton Verhees, Menno Verbrugge of Johan Janssen en het gescheiden slachten en opdelen van kalkoenen uit de verschillende proefeenheden werd mogelijk.

Bij de afronding van het proefschrift bleek al snel dat er onvoldoende tijd beschikbaar was als dit gedaan moest worden naast alle gewone zaken. Daarom is besloten om drie maanden ouderschapsverlof op te nemen om het proefschrift af te ronden. Ook in deze periode waren er weer mensen die de reguliere taken van mij overnamen. Wiert Jan Wiers, Koos van Middelkoop en Marko Ruis, hartelijk dank hiervoor.

Naast mijn werk bij Praktijkonderzoek Veehouderij ben ik met name in de zomermaanden druk op het sierteeltbedrijf van mijn ouders. Vooral tijdens de afronding van het proefschrift ben ik nauwelijks op het bedrijf werkzaam geweest. Pa, Ma, John, Karin en Regien, bedankt voor de extra tijd die jullie in het bedrijf hebben gestoken.

Pa en Ma, jullie hebben mij altijd gestimuleerd om goed te studeren met de slagzin: ‘Jonge, leer mar goed want doar heb ie later profijt van’. Ik heb van jullie altijd de tijd en ruimte gekregen om te kunnen studeren. Het resultaat ligt er nu en daarom draag ik dit proefschrift mede aan jullie op.

Lieve Regien, Fleur en Noor, jullie hebben het mij mogelijk gemaakt om het proefschrift tot een goed einde te brengen. Regien, jij nam de dagelijkse huislijke beslommeringen volledig op je. In de laatste maanden werd een werkplek ingericht in de garage, waar ik vele uren heb doorgebracht en dus op afstand bij jullie was. Fleur kwam af en toe belangstellend bij me en vroeg: ‘papa, mag ik mijn naam op de computer typen?’ Ook Noor kwam af en toe belangstellend en aan mijn broek trekkend ‘informeren’ naar de laatste stand van zaken. Na voltooiing van het proefschrift, heb ik weer meer tijd voor jullie en gaan we leuke dingen doen. Bedankt voor jullie geduld en steun. Ik draag dit proefschrift aan jullie op.

Welsum, juli 2002.

Voor Regien, Fleur en Noor

CONTENTS

GENERAL INTRODUCTION		1
CHAPTER 1	Impact of ambient temperature and age on dietary lysine and energy in commercial turkey production.	11
CHAPTER 2	Interaction between ambient temperature and supplementation of synthetic amino acids on performance and carcass parameters in commercial male turkeys.	37
CHAPTER 3	Effects of ambient temperature, arginine to lysine ratio, and electrolyte balance on performance, carcass and blood parameters in commercial male turkeys.	53
CHAPTER 4	Growth responses to dietary lysine at high and low ambient temperature in male turkeys.	73
CHAPTER 5	Growth responses to dietary energy and lysine at high and low ambient temperature in male turkeys.	101
GENERAL DISCUSSION		123
SUMMARY		153
SAMENVATTING		165
Curriculum Vitae		176

GENERAL INTRODUCTION

GENERAL INTRODUCTION

The wild turkey (*Meleagris gallopavo*) is a North American native and was transported to Europe by Spanish explorers in the early 16th century. Europeans colonizing the east coast of North America, 100 years later, brought the domesticated turkey with them and found it better eating than its wild relative (Schorger, 1966). The introduction of artificial insemination and incubation and specific selection programs increased the process of domestication in the second quarter of the twentieth century.

Turkey production and consumption nowadays is increasing all over the world. Over 50% of total turkey production takes place in the United States, followed by the European Union with a global share of about 35%. Within both continents, states or countries differ in climatic conditions and the season of the year has a profound impact on turkey performance and carcass composition. In areas with high ambient temperatures throughout the year or in spring, summer, or autumn turkeys often exhibit a retarded body weight gain, resulting in lower carcass and breast meat yields (Veldkamp, 1990; Halvorson et al., 1991; Krueger, 2000).

Rearing heavy birds is largely influenced by the costs associated with further processing and maximizing breast meat yield. Brake et al. (1995) observed a positive linear relationship between body weight and breast meat yield. On a global scale, most turkeys are grown in open sided houses with curtains along the open sides of the houses and thus they are subjected to the natural climate in that particular area. At least half of total turkey production takes place in areas where high ambient temperatures are common throughout the year or seasonally. The turkey industry is challenged to reduce adverse effects of high ambient temperatures (Veldkamp, 1990; Halvorson et al., 1991; Noll et al., 1991, Krueger, 2000) to increase animal health and welfare and to obtain higher profits from these flocks.

If environmental conditions are optimal, growth potential of male turkeys is very high relative to other commercial poultry species. This is graphically illustrated by Figure 1. Layer pullets (not selected for meat yields) have a flat growth curve. At the start of the laying period at 20 wk of age, layer pullets have multiplied their hatching weight by about 35 times with high feed:gain ratios during the entire rearing period. Broilers have multiplied their hatching weight (0.042 kg) 60 times at 6 wk of age (about 2.5 kg). At the same age, male turkeys have multiplied their hatching weight (about 0.055 kg) by about 50 times (2.7 kg). However, male turkeys reach this body weight more efficiently. Feed:gain ratios of broilers and turkeys until 6 wk of age are 1.80 and 1.70, respectively.

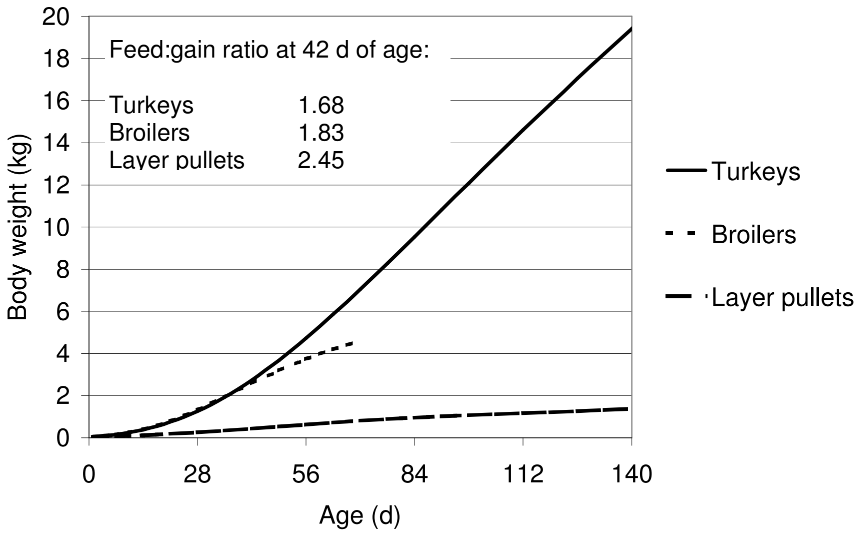
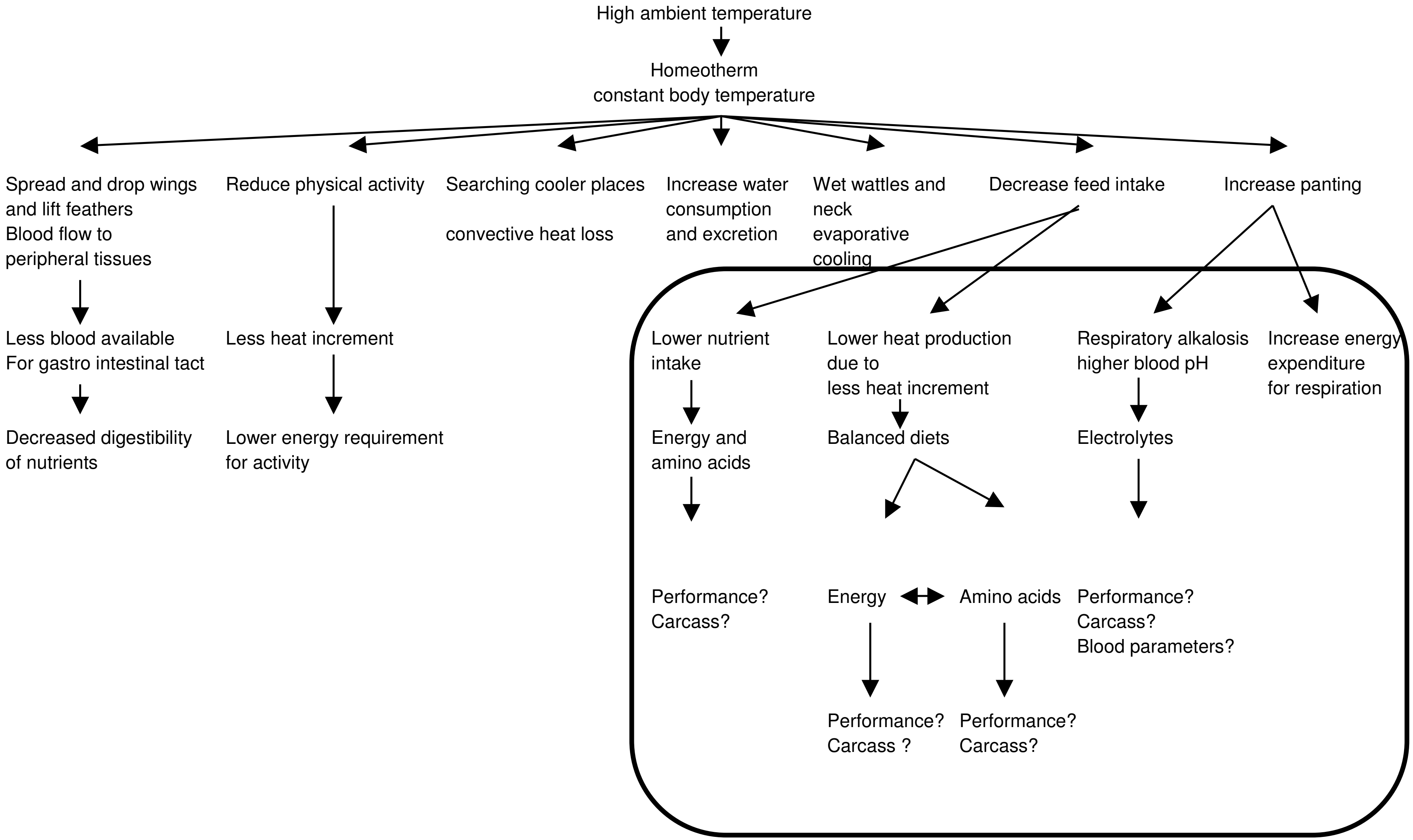


Figure 1. Growth potential of male turkeys compared with broilers and layers.

At 20 wk of age, male turkeys will have multiplied their hatching weight by about 340 times (almost 19.5 kg with a feed:gain ratio of about 2.8). The long period of growing turkeys from 0 to 20 wk of age and an increase in body weight from 0.055 to 19.5 kg requires the use of a feed program by changing feeds every three or four weeks. Highly fortified diets are used in feeding programs to reach the high growth potential of these birds.

Body weight gain and metabolic rate increases with increasing age, reaching a peak at about 13 wk of age, and thereafter decreases. Because body weight gain is maximized during this time, metabolism in these birds is very high. The thermal comfort temperature profile for these birds has a converse pattern with body weight gain. Emmans (1989) calculated that turkeys require temperatures between 10 to 12°C during 10 to 18 wk of age in order to enable dissipation of the heat produced by metabolism without stress. Turkeys are homeotherms, which means that they have developed mechanisms that enable them to maintain constant body temperature under varying environmental temperatures. Maintenance of body temperature relies more on physical than on chemical mechanisms (Brown-Brandl et al., 1997). Turkeys exhibit distinct behavior during hot weather, as shown in Figure 2. Behavioral and physiological adjustments of turkeys at high ambient temperatures are: decreasing feed intake, spreading and dropping of wings and lift feathers on the back to expose unfeathered areas, reducing physical activity, searching for cool places, increasing water consumption, and increasing panting (Ferket, 1995). In general, body weight gain of turkeys will be retarded if their diet is not balanced properly for amino acid content or their environment is too hot, or both. The capacity of turkeys to dissipate heat to the environment reaches the upper limit in these circumstances.

Figure 2. Behavioral and physiological adjustments of turkeys at high ambient temperatures and its effects on nutrition.



SCOPE OF THE STUDY

Although in some nutritional requirement experiments with turkeys, ambient temperature was included as a treatment variable, most have been conducted at moderate temperatures. Unfortunately, carcass composition is often not included in such research reports. This dissertation contributes to the knowledge how turkeys deal with high ambient temperatures when fed different amino acid balances, lysine *per se*, and lysine to energy ratios, with the emphasis on performance and carcass composition. It is aimed to derive more optimal amino acid composition in the diet relative to energy at different ambient temperature and weight range.

Feed intake is expected to decrease as ambient temperatures increase because the bird's heat production is increased by activity of feeding and metabolism caused by digestion and assimilation of food. This increased heat production has been referred to as heat increment. Heat increment after feed consumption and during digestion depends on the chemical composition of the diet. In literature, there are several examples of less ideal diet compositions that increased heat increment, and this may exacerbate heat stress situations. In addition, some diets have been developed that reduce heat increment and thus enable improved growth performance at high ambient temperatures. For example, the digestion and absorption of dietary fat produces less heat increment than dietary proteins and carbohydrates (Shannon and Brown, 1969). Other examples are diets with high crude protein levels at the expense of energy. Heat increment is much larger when protein is a source of energy than if carbohydrate or fat is the source of energy. Heat increment for protein is much greater when the animal's ambient temperature is high than when it is low (Musharaf and Latshaw, 1999). Heat increment from protein catabolism can be reduced by improving the amino acid balance (Austic, 1985). In practice, it is possible to formulate diets on minimum levels of lysine, methionine, threonine, and arginine without placing a minimum on crude protein, but it is more efficient to supplement diets with essential synthetic amino acids and to lower the crude protein content.

In heat-stressed animals, blood flow to the upper respiratory tract and other organs active in heat dissipation increases at the expense of capillary blood flow to the digestive system (Wolfenson, 1986). Blood flow is decreased more at the proventriculus than at the jejunum and ileum. This would reduce proteolytic enzymatic activities occurring in the upper part of the digestive tract and affects protein digestion (Bottje and Harrison, 1986; 1987). Conversely, feed passage rate was slower at a high temperature (Wilson et al., 1980), which might enhance nutrient absorption. Dietary electrolyte balance also may influence the tolerance of poultry to heat stress. Increased respiration necessary for evaporative cooling results in carbon dioxide loss, which can cause acid and base perturbations (Teeter et al., 1985, and Brake et al., 1994). Supplementation of certain electrolytes to the diet may affect these perturbations.

The aim of this dissertation was to study how commercial male turkeys respond to extra supplementation of dietary amino acids, dietary arginine to lysine ratios, dietary lysine *per se*, and dietary lysine to energy ratios at low and high ambient temperatures in order to minimize the possible adverse effects of high ambient temperatures on performance and carcass results.

OUTLINE OF THE DISSERTATION

First, the impact of ambient temperature on dietary lysine to energy ratios in commercial turkey production was studied. A literature review on this subject is presented in Chapter 1. A general overview of the world turkey production and the history of turkey production are described. Thereafter, factors affecting growth and breast meat yield were described. Ambient temperature is one of the most important factors affecting growth performance and breast meat yield. Effects of ambient temperature and how this interacts with dietary lysine and energy ratios are presented. At the end of the review, dietary lysine requirements of male turkeys at different ambient temperatures by age period are presented. Based on the conclusions of the review, experiments were conducted to get more detailed information on the response of male turkeys to adjustments in the diets, with special regard to high ambient temperatures.

In Chapter 2, the effect of extra dietary crystalline amino acid supplementation (lysine, methionine, and threonine) to a wheat and soybean based diet was studied when male turkeys were subjected to low and high ambient temperatures. Performance and carcass results were examined as well as nitrogen content of the litter.

In Chapter 3, two different arginine to lysine ratios were tested along with two different electrolyte balances in wheat, corn and soybean based diets to study how turkeys respond when they were grown at low and high ambient temperatures. Basal diets were supplemented with L-arginine to create a high arginine to lysine ratio and dietary electrolyte balances were adjusted by adding sodium bicarbonate or ammonium chloride at the expense of wheat. Performance and carcass results were examined and in this experiment also hematocrit, pH, pO_2, pCO_2, and HCO_3 in blood plasma were analyzed, as measures of respiratory alkalosis indicating hyperthermic panting.

Based on the results of Chapter 3, an experiment was conducted to determine if male turkeys respond different to largely different dietary lysine contents in corn and soybean based diets at low and high ambient temperatures. When L-lysine HCl was added to the diets, L-arginine was also added to maintain a constant arginine to lysine ratio. All diets within each age interval were isocaloric. Performance and carcass results were examined. The results are presented and discussed in Chapter 4.

In Chapter 5, male turkeys were exposed to low and high temperatures again and were fed diets with three levels of dietary energy and the two highest levels of dietary lysine from Chapter 4 to study the relation between dietary lysine and energy. From this experiment, conclusions can be drawn if adjustments in dietary energy content should be made when turkeys were fed diets with high lysine concentrations at low ambient temperatures and at high ambient temperatures.

In the General Discussion, the results reported in the Chapters 1-5 are discussed and evaluated and a discussion is made on how ambient temperature affects growth performance and carcass yields and how nutrition interfere with these parameters.

REFERENCES

Austic, R. E., 1985. Feeding poultry in hot and cold climates. In: Stress Physiology in Livestock. Vol. 3 Ed. M. K. Yousef, CRC Press, Inc. Boca Raton, Fl, USA.

Bottje, W. G. and P. C. Harrison, 1986. The effect of high ambient temperature and hypercapnia on postprandial intestinal hyperemia in domestic cockerels. Poultry Science 65: 1606-1614.

Bottje, W. G. and P. C. Harrison, 1987. Celiac cyclic blood flow pattern response to feeding and heat exposure. Poultry Science 66: 2039-2042.

Brake, J., P. R. Ferket, J. Grimes, D. Balnave, I. Gorman, and J. J. Dibner, 1994. Optimum arginine:lysine ratio changes in hot weather. Proceedings 21st Annual Carolina Poultry Nutrition Conference, Charlotte, NC, pp. 82-104.

Brake, J., G. B. Havenstein, P. R. Ferket, D. V. Rives, and F. G. Giesbrecht, 1995. Relationship of sex, strain, and body weight to carcass yield and offal production in turkeys. Poultry Science 74: 161-168.

Brown-Brandl, T.M., M. M. Beck, D. D. Schulte, A. M. Parkhurst, and J. A. Deshazer, 1997. Physiological responses of tom turkeys to temperature and humidity change with age. Journal of Thermal Biology 22: 43-52.

Emmans G. C., 1989. The growth of turkeys. In: Recent Advances in Turkey Science. Eds. C. Nixey, and T. C. Grey. Butterworths, London, UK. pp. 135-166.

Ferket, P. R., 1995. Nutrition of turkeys during hot weather. In: 18th Technical Turkey Conference. Renfrew, Scotland.

Halvorson, J. C., P. E. Waibel, E. M. Oju, S. L. Noll, and M. E. El Halawani, 1991. Effect of diet and population density on male turkeys under various environmental conditions. 2. Body composition and meat yield. Poultry Sci. 70: 935-940.

Krueger, K. K., 2000. Are production practices keeping up with genetic improvements? In: 24th Annual North Carolina Turkey Industry Days, Raleigh, NC, USA.

Musharaf, N. A. and J. D. Latshaw, 1999. Heat increment as affected by protein and amino acid nutrition. World's Poultry Science Journal 55: 233-240.

Noll, S. L., M. E. El Halawani, P. E. Waibel, P. Redig, and K. Janni, 1991. Effect of diet and population density on male turkeys under various environmental conditions. 1. Turkey growth and health performance. Poultry Sci. 70: 923-934.

National Research Council, 1994. Nutrient requirements of poultry. National Academy Press, Washington, DC.

Schorger, A. W., 1966. The Wild Turkey: its history and domestication. University of Oklahoma Press, Norman.

Shannon, D. W. F. and W. O. Brown, 1969. Calorimetric studies on the effect of dietary energy source and environmental temperature on the metabolic efficiency of energy utilization by mature Light Sussex cockerels. Journal of Agricultural Science, Cambridge, 72: 479-789.

Teeter, R. G., M. O. Smith, F. N. Owens, S. C. Arp, S. Sangiah, and J. E. Breazile, 1985. Chronic heat stress and respiratory alkalosis: Occurence and treatment in broiler chicks. Poultry Sci. 64: 1060-1064.

Veldkamp, T., 1990. Effect of relative humidity and ambient temperature on performance and carcass quality in commercial male turkeys (in Dutch). Onderzoekverslag 3: pp. 1-24.

Wilson, E. K., F. W. Pierson, P. V. Hester, R. L. Adams, and W. J. Stadelman, 1980. The effects of high environmental temperature on feed passage time and performance traits of white peking ducks. Poultry Science 59: 2322-2330.

Wolfenson, D., 1986. The effect of acclimatization on blood flow and its distribution in normothermic and hyperthermic domestic fowl. Comparative Biochemical Physiology 85A: 739-742.

Chapter 1

IMPACT OF AMBIENT TEMPERATURE AND AGE ON DIETARY LYSINE AND ENERGY IN COMMERCIAL TURKEY PRODUCTION

T. Veldkamp
Centre for Applied Poultry Research, "Het Spelderholt",
Spelderholt 9, PO Box 31, 7360 AA Beekbergen, The Netherlands

R. P. Kwakkel
Wageningen Institute of Animal Sciences, Animal Production Systems,
Wageningen University, Marijkeweg 40, 6709 PG Wageningen, The Netherlands

P. R. Ferket
North Carolina State University, Department of Poultry Science,
Scott Hall, Campus Box 7608, Raleigh, North Carolina 27695, USA

M. W. A. Verstegen
Wageningen Institute of Animal Sciences, Animal Nutrition, Wageningen University,
Marijkeweg 40, 6709 PG Wageningen, The Netherlands

World's Poultry Science Journal (2002) 58:4 (in press)

IMPACT OF AMBIENT TEMPERATURE AND AGE ON DIETARY LYSINE AND ENERGY IN COMMERCIAL TURKEY PRODUCTION

T. Veldkamp, R. P. Kwakkel, P. R. Ferket, and M. W. A. Verstegen

---

ABSTRACT

The commercial turkey market changed during the last two or three decades from predominantly whole turkey to mostly further processed products as consumer demand for breast meat and convenience increased in most western countries. Turkey operations focus on selection in breeding, management, and feeding programs to obtain a high breast meat yield. Main factors that affect breast meat yield are age, weight, sex, strain, genetic selection, and nutrition. The degree of influence by these factors on breast meat yield is highly dependent upon environmental conditions, especially ambient temperatures. This review deals with the response of commercial male turkeys on dietary lysine to energy ratios in moderate and hot climate conditions. A range dietary lysine to energy ratios have been determined to be optimal during each successive four-week period after hatch: 1.12 to 1.65, 1.10 to 1.36, 0.76 to 1.15, 0.64 to 0.81, and 0.53 to 0.86 g dietary lysine per MJ of ME, respectively). These optimum ranges in lysine to energy ratios are partly due to the continuous changes in genetic potential for growth and environmental effects on feed intake. Commercial male turkeys weighed about 18.5 kg at 140 days of age with a feed:gain ratio of 2.6 in 2001, as compared to about 8.0 kg at 220 days of age with a feed:gain ratio of 3.0 in 1966. Moreover, there is clear evidence in scientific literature that feed intake, and thus protein intake is negatively affected by short or long periods of heat stress in moderate and hot climates, respectively. Although some research included ambient temperature as a treatment variable in nutritional requirement studies with turkeys, most have been conducted at moderate temperatures. Feeding turkeys to minimize the adverse effects of heat stress is a big challenge for the modern turkey industry. More research is needed to better understand the relationship between dietary energy and lysine at different climatic conditions.

Keywords: turkeys, ambient temperature, dietary lysine, dietary energy, performance, carcass traits.

TURKEY MEAT PRODUCTION

The primary objective of commercial turkey production is to provide food for human consumption. Turkey meat is an important component of the daily menu of most western people and the production is increasing significantly all over the world. The increased global production and consumption of turkey meat is presented in Table 1a.

Table 1a. Global turkey meat production and consumption in the world in the period from 1997 to 2000 (Foreign Agricultural Service, 2002).

	Year			
Country	1997	1998	1999	2000
	(Production (1,000 Metric Tons))			
United States	2,455	2,366	2,372	2,419
Canada	142	139	139	152
Mexico	11	11	12	12
Brazil	101	107	115	137
European Union	1,638	1,700	1,830	1,740
Russian Federation	12	9	8	7
Other Countries	127	155	160	171
TOTAL	4,486	4,487	4,636	4,638
	(Consumption (1,000 Metric Tons))			
United States	2,141	2,214	2,223	2,223
Canada	126	130	126	131
Mexico	120	123	132	141
Brazil	78	88	89	93
European Union	1,486	1,526	1,640	1,553
Russian Federation	159	105	92	165
Other Countries	186	183	198	205
TOTAL	4,296	4,369	4,500	4,511

Over 50% of total turkey production take place in the United States, followed by the European Union with a global share of about 35%. These two main areas have various climatic conditions within each continent and management practices must be adjusted to maintain efficiency. Even within Europe, a variety in climatic conditions occurs between Southern countries like Italy and France and Northern countries like Germany, UK, and The Netherlands. In 2000, approximately 1.8 million tons of turkey was produced in Europe. Over 40% of these turkeys were produced in France, followed by Italy, Germany, and the UK that produced up about 48% of Europe's turkeys combined (Table 1b). The other European countries produce a much lower proportion of Europe's turkeys.

Table 1b. Share of European countries in total EU-turkey production in 2000 (Eurostat, European Community, 2001).

Country	Share in EU-turkey production (%)	Country	Share in EU-turkey production (%)
France	41.2	Ireland	1.9
Italy	17.2	Austria	1.1
Germany	16.7	Spain	1.0
United Kingdom	14.0	Denmark	0.6
Portugal	2.7	Others	1.0
Netherlands	2.5		

As in many countries, turkey production in the Netherlands continues to increase. The number of turkeys grown in The Netherlands increased from 1 million in 1990 to over 1.5 million in 2000, while the average farm size increased from 7,718 to 12,760 turkeys per farm. The gross production of turkey meat in The Netherlands in 2000 was 44,000 tons, which was 2.5% of total turkey production in the EU (European Community, 2001). In The Netherlands, annual meat consumption in 2000 was 87.0 kg (carcass weight) per capita, of which about 21.6 kg was poultry meat, and 2.2 kg turkey meat per capita (Productschappen Vee, Vlees en Eieren, 2001).

HISTORY OF TURKEY PRODUCTION

Turkey production has changed tremendously during the last century. At the turn of the twentieth century, turkey production was very seasonal practice because breeding stock started laying eggs after a period with natural photo-stimulation in springtime. A young turkey flock was hatched in late spring or at the start of summer and reached marketing age at the end of the year. Because people did not have freezers at that time to store meat for long periods, turkey meat had to be eaten right after killing of the birds. Therefore, whole turkey was a delicate part of the traditional dinner in most families at Thanksgiving in the USA and Christmas in the USA and Europe (Gascoyne, 1989).

In the second quarter of the twentieth century, the poultry industry began to change turkey husbandry and meat handling practices that made a year-round availability of turkey meat possible. The introduction of artificial incubation, artificial light and lighting programs and the widespread distribution of freezers in retail operations and homes meant that turkeys could be produced year-round and stored before consumption. By the introduction of more sophisticated incubators and artificial insemination techniques, turkey breeders could supply more turkey poults throughout the year. Consequently, prices of the young poult and turkey meat became more affordable for people with a low budget. During the last four decades, turkey production changed from a supply- to a demand-oriented industry. Turkey production operations integrated with processing plants and retailers. (Gascoyne, 1989).

In order to meet the increased consumer demands for healthy convenience foods, the turkey industry increased the proportion of turkey meat marketed as further processed products at the expense of whole and cut turkey parts. This shift in the form of turkey meat products marketed made it more profitable for processing plants to slaughter heavier birds with higher lean meat yields without excess bone. Breast meat is the most valuable cut of the turkey in western countries because it is ideal for further processing into value-added meat products. Although breast muscles represent about 33% of the total dressed carcass weight of a commercial market turkey; the price of breast meat is about twice as high as the price of drums, thighs and wings combined. To meet the demand of processing plants for high breast meat yields, primary turkey breeders continue to select for increased market weights and body conformation with special regard to higher breast meat yields.

In a review of historic turkey production in the USA, Ferket (2002) showed a remarkable progress in turkey growth performance during the last 35 years. To illustrate the progress, the weight, time to target market weight, and feed:gain ratio is presented since 1966 in Table 2. Since 1966, the weight of 18 week-old male turkeys has increased by about 83% and feed:gain ratio was improved by over 13%. Time to target market weight has also decreased drastically: it takes 38% fewer days to produce a 16-kg male turkey in 2000 than it took in 1966. Live weight at 18 weeks of age has increased linearly ($R^2 = 0.95$, $P < 0.001$) at a rate of about 0.194 kg per year.

Table 2. Average live weights, time to market weight, and feed:gain ratio of large white male turkeys in the USA, 1966 to 2002 (Ferket, 2002).

Year	Live weight at 18 wk of age (kg)	Time to market weight (15.9 kg) (d)	Feed:gain ratio (g:g)
1966	7.98	> 220	3.00
1970	7.67	> 235	3.10
1975	9.66	194	2.80
1980	10.16	185	2.70
1985	10.43	175	2.74
1990	12.29	156	2.80
1995	13.29	149	2.69
2000	14.47	143	2.62
2002	14.61	136	2.61

FACTORS AFFECTING BREAST MEAT YIELD

Main factors that affect breast meat yield in turkeys are age, weight, sex, strain, genetic selection, and nutrition (Wood, 1989). However, the degree of influence by these factors on breast meat yield, is highly dependent upon environmental conditions, especially ambient temperatures (Hurwitz et al., 1980; Halvorson et al., 1991; and Ferket et al., 1995). Leeson and Summers (1980) demonstrated that the relative weight of carcass, breast, and thighs increased and drums and wings decreased as age (and weight) increased. In turkeys, there has been an impressive trend towards increased body weights at marketing (Fisher, 1984; Ferket, 2002). Much of this progress was due to genetic selection for growth rate, which has a 'moderately high' heritability of 0.3-0.5 (Nestor et al., 2000). Genetic selection for increased growth rate has consequences on nutritional and environmental requirements (Emmans and Kyriazakis, 2000). Higher ratios of nutrients to energy, and lower temperatures, will be needed by improved genotypes. In addition, the capacity of digestive, respiratory, circulatory and excretory systems has to increase due to the increased metabolic rate.

Sex has a greater effect on weight and composition in turkeys than in most other meat species. Commercial male turkeys are considerably heavier than females at ages approaching slaughter age. Females reach the plateau level in body weight earlier with more body fat than males (Leeson and Summers, 1980; Hurwitz et al., 1983a). Weight of the eviscerated carcass as a proportion of live weight was reported to be similar among sexes in some studies (Salmon, 1979; Hurwitz et al., 1983a). In other studies, male turkeys had higher proportions of eviscerated carcass than females (Moran et al., 1971; Leeson and Summers, 1980; Brake et al., 1995). Leeson and Summers (1980) reported higher proportions of drums in males, whereas Perenyi et al. (1980) reported higher proportions of breast meat in males than in females. Brake et al. (1995) reported a linear increase of carcass yield with body weight for males and linearly with a negative quadratic term for females. This suggests that males are more efficient producers of meat at higher body weight than females.

Most differences observed among commercial turkey strains are in size and growth rate up to slaughter age; thus carcass parts yield and composition will vary. Meyer (1999) compared strain BUT (British United Turkeys) Big 6 (late maturing) with BUT T8 (early maturing) and observed higher body weights for BUT Big 6 at slaughter age. Total breast meat in the Big 6 strain was higher than in the T8 strain, however breast meat relative to the eviscerated weight was higher in T8 strain (36.6% vs. 35.9%). Moran (1977) found few differences in yield or composition of parts between large and small turkey strains. Clayton et al. (1978) found significant differences in live weight between three large strains, but inconsistent differences in carcass yield and composition.

Because commercial turkeys are usually allowed to consume a complete feed ad libitum, an adequate concentration of nutrients in the diet is necessary to maximize growth rate and feed:gain ratio from hatch to slaughter (Wood, 1989). In general, the most rapid and efficient growth is associated with the highest accretion of lean and meat yields. Lean muscle contains more water and is heavier than fatty tissue, which requires much more dietary energy per unit of weight gain. Thus, growth rate and feed:gain ratio are most affected by dietary protein (amino acids) and energy concentration.

In literature, dietary lysine and energy requirements are often presented regardless of ambient temperature. Ambient temperature has a major impact on partitioning of nutrients for maintenance or production. This review deals with the response of commercial male turkeys to dietary lysine and energy in moderate and hot conditions.

TEMPERATURE AND METABOLIC HEAT PRODUCTION

Birds are homeotherms, and as such, they are able to maintain their body temperature within a narrow range. An increase in body temperature above the regulated range, because of exposure to environmental conditions and/or excessive metabolic heat production, may lead to a cascade of irreversible thermoregulatory events that may be lethal for the birds (Yahav, 2001). Homeothermal animals and birds have well-developed temperature regulating mechanisms which enable them to maintain constant body temperature and to function under varying environmental temperatures. High environmental temperature and heat stress is a relative term for each animal as it depends upon the degree the ambient temperature exceeds the animal's thermoneutral zone and it depends upon the relative humidity and air velocity.

Prince et al. (1961) found in broilers an increased adverse effect of high ambient temperatures on feed intake when high ambient temperatures were combined with a low air velocity and a high relative humidity. Yahav (2000) observed in broilers a bell-shaped response function of body weight gain in 5 to 8-week-old chickens to relative humidity with a maximum at 60 to 65% relative humidity, both at 30 and 28°C. On the other hand, 5 to 8-week-old turkeys were not affected by relative humidity at ambient temperature of 30°C whereas at 35°C (Yahav et al., 1995) a decrease in body weight gain was found as relative humidity increased from 40 to 50%. Thereafter body weight gain was not affected despite the increase in relative humidity. Brown-Brandl et al. (1997) observed a decreased rate of change of respiration rate with increasing temperature but the rate of change was more sensitive to changes in temperature at higher relative humidity.

In the thermoneutral zone, blood vessels in the skin are neither totally dilated nor totally constricted, moisture evaporation from the skin surface and/or respiratory tract is minimal, feathers are not erected and behavioral responses to heat or cold do not occur. The thermoneutral zone may vary with the age (body size) of the animal, and genetic and physiological resistance to high environmental temperature. Defense of body temperature relies more on physical than on chemical mechanisms (Brown-Brandl et al., 1997). Body heat is mainly lost by radiation, conduction, and convection and by vaporization through the lungs by increased respiration and panting. Heat loss is also regulated by the pilomotor and vasomotor nervous mechanisms. Erection of feathers tends to conserve heat; in the non-erected state, heat loss is facilitated. When the air temperature is high, blood vessels in the skin dilate, thus increasing heat loss, and when the temperature is low, the vessels constrict, which tends to conserve heat (Sturkie, 1954). Turkeys exhibit distinct behavior during hot weather, such as decreasing feed intake, spreading and dropping of wings to expose unfeathered areas, reducing physical activity, assuming positions in cool places and taking advantage of conductive and convective heat loss, increasing water consumption, wetting of wattles and neck to enhance evaporative cooling, and increasing panting (Ferket, 1995). Waibel and Macleod (1995) determined that heat production per metabolic weight in a hot environment was higher than in a cool environment, which may be caused by the expense of more energy to remove body heat (i.e. increased panting, change in posture, and other heat-stress behaviors as mentioned above).

The activity of feeding and the metabolism caused by digestion and assimilation of food increase an animal's heat production. This increased heat production has been referred to as heat increment. The heat increment produced after feed consumption and during digestion depends on the chemical composition of the diet. Digestion and absorption of dietary fat resulted in less heat increment than dietary proteins and carbohydrates (Shannon and Brown, 1969) so dietary composition may also influence an animal's response during heat stress because heat increment may exacerbate heat stress situations.

In contrast to dietary energy components, dietary protein (amino acid) utilization and metabolism is particularly influenced by animals subjected to heat stress conditions. In their literature review, Musharaf and Latshaw (1999) explained that a significant proportion of the increased heat production after a protein meal results from the excretion of nitrogen from dietary amino acids when protein is used as energy source for maintenance or production.

Moreover, protein digestion and active amino acid absorption in a heat-stressed animal may be less efficient than in a thermal neutral animal. In heat-stressed animals, blood flow to the upper respiratory tract and other organs active in heat dissipation increases at the expense of capillary blood flow to the digestive system (Wolfenson, 1986). Wolfenson et al. (1981) demonstrated a gradient in the response to hyperthermia along the digestive tract. Blood flows decreased more at the proventriculus than at the jejunum and ileum. This would reduce proteolytic enzymatic activities occurring in the upper part of the digestive tract and affects protein digestion (Bottje and Harrison, 1986; Bottje and Harrison, 1987). Conversely, feed passage rate was slower at a high temperature (Wilson et al., 1980), which might enhance nutrient absorption. These apparently opposite changes might explain the absence of temperature effect on ME digestibility, whereas digestibility of protein and amino acids were reduced under hot conditions (Zuprizal et al., 1993). Heat-exposed birds will consume less feed in order to reduce the thermogenic effect associated with nutrient absorption, assimilation, and utilization (Withers, 1992). Decreased feed consumption and reduced blood flow to the gastrointestinal tract decreases metabolic energy input. These factors contribute to depressed performance characteristics of birds exposed to heat.

Breast meat yields are typically reduced when turkeys are reared at high temperatures because protein intake is reduced when feed intake is depressed. Turkeys reduce their feed intake at high temperatures to balance dietary energy intake with caloric requirements, but protein requirement should remain constant, regardless of the ambient temperature. A possible explanation of poor breast meat yields obtained at high temperatures is that the reduced protein intake of the turkeys results in lower protein synthesis of breast muscle. However, Rose and Michie (1987) showed that poor breast meat yields, which resulted from rearing at high temperatures, could not be counteracted by high dietary protein concentrations. Protein consumption in this experiment increased as protein concentration in the diet increased. Oju et al. (1987) found that turkey hens reared at 28°C require higher dietary protein levels to achieve maximum body weight than hens reared at moderate temperatures. Noll et al. (1991) found that body weights of male turkeys at 20 wk of age decreased with increasing temperature (13.86 kg vs. 12.26 kg at 7 and 21°C constant temperatures, respectively). Cycling temperatures (2 h light: 7°C and 4 h dark: 21°C or 18 h light: 7°C and 6 h dark: 21°C) resulted in intermediate body weights. Breast meat yields expressed as a total weight or as a percentage of dressed carcass were greater when turkeys were raised at 7°C than at 21°C and the cycling temperatures (Halvorson et al., 1991). The response of weight gain and energy intake to diurnal cycling temperatures is similar to that obtained from an equivalent constant average temperature, provided that the upper temperature does not exceed 30°C (Hurwitz and Ben-Gal, 1982).

Dietary fat supplementation should be used to improve performance of poultry during hot temperatures (Dale and Fuller, 1980; and Ferket, 1995). However, the response to supplemental fat requires adequate amino acid intake (McNaughton and Reece, 1984). Ferket (1995) stated that supplemental fat improve energetic efficiency of a diet fed during hot weather in three ways. Fat has 2.25 times more energy per unit of weight than carbohydrate or protein; therefore, fat can be used to increase flexibility of feed formulation by allowing more room for other crucial nutrients, thereby increasing dietary nutrient density. Digestion and metabolism of fat generate less body heat from the heat increment of digestion than that of carbohydrate and protein. In contrast to the active transport of glucose and amino acids, fat micelles are passively absorbed and do not generate as much metabolic heat. Fat may also improve palatability, slow rate of food passage, and thereby improve the digestibility of other ingredients (Mateos et al., 1982).

DIETARY LYSINE AND ENERGY RELATIONSHIPS

Dietary protein (amino acid) requirements must be considered within the context of dietary energy requirements, which is dependent upon metabolic body size and the rate of body weight gain. Hurwitz et al. (1980) estimated that energy requirements for maintenance at 12°C ranged between 0.59 and 0.64 MJ ME/g body weight$^{2/3}$, for broilers and turkeys, respectively. Requirements for weight gain averaged 0.64 and 0.17 MJ ME/g body weight$^{2/3}$, in chicks and turkeys, respectively. In both species, maintenance energy requirement decreased as ambient temperature increased from 12 to 24°C, reaching the lowest point at thermal neutral temperature between 24 and 28°C, then increased as ambient temperature was raised further.

Ambient temperature has a major influence on dietary energy intake, which in turn affects amino acid consumption. In a study with broilers, Reece and McNaughton (1982) observed that dietary lysine requirement was related to the energy intake by a fixed ratio. The decrease in energy intake at high temperatures resulted in a corresponding decrease in lysine intake. These experimental data lead to the question: What growth response to dietary energy would be obtained at high temperatures if the lysine to energy ratio is changed so that lysine intake at high temperatures would be the same as at low temperatures? McNaughton and Reece (1984) found that body weight of broilers raised in a warm environment respond to increased dietary energy only when the birds were fed adequate dietary amino acid levels. Dietary energy requirement was at least 13.60 MJ ME/kg of feed when broilers were fed 0.77 g lysine/MJ (kg) and reared in a hot environment, but the dietary energy requirement was lower when broilers were fed 0.74 g lysine/MJ ME. Similarly, Sinurat and Balnave (1985) observed that increasing dietary metabolizable energy (ME) at similar amino acid to ME ratios, significantly improved growth and feed utilization of broilers kept at moderate (18 to 26°C) and high (25 to 35°C) ambient temperatures from 22 to 42 d of age. The optimum amino acid to ME ratio varied with dietary ME concentrations in the hot, but not in the moderate environment. Relatively greater increases in food intake and growth rate occurred in the hot environment when dietary ME was increased and the amino acid to ME ratio was reduced. In contrast, Sell et al. (1994) did not observe an effect of dietary protein-EAA concentrations (93, 100, 107% of NRC (1984) on body weight or feed:gain ratio of male turkeys at 104 or 117 d of age and had also no effect on carcass and breast meat yields, irrespective of ME feeding sequence, but this research was not conducted under heat stress conditions. Dietary calorie and protein have independent effects in thermal comfort temperatures, but they are dependent during periods of heat stress because feed calorie intake is much more critical during high ambient temperatures. Cheng et al. (1997) found that broilers do not compensate for lower feed intake at high ambient temperatures when dietary protein and amino acid levels exceed the levels recommended by NRC (1994). Moreover, increasing dietary protein while keeping ME content constant at high ambient temperatures had little or no effect on feed intake and growth rate of broilers (Cowan and Michie, 1978) and turkeys (Hurwitz et al., 1980).

Because protein is one of the major cost components of the turkey diet, it has a major effect on the turkey production costs and cost per kg of turkey meat. Determining requirements for each amino acid at each phase of growth is expensive and tedious and has to be modified each time when growth characteristics change substantially. An alternative approach is to first establish the ideal protein requirements for the turkey relative to body weight and then periodically determine the requirement of one of the amino acids. A concept of ideal protein was published for the first time in the late fifties and early sixties (Dean and Scott, 1965). This concept, basically states that the amino acid requirements are relative to each other because amino acid composition of total body protein (ideal protein) is static. Baker (1997) established ideal protein (amino acid ratio) estimates for the chicken and pig relative to lysine requirements because lysine is most responsive to growth and it is relatively simple to determine in growth trials. Ideal protein estimates for the turkey poult were recently developed and reported by Firman and Boling (1998). A comparison of ideal protein ratios for the turkey, chick, and pig are presented in Table 3. Relative to lysine, the turkey requires less methionine + cystine, and threonine than the chick, or pig. It is important to note that ideal protein ratio may change as the animal grows because the amino acid profile requirements change as the demand for maintenance and growth change through the coarse of the animal's life.

Table 3. Estimated ideal protein ratio for the starting hen turkey, broiler chicken and pig, expressed as a percentage of the lysine requirement (Firman and Boling, 1998).

Amino acid	Turkeys	Broiler Chickens	Pigs
Lysine	100	100	100
Methionine+Cystine	59	72	60
Threonine	55	67	65
Valine	76	77	68
Arginine	105	105	NA [1]
Histidine	36	31	32
Isoleucine	69	67	60
Leucine	124	100	111
Phenylalanine+Tyrosin	105	105	95
Tryptophan	16	16	18

[1] NA = not available

Whether one uses set amino acid requirements or ideal protein ratio, formulations can only be as accurate as the estimates for digestibility of various dietary ingredients have been determined. Digestibility values based on the Sibbald true amino acid digestibility method or ileal digestibility are readily available for the chicken. Because the turkey is anatomically different then the chicken, chicken digestibility values for several feed ingredients may not be correct for the turkey (Firman and Boling (1998). Considerably more work must be done to determine amino acid digestibility of ingredients before diet formulation on a digestibility basis can be routinely practiced for turkeys.

Even though amino acid requirements may be estimated by using ideal protein concept with lysine as the denominator, the accuracy of these estimates would be limited to the accuracy of the lysine requirement determined by experimental research. Dietary lysine requirements estimated by previous research vary over a wide range (Lehmann et al., 1996). This variation in results may be due to differences in growth rate and feed intake as influenced by genetic and environmental factors (Waibel and Noll, 1985). Growth potential of commercial strains has improved during the past two decades (Nestor et al., 2000; and Ferket, 2002). In addition, the lysine requirement experiments conducted by different researchers are done under different ambient temperatures, which greatly impacts dietary nutrient utilization (Withers, 1992). The dietary lysine and energy requirements of fast growing commercial strains may also differ at moderate and high ambient temperatures.

DIETARY LYSINE REQUIREMENTS RELATED TO TEMPERATURE AND AGE

To overcome the influence of the metabolizable energy content of the diet on feed intake, dietary lysine requirements of male turkeys will hereafter be expressed as grams of lysine per MJ ME as recommended by Nixey (1991). Because ambient temperature also influences caloric intake, some researchers reported temperature associated with the determined lysine requirement. Table 4 is a summary of the research reported during the past two decades that included ambient temperature along with responses of commercial male turkeys to dietary lysine and energy.

A remark should be made about the models, which are used to evaluate the requirements in Table 4. Noll and Waibel (1989) used a broken line regression model as well as an exponential model and Lehmann et al. (1996) used an exponential model to determine the lysine requirements of turkeys at different ages. In literature, lysine requirements have been evaluated with both models. When the highest concentrations of lysine do not suppress growth rate and feed efficiency, the broken line method is appropriate to describe the growth and feed efficiency responses to dietary lysine. In studies with broilers, the broken line method is used by Latshaw (1993), Han and Baker (1994), and Hurwitz et al. (1998). Lysine requirements determined by an exponential model are often higher than determined by broken line analyses (Noll and Waibel, 1989; and Nixey, 1991). The large variation in dietary lysine and energy requirements determined at the different age intervals should be noted.

Age: 0 - 4 weeks

Based on the literature, the dietary lysine requirement of turkeys during the first 4 weeks after hatch ranges from 1.12 to 1.65 g/MJ ME, depending upon environmental conditions, dietary energy content, and genetic characteristics. Tuttle and Balloun (1974) found that the dietary lysine requirement to be at least 1.24 g/MJ ME during this period. Nixey (1991) recommended a dietary lysine requirement of 1.50 g/MJ ME. Plavnik and Hurwitz (1993) stated that the dietary lysine requirement should be between 1.12 and 1.15 g/MJ ME, and this requirement was close to model predictions by Hurwitz et al. (1983a).

Table 4. Optimal performance responses of commercial male turkeys to dietary lysine (LYS) and energy (E) in four-week age intervals at different ambient temperatures (T) as suggested by different authors.

Age	T	LYS		E	LYS/E ratio		Model used to determine optimal response	Number of LYS/E ratio in experiments	Authors
(wk)	(℃)	test range (g/kg)	optimum (g/kg)	(MJ/kg)	test range (g/MJ)	optimum (g/MJ)			
0-4	32-28	14.4-18.4	16.8	11.72	1.23-1.57	1.40	-	6	Waldroup et al. (1997a,b)
4-8	12	17.0 or 18.2	17.0	12.56	1.35 or 1.53	1.35	-	2	Hurwitz et al. (1980)
4-8	18	17.0 or 18.2	17.0	12.56	1.35 or 1.53	1.35	-	2	Hurwitz et al. (1980)
4-8	24	17.0 or 18.2	17.0	12.56	1.35 or 1.53	1.35	-	2	Hurwitz et al. (1980)
4-8	28	17.0 or 18.2	18.2	11.93	1.35 or 1.53	1.53	-	2	Hurwitz et al. (1980)
4-8	32	17.0 or 18.2	18.2	11.93	1.35 or 1.53	1.53	-	2	Hurwitz et al. (1980)
4-8	25-28	13.5-17.3	15.8	12.14	1.11-1.43	1.30	-	6	Waldroup et al. (1997a,b)
8-12	6	7.8-14.9	11.3	14.99	0.52-0.99	0.75	Broken line	7	Noll and Waibel (1989)
8-12	23	7.8-14.9	12.5	14.99	0.52-0.99	0.83	Broken line	7	Noll and Waibel (1989)
8-12	7	6.7-15.7	11.0	14.43	0.46-1.09	0.76	Broken line	7	Noll and Waibel (1989)
8-12	20	6.7-15.7	10.9	14.43	0.46-1.09	0.76	Broken line	7	Noll and Waibel (1989)
8-12	26	6.7-15.7	12.3	14.43	0.46-1.09	0.85	Broken line	7	Noll and Waibel (1989)
8-12	18	8.7-13.7	12.0	12.71	0.68-1.08	1.00	Exponential equation	6	Lehmann et al. (1996)
8-12	25-28	11.7-15.0	13.7	12.56	0.93-1.19	1.09	-	6	Waldroup et al. (1997a,b)
12-16	28-33	9.0-11.5	10.5	12.98	0.69-0.89	0.81	-	6	Waldroup et al. (1997a,b)
16-20	8	4.6-9.6	7.5	14.52	0.32-0.66	0.52	Broken line	7	Noll and Waibel (1989)
16-20	24	4.6-9.6	7.7	14.52	0.32-0.66	0.53	Broken line	7	Noll and Waibel (1989)
16-20	7	5.0-11.0	7.4	14.31	0.35-0.77	0.52	Broken line	7	Noll and Waibel (1989)
16-20	15	5.0-11.0	7.2	14.31	0.35-0.77	0.50	Broken line	7	Noll and Waibel (1989)
16-20	24	5.0-11.0	7.8	14.31	0.35-0.77	0.55	Broken line	7	Noll and Waibel (1989)
16-20	14	6.1-9.6	> 9.6	13.50	0.45-0.71	> 0.71	Exponential equation	6	Lehmann et al. (1996)
16-20	32-33	7.2-9.2	8.4	13.40	0.54-0.69	0.63	-	6	Waldroup et al. (1997a,b)

Boling and Firman (1998) confirmed this requirement by broken line analysis on a digestible lysine basis. In contrast, body weight of turkeys increased as dietary lysine increased from 1.38 to 1.65 and from 1.22 to 1.43 g lysine/MJ ME in experiments conducted by Lilburn and Emmerson (1993) and Waldroup et al. (1997a,b), respectively. However, these researchers formulated experimental diets to contain lower dietary metabolizable energy contents than in the experiments by Hurwitz et al. (1983b) and Boling and Firman (1998), and some of the dietary lysine may have been used to supply energy. Although ambient temperature was not reported by all the studies cited above, rearing temperature was almost likely similar among studies conducted within this age period.

Age: 4 - 8 weeks

The dietary lysine requirement of turkeys from 4 to 8 weeks of age was determined to range from 1.10 to 1.36 g/MJ ME. Tuttle and Balloun (1974) stated that the dietary lysine requirement in this period is 1.10 g/MJ ME. Nixey (1991) determined a dietary lysine requirement of 1.26 g/MJ ME. Hurwitz et al. (1980) observed that body weight gain was not affected when male turkeys were fed a high-energy or a high-protein diet. Dietary lysine content in the experimental diets varied from 1.36 to 1.53 g/MJ ME. Feed:gain ratio was significantly improved in male turkeys fed the high-energy diet (1.36 g lysine/MJ ME). Energy requirements in this study varied considerably with no consistent pattern with regard to ambient temperature. Lilburn and Emmerson (1993) did not find a significant difference in body weight at 8 weeks of age when turkeys were fed a diet containing 1.27 or 1.34 g lysine/MJ ME from 4 to 8 weeks of age. However, a requirement of 1.31 - 1.36 g lysine/MJ ME during this age period was found to optimize body weight gain and feed:gain ratio (Waldroup, 1997a,b; and Waldroup et al., 1998).

Age: 8 - 12 weeks

Dietary lysine requirement in turkeys from 8 to 12 weeks of age was found to range from 0.76 to 1.15 g/MJ ME. Tuttle and Balloun (1974) suggested a dietary lysine requirement of 0.96 g/MJ ME. Nixey (1991) recommended a dietary lysine requirement of 1.15 g/MJ ME. In a first experiment on dietary lysine requirements in various temperature environments, Noll and Waibel (1989) determined that the dietary lysine requirements by broken line regression were 0.76 and 0.84 g/MJ ME at 6 and 23°C, respectively. In a second experiment, the dietary lysine requirements were determined to be 0.76, 0.76, and

0.86 g/MJ ME at 7, 20, and 26°C, respectively. In both experiments, Noll and Waibel (1989) used high-energy diets (14.99 and 14.43 MJ ME/kg, respectively) to determine dietary lysine requirements. Dietary lysine requirement increased as ambient temperature increased. Ambient temperature also affected the weight gain response to dietary lysine intake, resulting in different response curves at the different ambient temperatures. The weight gain response to dietary lysine intake by broken line regression model was 118.1 + 32.3(x-3.08), 107.5 + 41.4(x-2.61), and 100.3 + 34.6(x-2.65) at 7, 20, and 26°C, respectively. Lehmann et al. (1996) studied the dietary lysine requirements at moderate temperatures (18°C) and found that 0.96 g lysine/MJ ME was adequate to obtain optimum growth and feed:gain ratio from 8 to 12 weeks of age. Waldroup et al. (1997a,b) determined a dietary lysine requirement of 1.10 g/MJ ME to yield maximal growth rate, while ambient temperature in this experiment frequently exceeded 27°C.

Age: 12 - 16 weeks

Although little research has been done on determining lysine requirement in turkeys from 12 to 16 weeks of age, dietary lysine requirements have been reported to range from 0.64 to 0.81 g/MJ ME. Nixey (1991) determined a dietary lysine requirement of 0.80 g/MJ ME in this age interval. Plavnik and Hurwitz (1993) determined that the dietary lysine requirement in this age interval was 0.64 g/MJ ME and this result agreed well with the model predictions by Hurwitz et al. (1983a). Waldroup et al. (1997a,b) determined the dietary lysine requirement to be 0.81 g/MJ ME for maximal body weight gain, while ambient temperature in this experiment frequently exceeded 27°C. The effect of ambient temperature on dietary lysine requirements during this age period has not been studied.

Age: 16 - 20 weeks

Recommendations of dietary lysine requirement for turkey toms from 16 to 20 weeks of age has been reported to range from 0.53 to 0.86 g/MJ ME, depending upon ambient temperature and genetic potential for growth. Nixey (1991) recommended a dietary lysine requirement of 0.60 g/MJ ME in this age interval. Using the broken line regression methodology, Noll and Waibel (1989) determined the dietary lysine requirements for toms during this period to be 0.53 and 0.53 g/MJ ME at 8 and 24°C, respectively in one experiment, and 0.53, 0.50, and 0.55 g/MJ ME at 7, 16, and 24°C, respectively in another experiment. Because high-energy diets (14.52 and 14.31 MJ ME/kg, respectively) were used in both of these experiments, the amount of dietary lysine required to achieve a plateau in weight gain using the broken-line model was statistically similar in all temperature environments. Carcass composition was not determined in this study. Plavnik and Hurwitz (1993) determined the dietary lysine requirement to be 0.53 g/MJ ME, which was higher than the 0.48 g lysine/MJ ME predicted by the mathematical model of Hurwitz et al. (1983a). Requirements for carcass yields were not determined in this study. In contrast, Waldroup et al. (1997a,b) concluded that toms require 0.62 g lysine/MJ ME for maximal body weight gain, feed:gain ratio, and breast meat yield while ambient temperature in this experiment frequently exceeded 27°C. Lehmann et al. (1996) concluded that 0.72 g lysine/MJ ME was insufficient to maximize weight gain and breast meat yield of male turkeys reared under moderate ambient temperatures (14°C). The lysine requirements for 16 to 20-week-old toms determined by Lehmann et al. (1996) exceeded the requirement estimates of all other researchers (Jensen et al., 1976; Potter et al., 1981; and Noll and Waibel, 1989) possibly because of higher growth rates. Waibel and Noll (1985) suggested that turkey strains with a higher genetic potential for growth have higher lysine requirements than slower growing turkey strains. The data of Lehmann et al. (1996) were similar to the recommendations of Cuddy Farms (1990), BUT (1994), and Degussa (1993). Moreover, Westermeier et al. (2000) recommended fast growing turkeys required 0.81 and 0.86 g lysine/MJ ME for optimal body weight gain and feed:gain ratio, respectively. The requirement for optimal breast meat yield may even be higher than 0.86 g lysine/MJ ME.

ARGININE TO LYSINE RELATIONSHIPS

Arginine is one of the indispensable amino acids for poultry. In contrast to mammals, avians cannot take up carbamoyl phosphate synthetase into the urea cycle to combine with ornithine to form citrulline and ultimately arginine because they lack mitochondrial source of carbamoyl phosphate synthetase. Therefore, a dietary source of arginine is essential. Arginine has not only a function in structural proteins but arginine is intimately involved in many crucial metabolic processes. In the urea cycle, it enables the disposal of excess amino acid nitrogen (Ferket et al., 1998). Arginine is also a precursor of nitric oxide (NO), which plays an important role in vasodilatation of periferal blood vessels and helps dissipating heat (Moncada et al., 1991).

Jones (1961), D'Mello and Lewis (1970), and Austic (1986) demonstrated an antagonistic interaction of lysine and arginine. This antagonism can be exacerbated by excess anions, such as chloride, and it can be alleviated by cations, such as sodium and potassium.

Some authors mentioned a remarkable impact of dietary arginine to lysine ratio on heat dissipation in broilers and turkeys (Brake et al., 1994; Ferket et al., 1995; England et al., 1996; Kroon and Balnave, 1996; Mahmoud et al., 1996; Mendes et al., 1997; Brake et al., 1998; and Waldroup et al., 1998). Ferket et al. (1995) reported that increasing dietary arginine to lysine ratio from 1.0 to 1.3 using synthetic free-base arginine did not significantly affect body weight gain, but feed:gain ratio and breast meat yield were significantly improved in toms fed the higher dietary arginine level and raised during a hot summer season. This positive response of meat birds to increased dietary arginine to lysine ratio during hot weather conditions may be associated with the degree of arginine absorption relative to lysine. Brake et al. (1994) reported that arginine uptake by enterocytes from heat-stressed birds was significantly lower than lysine uptake, but arginine and lysine uptake by enterocytes was the same under thermal neutral conditions. This hypothesis was confirmed in broilers by Brake et al. (1994) and Kroon and Balnave (1996) who observed improved feed:gain ratio of broiler chicks heat stressed at 32°C when arginine to lysine ratio exceeded 1.2. In contrast, Mahmoud et al. (1996) and Mendes et al. (1997) found no effect of arginine to lysine ratio greater than 1:1 on performance of broilers raised during thermal neutral or heat stress conditions. The major difference among studies that observed a positive response of increased dietary arginine to lysine in heat stressed birds and those that did not, may be related to the source of arginine in the diets. Brake et al. (1994), and Kroon and Balnave (1996) increased dietary arginine to lysine ratio by modifying dietary ingredient inclusion levels, whereas Mahmoud et al. (1996), Mendes et al. (1997), and Ferket et al. (1995) used synthetic arginine. In contrast, Brake et al. (1998) found that broilers raised in high ambient temperatures had improved feed:gain ratio when arginine to lysine ratios were increased by either L-arginine free base or practical feed ingredients with high arginine to lysine content. England et al. (1996) observed improved body weight and feed:gain ratio of turkeys raised under thermal neutral conditions when dietary arginine to lysine ratio exceeded 1.0 only when dietary lysine content was at 100% of NRC (1994) recommendations and not at higher levels. No dietary arginine to lysine ratio effect was observed on breast meat yield. Similarly, Waldroup et al. (1998) found that increasing dietary arginine to lysine ratios did not improve performance when lysine levels were adequate.

CONCLUSIONS

In the NRC (1994) recommendations for dietary lysine requirements (expressed as g/Mcal ME) are: 1.36, 1.24, 1.03, 0.76, and 0.60 g/MJ ME in the age periods: 0-4, 4-8, 8-12, 12-16, and 16-20 weeks of age, respectively. As presented in this review, however, dietary lysine requirements during these succeeding age intervals varied over a wide range (1.12-1.65, 1.10-1.36, 0.76-1.10, 0.64-0.81, and 0.50-0.72 g/MJ ME, respectively). NRC (1994) lysine requirements per age interval are approximately in the middle of the variation per age period. The variation in lysine requirements may be due to genetic and environmental factors. Genetic potential for growth in turkeys continues to improve, thus altering the nutrient intake is needed to achieve optimum growth performance.

Ambient temperature also has a significant impact on dietary nutrient utilization. High ambient temperatures negatively affect growth performance and carcass characteristics by having a negative influence on feed consumption and herewith decreased caloric and dietary lysine intake. Some authors (Hurwtiz et al., 1980; Noll and Waibel, 1989; and Waldroup, 1997a) suggested higher dietary lysine requirements as ambient temperature increases, while other authors (Brake et al., 1994 and Kroon and Balnave, 1996) suggested higher arginine to lysine ratios to maximize growth performance and breast meat yield.

From this literature review it can be concluded that there is no consistent effect of dietary lysine to energy ratios on performance in turkeys kept at temperatures above their thermal neutral zone. The effect of ambient temperature on energy and amino acid requirements needs further research to obtain accurate data for commercial male turkeys.

Researchers should express amino acid requirement data as g/MJ and include ambient temperature in their reports, to make research results more comparable.

REFERENCES

Austic, R. E., 1986. Biochemical description of nutritional effects. Pages 59-57 in Nutrient Requirements of Poultry and Nutritional Research. C. Fisher and K.N. Boorman, editors. Butterworths, London.

Baker, D. H., 1997. Ideal amino acid profiles for swine and poultry and their applications in feed formulation. BioKyowa Technical Review 9, BioKyowa, Inc., Chesterfield, USA.

Boling, S. D., and J. D. Firman, 1998. Digestible lysine requirement of female turkeys during the starter period. Poultry Science 77: 547-551.

Bottje, W. G., and P. C. Harrison, 1986. The effect of high ambient temperature and hypercapnia on postprandial intestinal hyperemia in domestic cockerels. Poultry Science 65: 1606-1614.

Bottje, W. G., and P. C. Harrison, 1987. Celiac cyclic blood flow pattern response to feeding and heat exposure. Poultry Science 66: 2039-2042.

Brake, J., P. R. Ferket, J. Grimes, D. Balnave, I. Gorman, and J. J. Dibner, 1994. Optimum arginine:lysine ratio changes in hot weather. Pages 82-104 in Proceedings 21st Annual Carolina Poultry Nutrition Conference, Charlotte, NC.

Brake, J., G. B. Havenstein, P. R. Ferket, D. V. Rives, and F. G. Giesbrecht, 1995. Relationship of sex, strain, and body weight to carcass yield and offal production in turkeys. Poultry Science 74: 161-168.

Brake, J., D. Balnave, and J. J. Dibner, 1998. Optimum dietary arginine:lysine ratio for broiler chickens is altered during heat stress in association with changes in intestinal uptake and dietary sodium chloride. British Poultry Science 39: 639-647.

British United Turkeys. 1994. BUT Big 6 Performance Goals. Broughton, Chester, UK.

Brown-Brandl, T. M., M. M. Beck, D. D. Schulte, A. M. Parkhurst, and J. A. DeShazer, 1997. Physiological responses of tom turkeys to temperature and humidity change with age. Journal of Thermal Biology 22: 43-52.

Cheng, T. K., M. L. Hamre, and C. N. Coon, 1997. Effect of environmental temperature, dietary protein, and energy levels on broiler performance. Journal of Applied Poultry Research 6: 1-17.

Clayton, G. A., C. Nixey, and G. Monaghan, 1978. Meat yield in turkeys. British Poultry Science 19: 755-763.

Cowan, P. J., and W. Michie, 1978. Environmental temperature and broiler performance: the use of diets containing increased amounts of protein. British Poultry Science 19: 601-605.

Cuddy Farms. 1990. Recommendations for feeding commercial turkeys. S. Leeson, ed. Strathroy, ON, Canada.

Dale, N. M., and H. L. Fuller, 1980. Effect of diet composition on feed intake and growth of chicks under heat stress. II. Constant vs. Cycling temperatures. Poultry Science 59: 1434-1441.

Dean, W. F., and H. M. Scott, 1965. The development of an amino acid reference diet for the early growth of chicks. Poultry Science 44: 803-808.

Degussa. 1993. Amino Acid Recommendations for Poultry. Degussa AG, Hanau, Germany.

D'Mello, J. P. F., and D. Lewis, 1970. Amino acid interactions in chick nutrition. 1. The interrelationship between lysine and arginine. British Poultry Science 11: 299-311.

Emmans, G. C., and I. Kyriazakis, 2000. Issues arising from genetic selection for growth and body composition characteristics in poultry and pigs. Pages 39-53 in Occasional Publication No. 27, British Society of Animal Science, Edinburgh, Scotland.

England, J. A., P. W. Waldroup, M. L. Kidd, and B. J. Kerr, 1996. Increasing arginine:lysine ratios in turkey diets does not improve performance when lysine levels are adequate. Poultry Science 75(supplement 1): 3.

European Community. 2001. Gross production of turkey meat per country in the EU.

Ferket, P. R., 1995. Nutrition of turkeys during hot weather. In: 18th Technical Turkey Conference. Renfrew, Scotland.

Ferket, P. R., J. D. Garlich, R. Kuiper, and M. T. Kidd, 1998. Dietary arginine requirement of growing and finishing turkey toms. Pages 6-14 in Proceedings of turkey nutrition workshop. North Carolina State University, Raleigh, NC, USA.

Ferket, P. R., J. L. Grimes, J. Brake, and D. V. Rives, 1995. Effects of dietary virginiamycin, arginine:lysine ratio, and electrolyte balance on the performance and carcass yield of turkey toms. Poultry Science 74(supplement 1): 190.

Ferket, P. R., 2002. Turkey performance similar to last year. Poultry USA (in press).

Firman, J. D., and S. D. Boling, 1998. Symposium: lysine. Ideal protein in turkeys. Poultry Science 77: 105-110.

Fisher, C., 1984. Fat deposition in broilers. Pages 437-470 in Fats in Animal Nutrition (J. Wiseman, Ed), London, Butterworths, U.K., pp. 437-470.

Foreign Agricultural Service. 2002. Page 25 in World markets and trade. Councelor and attache reports, official statistics, and results of office research. U.S. Department of Agriculture, Washington, D.C., USA.

Gascoyne, J., 1989. The world turkey industry, structure and production. Pages 3-9 in Recent Advances in Turkey Science. (C. Nixey, and T. C. Grey, Eds) Butterworth & Co. (Publishers) Ltd., U.K.

Halvorson, J. C., P. E. Waibel, E. M. Oju, S. L. Noll, and M. E. El Halawani, 1991. Effect of diet and population density on male turkeys under various environmental conditions. Poultry Science 70: 935-940.

Han, Y., and D. H. Baker, 1994. Digestible lysine requirement of male and female broiler chicks during the period three to six weeks posthatching. Poultry Science 73: 1739-1745.

Hurwitz, S., M. Weiselberg, U. Eisner, I. Bartov, G. Riesenfeld, M. Sharvit, A. Niv, and S. Bornstein, 1980. The energy requirements and performance of growing chickens and turkeys as affected by environmental temperature. Poultry Science 59: 2290-2299.

Hurwtiz, S., and I. Ben-Gal, 1982. Energy use and performance of young turkeys kept under various constant and cycling environmental temperatures. Poultry Science 61: 1082-1085.

Hurwitz, S., Y. Frisch, A. Bar, U. Eisner, I. Ben-Gal, and M. Pines, 1983a. The amino acid requirements of growing turkeys. 1. Model construction and parameter estimation. Poultry Science 62: 2208-2217.

Hurwitz, S., I. Plavnik, I. Ben-Gal, H. Talpaz, and I. Bartov, 1983b. The amino acid requirements of growing turkeys. 2. Experimental validation of model-calculated requirements for sulfur amino acids and lysine. Poultry Science 62: 2387-2393.

Hurwitz, S., D. Sklan, H. Talpaz, and I. Plavnik, 1998. The effect of dietary protein level on the lysine and arginine requirements of growing chickens. Poultry Science 77: 689-696.

Jensen, L. S., B. Manning, L. Falen, and J. McGinnis, J., 1976. Lysine needs of rapidly growing turkeys from 12-22 weeks of age. Poultry Science 55: 1394-1400.

Jones, J. D., 1961. Lysine toxicity in the chick. Journal of Nutrition 73: 107-112.

Kroon, J. M. M., and D. Balnave, 1996. Heat stress in broilers. Thesis, Wageningen Agricultural University, The Netherlands and University of Sidney, Australia.

Latshaw, J. D., 1993. Dietary lysine concentrations from deficient to excessive and the effects on broiler chickens. British Poultry Science 34: 951-958.

Leeson, S., and J. D. Summers, 1980. Production and carcass characteristics of the Large White turkey. Poultry Science 59: 1237-1245.

Lehmann, D., M. Pack, and H. Jeroch, 1996. Responses of growing and finishing turkey toms to dietary lysine. Poultry Science 75: 711-718.

Lilburn, M. S., and D. Emmerson, 1993. The influence of differences in dietary amino acids during the early growing period on growth and development of Nicholas and British United Turkey toms. Poultry Science 72: 1722-1730.

Mahmoud, H. A., R. G. Teeter, and M. N. Makled, 1996. Arginine:lysine ratio effects on performance and carcass variables of broilers reared in thermoneutral and heat stress environments. Poultry Science 75(supplement 1): 88.

McNaughton, J. L., and F. N. Reece, 1984. Response of broiler chickens to dietary energy and lysine levels in a warm environment. Poultry Science 63: 1170-1174.

Mateos, G. G., J. L. Sell, and J. A. Eastwood, 1982. Rate of food passage (transit time) as influenced by level of supplemental fat. Poultry Science 61: 94-100.

Mendes, A. A., S. E. Watkins, J. A. England, E. A. Saleh, A. L. Waldroup, and P. W. Waldroup, 1997. Influence of dietary lysine and arginine:lysine ratio on performance of broilers exposed to heat or cold stress from 3 to 6 weeks of age. Poultry Science 76: 472-481.

Meyer, H., 1999. Einfluss unterschiedlicher F tterungsintensit„ten bei schweren un mittelschweren Putenh„hnen auf Mastleistung, Schlachtk”rperzusammensetzung und Fleischqualit„t. Thesis, Institut f r Tierzuchtwissenschaft der Rheinischen Friedrich-Wilhelms-Universit„t, Bonn, Germany.

Moncada, S., R. M. J. Palmer, and E. A. Higgs, 1991. Nitric oxide: physiology, pathophysiology, and pharmacology. Pharmacological Reviews 43: 109-142.

Moran, E. T., H. L. Orr, and E. Larmond, 1971. Sex and age related production efficiency, grades and yields with the Small White broiler-fryer type turkey. Poultry Science 50: 411-425.

Moran, E. T., 1977. Growth and meat yield in poultry. Pages 145-173 in Growth and Poultry Meat Production (K. N. Boorman, and B. J. Wilson, Eds.). Edinburgh, Scotland.

Musharaf, N. A., and J. D. Latshaw, 1999. Heat increment as affected by protein and amino acid nutrition. World's Poultry Science Journal 55: 233-240.

National Research Council. 1994. Nutrient Requirements of Poultry. 9th rev. ed. National Academy Press, Washington, DC.

Nestor, K. E., J. W. Anderson, and R. A. Patterson, 2000. Genetics of growth and reproduction in the turkey. 14. Changes in genetic parameters over thirty generations of selection for increased body weight. Poultry Science 79: 445-452.

Nixey, C., 1991. The lysine response of the turkey. Thesis. University of Nottingham. October 1991.

Noll, S. L., and P. E. Waibel, 1989. Lysine requirements of growing turkeys in various temperature environments. Poultry Science 68: 781-794.

Noll, S. L., M. E. El Halawani, P. E. Waibel, P. Redig, and K. Janni, 1991. Effect of diet and population density on male turkeys under various environmental conditions. 1. Turkey growth and health performance. Poultry Science 70: 923-934.

Oju, E. M., P. E. Waibel, and S. L. Noll, 1987. Protein, methionine, and lysine requirements of growing hen turkeys under various environmental temperatures. Poultry Science 66: 1675-1683.

Perenyi, M., Z. Suto, and J. Ujvarine, 1980. Changes in the proportion of the carcass parts of male and female heavy type turkeys between 4 and 20 weeks of age. Pages 514-519 in Proceedings 6th European Poultry Conference, World's Poultry Science Association.

Plavnik, I., and S. Hurwitz, 1993. Amino acids and protein requirement in turkeys. Pages 236-243 In: 9th European Symposium on Poultry Nutrition. Jelenia G•ra, Poland.

Potter, L. M., J. R. Shelton, and J. P. McCarthy, 1981. Lysine and protein requirements of growing turkeys. Poultry Science 60: 2678-2686.

Prince, R. P., L. M. Potter, and W. W. Irish, 1961. Response of chickens to temperature and ventilation environments. Poultry Science 40: 102-108.

Productschappen Vee, Vlees en Eieren. 2001. Vee, Vlees en Eieren in cijfers, 2001. In: Statistisch jaarrapport 2000. Productschappen Vee, Vlees en Eieren, Rijswijk, The Netherlands, Printer Trento, Trento, Italy.

Reece, F. N., and J. L. McNaughton, 1982. Effects of dietary nutrient density on broiler performance at low and moderate environmental temperatures. Poultry Science 61: 2208-2211.

Rose, S. P., and W. Michie, 1987. Environmental temperature and dietary protein concentrations for growing turkeys. British Poultry Science 28: 213-218.

Salmon, R. E., 1979. Slaughter losses and carcass composition of the Medium White Turkey. British Poultry Science 20: 297-302.

Sell, J. L., M. J. Jeffrey, and B. J. Kerr, 1994. Influence of amino acid supplementation of low-protein diets and metabolizable energy feeding sequences on performance and carcass composition of toms. Poultry Science 73: 1867-1880.

Shannon, D. W. F., and W. O. Brown, 1969. Calorimetric studies on the effect of dietary energy source and environmental temperature on the metabolic efficiency of energy utilization by mature Light Sussex cockerels. Journal of Agricultural Science, Cambridge, 72: 479-789.

Sinurat, A. P., and D. Balnave, 1985. Effect of dietary amino acids and metabolisable energy on the performance of broilers kept at high temperatures. British Poultry Science 26: 117-128.

Sturkie, P. D., 1954. Regulation of body temperature. Pages 118-137 in Avian Physiology. Comstock publishing associates, Ithaca, New York.

Tuttle, W. L., and S. L. Balloun, 1974. Lysine requirements of starting and growing turkeys. Poultry Science 53: 1698-1704.

Waibel, P. E., and S. L. Noll, 1985. Amino acid requirements in turkeys. Feed Management 38: 22-32.

Waibel, P. E., and M. G. Macleod, 1995. Effect of cycling temperature on growth, energy metabolism and nutrient retention of individual male turkeys. British Poultry Science 36: 39-49.

Waldroup, P. W., M. H. Adams, and A. L. Waldroup, 1997a. Evaluation of national research council amino acid recommendations for large white turkeys. Poultry Science 76: 711-720.

Waldroup, P. W., J. A. England, A. L. Waldroup, and N. B. Anthony, 1997b. Response of two strains of large white male turkeys to amino acid levels when diets are changed at three- or four-week intervals. Poultry Science 76: 1543-1555.

Waldroup, P. W., J. A. England, M. T. Kidd, and B. J. Kerr, 1998. Dietary Arginine and Lysine in large white toms. 1. Increasing arginine:lysine ratios does not improve performance when lysine levels are adequate. Poultry Science 77: 1364-1370.

Westermeier, C., E. Strobel, and H. Jeroch, 2000. Stimmen die Lysin-bedarfswerte noch? DGS Magazin 13: 35-39.

Wilson, E. K., F. W. Pierson, P. V. Hester, R. L. Adams, and W. J. Stadelman, 1980. The effects of high environmental temperature on feed passage time and performance traits of white pekin ducks. Poultry Science 59: 2322-2330.

Withers, P. C., 1992. Animal energetics. Page 108 in Comparative Animal Physiology. Saunders College Publishing. New York, NY.

Wolfenson, D., Y. F. Frei, N. Snapir, and A. Berman, 1981. Heat stress effects on capillary blood flow and its redistribution in the laying hen. Pfl gers Archiv ges. Physiologie 390: 86-93.

Wolfenson, D., 1986. The effect of acclimatization on blood flow and its distribution in normothermic and hyperthermic domestic fowl. Comparative Biochemical Physiology 85A: 739-742.

Wood, J. D., 1989. Meat yield and carcass composition in turkeys. Pages 271-288 in Recent Advances in Turkey Science. (C. Nixey, and T. C. Grey, Eds) Butterworth & Co. (Publishers) Ltd., U.K.

Yahav, S., S. Goldfeld, I. Plavnik, and S. Hurwitz, 1995. Physiological response of chickens and turkeys to relative humidity during exposure to high ambient temperature. Journal of Thermal Biology 20: 245-253.

Yahav, S., 2000. Relative humidity at moderate ambient temperatures: its effect on male broiler chickens and turkeys. British Poultry Science 41: 94-100.

Yahav, S., 2001. Different strategies to alleviate climatic stress in poultry production. Pages 233-236 in Proceedings of the 13th European Symposium on Poultry Nutrition. Blankenberge, Belgium.

Zuprizal, M. Larbier, A. M. Chagneau, and P. A. Geraert, 1993. Influence of ambient temperature on true digestibility of protein and amino acids of rapeseed and soybean meals in broilers. Poultry Science 72: 289-295.

Chapter 2

INTERACTION BETWEEN AMBIENT TEMPERATURE AND SUPPLEMENTATION OF SYNTHETIC AMINO ACIDS ON PERFORMANCE AND CARCASS PARAMETERS IN COMMERCIAL MALE TURKEYS

T. Veldkamp

Centre for Applied Poultry Research, "Het Spelderholt",

Spelderholt 9, PO Box 31, 7360 AA Beekbergen, The Netherlands

P. R. Ferket

North Carolina State University, Department of Poultry Science,

Scott Hall, Campus Box 7608, Raleigh, North Carolina 27695, USA

R. P. Kwakkel

Wageningen Institute of Animal Sciences, Animal Nutrition Group,

Wageningen University, Marijkeweg 40, 6709 PG Wageningen, The Netherlands

C. Nixey

British United Turkeys Ltd., Hockenhull Hall,Tarvin, CH3 8LE Chester, United Kingdom

J.P.T.M. Noordhuizen

University Utrecht, Department of Herd Health and Reproduction,

Yalelaan 7, 3584 CL Utrecht, The Netherlands

Published in: Poultry Science (2000) 79: 1472-1477

INTERACTION BETWEEN AMBIENT TEMPERATURE AND SUPPLEMENTATION OF SYNTHETIC AMINO ACIDS ON PERFORMANCE AND CARCASS PARAMETERS IN COMMERCIAL MALE TURKEYS

T. Veldkamp, P.R. Ferket, R.P. Kwakkel, C. Nixey, and J.P.T.M. Noordhuizen

---

ABSTRACT

An experiment with male turkeys was conducted to test the hypothesis that turkey production performance responds positively to extra crystalline amino acid supplementation (lysine, methionine, and threonine) when subjected to a high ambient temperature regimen in the grower period. Two diets were formulated to provide lysine, methionine, and threonine concentrations that either 1) met the breeder recommendations, or 2) contained 10% higher lysine and methionine concentrations from 22 to 134 d of age and 10% higher threonine concentrations from 22 to 68 d of age. Both diets were fed at two temperatures (15 or 25℃) from 42 d of age onward.

At 134 d of age, turkeys at high temperature had generally lower BW than those at low temperature. Up to 68 d of age and from 106 to 134 d of age, feed intake of turkeys at high temperature was significantly lower than that of turkeys at low temperature. Up to 42 d of age, feed:gain ratio of turkeys at high temperature was significantly lower than those of turkeys at low temperature. Significant treatment interactions were observed from 22 to 41 d of age. Turkeys fed the amino acid-supplemented diets at low temperature had significantly reduced feed:gain ratio, whereas those at high temperature did not respond. From 69 to 105 d of age, turkeys at high temperature that were fed the supplemented diets had significantly increased feed:gain ratio, but there were no dietary effects among turkeys at low temperature. There were no consistent diet effects on growth performance or carcass yields. Breast meat yields of turkeys at low temperature were higher (33.5 vs. 32.1%), and drum yields were lower (12.7 vs. 13.0%), than those of turkeys at the high temperature. There were no significant amino acid balance * ambient temperature effects on processing yields.

The hypothesis of this experiment could be rejected as production performance did not respond positively to extra supplementation of lysine, methionine, and threonine when subjected to a high temperature.

Keywords: amino acid, temperature, turkey, performance, carcass yield.

INTRODUCTION

Breast meat is the most economically valuable body constituent of the turkey because of the strong consumer demand for white meat. Breast muscle yield is positively related to growth rate (Lehmann et al., 1996); therefore, commercial turkeys have been genetically selected for growth rate and, thus, high breast meat yield. To achieve the turkey's genetic potential for growth and breast meat, an appropriate dietary level and balance of amino acids (AA) is necessary. In contrast, an imbalance of AA can contribute to an increased dietary heat increment that can exacerbate the effects of high environmental temperatures (Brake et al., 1994). Therefore, improper dietary AA balance partitions energy away from growth towards maintenance, which is dispersed as metabolic heat (Hurwitz et al., 1980). Increased metabolic heat adversely affects feed intake in animals subjected to ambient temperatures above their thermal comfort zone.

High ambient temperatures adversely affects turkey performance (Veldkamp, 1990; Halvorson et al., 1991; Noll et al., 1991). Cowan and Michie (1978) hypothesized that the total amount of digestible AA intake per day has to be the same at high temperatures as compared with low temperatures to maintain optimal growth. Using a choice feeding experiment, they demonstrated that turkeys maintain a constant protein intake by consuming more of a high protein diet at high ambient temperatures than at lower temperatures.

The objective of the research reported herein was to test the hypothesis that performance characteristics respond positively to extra dietary crystalline AA supplementation (lysine, methionine, and threonine) when turkeys are subjected to an ambient temperature regimen above their thermal comfort zone.

MATERIALS AND METHODS

Birds and Housing

Six hundred 1-d-old commercial male turkeys[1] were equally distributed over eight rooms (22.5 m^2) with 75 poults in each. Turkeys were reared within welded wire rings during the 1st wk after hatch. Electrical infrared heat lamps were used as supplemental localized

[1] British United Turkeys Ltd., Hockenhull Hall, Tarvin, Chester CH3 8LE, UK.

heat during the first 6 wk after placement. All of the birds were exposed to 23 h light (L):1 h dark (D) from 1 to 7 d; 16 L:8 D from 8 to 105 d; and, subsequently, 23 L:1 D, asrecommended by the breeder. Soft pine shavings were used as litter, and it was added to each room as necessary to maintain acceptable litter conditions. Each room was equipped with two tube feeders and two automatic plasson water drinkers. During the 1st wk after placement, two additional flat feed trays and two mini-drinkers were provided in each room. Feed and water were provided for *ad libitum* consumption.

Environmental Temperature and Humidity Conditions

Ambient temperature (T) under the heat lamps was decreased gradually from 36 to 28°C from 1 to 21 d of age for all birds. From 21 to 42 d of age, ambient temperatures under the heat lamps were gradually decreased to 27 and 22°C for the high T regimen and the low T regimen, respectively. Ambient room temperatures decreased gradually during the 1- to 42-d period from 28 to 25°C and from 23 to 15°C for high and low T, respectively. Thus, birds exposed to low T during the period from 1 to 42 d of age had a greater range of choice in decreasing temperature gradient because of the supplemental heat lamps as compared with those subjected to high T.

After 42 d of age the supplemental heat lamps were removed from each pen, and the birds were exposed to constant ambient temperatures of 25 and 15°C for the high and low T, respectively. Relative humidity was adjusted to 60 and 80% for high and low T, respectively. These humidity adjustments for high and low T were chosen differently to simulate average Western European summer and winter conditions. Temperature and humidity were maintained constant during the day using computer-aided controllers that adjusted each room independently. Ventilation rates were equal in all rooms. Each of the ambient temperature regimens were replicated in four individually climate controlled rooms.

Dietary Treatments

Dietary compositions are presented in Table 1. Five wheat- and soybean-based feed phases were provided to the birds *ad libitum* from 1 to 21, 22 to 41, 42 to 68, 69 to 105, and 106 to 134 d of age, respectively. The diet in the first feed phase was similar for all treatment groups.

Table 1. Composition of the experimental diets of turkeys subjected to high and low temperature regimens.

		22 to 41 d		42 to 68 d		69 to 105d		106 to134 d	
	1 to 21 d	Basal	+AA[1]	Basal	+AA	Basal	+AA	Basal	+AA
	(%)								
Ingredients									
Wheat	22.75	45.00	41.80	44.89	42.22	48.75	46.86	49.99	48.73
Heated soybeans	-	-	-	6.00	6.00	16.00	16.00	16.80	16.80
Soybean meal	41.23	35.00	35.00	24.50	24.50	16.10	16.10	10.20	10.20
Yellow corn	10.81	1.35	1.34	-	-	-	-	5.40	5.40
Tapioca	5.00	-	-	-	-	-	-	-	-
Peas	-	-	-	-	2.50	-	-	-	-
Sunflower meal	1.49	-	-	2.50	2.50	3.40	3.40	3.50	3.50
Fish meal	10.00	6.71	6.71	4.30	4.30	1.00	1.00	0.30	0.30
Meat meal	-	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Potato protein	-	-	-	0.80	0.80	-	-	-	-
Fat	0.31	1.43	1.43	3.82	3.82	4.00	4.00	4.00	4.00
Soybean oil	3.00	0.37	0.37	-	-	0.50	0.50	-	-
DL-Methionine	0.19	0.20	0.32	0.23	0.33	0.23	0.33	0.20	0.29
L-Threonine	-	-	0.12	-	0.10	-	0.03	-	-
L-Lysine HCl	-	-	0.19	-	0.16	-	0.13	-	0.09
Limestone	0.84	0.66	0.66	0.88	0.88	0.86	0.86	0.87	0.87
Monocalcium phosphate	1.22	1.00	1.00	1.02	1.02	1.11	1.11	0.99	0.99
Vitamin-mineral premix	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Anticoccidial Avatec	0.50	0.50	0.50	0.50	0.50	-	-	-	-
	(g/kg)								
Calculated analysis									
ME, MJ/kg[2]	11.1	11.1	10.8	11.7	11.5	12.4	12.2	12.6	12.5
CP	300	284	286	259	261	229	231	206	207
Crude fat	60	48	47	75	74	95	95	92	92
Crude fiber	28	24	24	31	31	35	35	35	35
Total lysine	18.5	17.0	18.7	15.1	16.6	12.6	13.8	10.8	11.6
Total methionine	7.3	7.0	8.1	6.8	7.8	6.1	7.0	5.4	6.2
Total methionine + cystine	11.9	11.5	12.6	11.0	11.9	10.0	10.9	9.0	9.8
Total threonine	11.7	11.0	12.0	10.1	10.9	8.7	8.9	7.7	7.7
Total tryptophan	3.6	3.4	3.4	3.1	3.1	2.8	2.8	2.5	2.4
Total arginine	19.8	18.7	18.6	17.2	17.1	15.3	15.2	13.5	13.5
Digestible lysine	16.3	14.8	16.5	13.1	14.5	10.7	11.9	9.1	9.9
Digestible methionine + cystine	10.5	10.1	11.2	9.7	10.6	8.7	9.7	7.8	8.7
Calcium	12.0	12.0	12.1	12.0	12.1	11.0	11.1	10.5	10.5
Phosphorus	9.1	8.6	8.6	8.1	8.1	7.6	7.6	7.1	7.1
Available Phosphorus	7.0	7.0	7.0	6.5	6.5	6.0	6.0	5.5	5.5

[1] AA = amino acid.

[2] The ME (MJ/kg) values for the different ingredients were based on the Dutch Energy Tables for broilers (CVB, 1995).

Beginning at 22 d of age, turkeys were fed either basal diets formulated to meet breeder recommendations or diets supplemented with 10% higher lysine, methionine, and threonine concentrations up to 68 d and 10% higher lysine and methionine concentrations up to 134 d of age (Table 1). These higher dietary AA concentrations were achieved by the supplementation of crystalline L-lysine HCl, DL-methionine, and L-threonine at the expense of wheat in the diet. In the first feed phase, all diets were fed as crumbles; all other diets were fed as 3 mm-pellets. Small differences in ME content between basal and supplemented diets were due to differences in wheat inclusion levels; however, these differences were expected to have no influence on the observed traits.

Traits Measured

Body weight (BW) gain and feed consumption per room were recorded during each feed phase. Weight of mortality and culled birds from each room were used to adjust feed:gain ratio, but they were not included in the calculation of average BW. All mortality was subjected to post-mortem dissection to determine cause of death. For carcass measurements, a group of 16 turkeys from each room were randomly selected and slaughtered. Yields of breast meat, breast skin, thigh, drumstick, and wings were determined as a percentage of eviscerated carcasses (without feet, head, and giblets). The incidence of sternal bursitis, focal ulcerative dermatitis, scabby hips, and hemorrhages were also recorded during slaughter processing. All individual measurements were averaged to obtain a trait value per room. One day after delivery, all litter per room was weighed, and samples were taken to determine DM and N.

Statistical Analyses

The experiment was designed and statistically analyzed as a 2 * 2 factorial arrangement of two temperature regimens and two dietary treatments. Each of the four treatment combinations was replicated in two rooms containing 75 birds each. Analysis of variance of data was performed using the Genstat 5 procedure (Genstat 5 Committee, 1993); room was the experimental unit.

The following statistical model was used to assess the main effect of temperature (T): high T vs. low T; the main effect of diet (D): basal vs. supplemented; and the corresponding interaction T * D:

$$Y_{ijk} = \mu + T_i + D_j + T_i * D_j + e_{ijk}$$

where Y_{ijk} = observed trait; μ = overall mean; T_i = effect of ambient temperature (i = high T or low T); D_j = effect of diet (j = basal or supplemented); $T_i * D_j$ = interaction of D_j and T_i; and e_{ijk} = random error.

RESULTS

Temperature-Related Behavior

The actual difference in temperature between low and high T was 8.7°C instead of the intended value of 10°C. Turkey poults subjected to low T crowded under the heat lamps, and those subjected to high T were spread all out over the ring during the 1st wk after hatch. Turkeys at high T showed panting behavior beginning at 6 wk of age.

It was observed that turkeys subjected to high T at 42 d of age had a higher incidence of split wing feather alignment (about 80% of all birds at high T) as compared with turkeys subjected to low T (about 20%).

Feed Intake, BW Gain, and Feed:gain ratio

Results on feed intake, BW gain, and feed:gain ratio are summarized in Table 2. Temperature had a major effect on feed intake. Feed intake was higher at low T in all phases ($P < 0.05$ in the phases up to 68 d of age and in the phase from 106 to 134 d of age; $P < 0.10$ in the phase from 69 to 105 d of age). Feed intake was not affected by diet, and there were no temperature * diet interaction effects.

Body weight gain was significantly higher ($P < 0.05$) in poults subjected to high T from 1 to 21 d of age than in those subjected to low T. Significant temperature effects on BW gains during subsequent periods were not consistent. Weight gains were not affected by diet or temperature * diet effects.

Table 2. Effects of ambient temperature (T) and amino acid (AA) supplementation on feed intake, BW gain and feed:gain ratio[1].

	Low temperature		High temperature		Source of variation[5]			
Variable	Basal	+AA[2]	Basal	+AA[2]	T	Diet	T * Diet	SEM[3]
	(kg)				*P*			
Feed intake								
1 to 21 d	1.01	1.00	0.96	0.97	**0.021**	0.936	0.325	0.01
22 to 41 d	3.37	3.39	2.99	3.06	**0.002**	0.421	0.634	0.03
42 to 68 d	9.87	9.44	7.86	8.42	**< 0.001**	0.726	**0.047**	0.09
69 to 105 d	17.92	18.46	16.98	17.35	0.092	0.386	0.868	0.23
106 to 134 d	16.88	17.23	14.85	14.15	**0.008**	0.755	0.372	0.26
1 to 134 d	49.05	49.52	43.64	43.96	**0.001**	0.591	0.919	0.31
	(kg)							
Body weight gain								
1 to 21 d	0.74	0.74	0.76	0.78	**0.034**	0.578	0.359	0.01
22 to 41 d	2.08	2.17	2.04	2.11	0.240	0.077	0.804	0.02
42 to 68 d	4.75	4.85	4.06	4.31	**0.007**	0.230	0.571	0.06
69 to 105 d	6.32	6.42	6.57	6.01	0.634	0.209	0.097	0.08
106 to 134 d	4.95	4.94	4.29	3.91	**0.009**	0.327	0.362	0.09
1 to 134 d	18.83	19.11	17.72	17.13	**0.002**	0.507	0.118	0.11
	(g feed intake/g BW gain)							
Feed:gain ratio[4]								
1 to 21 d	1.37	1.36	1.25	1.24	**0.003**	0.635	0.886	0.01
22 to 41 d	1.62	1.56	1.47	1.45	**< 0.001**	**0.001**	**0.009**	0.00
42 to 68 d	2.08	1.95	1.94	1.95	0.384	0.438	0.345	0.03
69 to 105 d	2.84	2.88	2.59	2.89	**0.042**	**0.014**	**0.032**	0.02
106 to 134 d	3.41	3.49	3.46	3.64	0.578	0.479	0.797	0.08
1 to 134 d	2.53	2.54	2.41	2.50	0.066	0.173	0.272	0.02

1 Mean values are expressed as an average of two replicate rooms of 75 poults.
2 AA = amino acid. Dietary treatments were either a basal diet or basal diet with 10% additional lysine, and methionine up to 134 d and 10% additional threonine up to 68 d of age supplemented as crystalline AA at the expense of dietary wheat.
3 4 df.
4 Feed:gain ratio was adjusted by including the gain of the birds that had died or were culled during the observation period.
5 Significant effects ($P < 0.05$) are printed in bold.

Up to 42 d of age, feed:gain ratio was significantly better (lower) for turkeys at high than at low T. The high T treatment significantly improved feed:gain ratio from 1 to 42 d of age in comparison with the low T treatment (1.24 vs. 1.36, $P < 0.05$, in the period from 1 to 21 d of age; 1.46 vs. 1.59, $P < 0.001$, in the period from 22 to 41 d of age). A significant temperature * diet interaction ($P < 0.009$) effect was observed during the period from 22 to 41 d of age. Poults fed the AA-supplemented diets had significantly lower feed:gain ratio than those fed the basal diet when subjected to low T (1.56 vs. 1.62). No diet effect, however, was observed in poults subjected to high T (1.45 vs. 1.47).

Table 3. Effects of ambient temperature and diet supplementation on carcass yields and carcass quality[1].

	Low temperature		High temperature		Source of variation[6]			
Variable	Basal	+AA[2]	Basal	+AA[2]	T	Diet	T * Diet	SEM[3]
	(kg)				*P*			
BW	19.17	19.76	17.83	17.06	**0.001**	0.735	0.060	0.13
Eviscerated yield	14.46	14.81	13.57	12.83	**< 0.001**	0.309	**0.030**	0.08
	(% Carcass yields)[4]							
Drums	12.7	12.6	12.9	13.0	**0.029**	0.955	0.387	0.0
Thighs	17.1	17.2	17.3	17.4	0.403	0.891	0.975	0.1
Wings	11.3	10.9	11.2	11.6	0.211	0.812	0.124	0.1
Breast meat	33.3	33.8	31.9	32.4	**0.045**	0.343	0.964	0.2
	(Carcass quality)[5]							
Sternal bursitis	157	128	157	100	0.698	0.272	0.704	17
Focul ulcerative dermatitis	152	134	184	100	0.987	0.225	0.401	18
Haemorrhages	136	106	135	100	0.949	0.576	0.968	26
Scabby Hips	76	85	77	100	0.395	0.129	0.457	4

1 Mean values are expressed as an average of two rooms from which eight birds were sampled at 134 d of age.
2 AA = amino acid. Dietary treatments were either a basal diet or basal diet with 10% additional lysine, and methionine up to 134 d and 10% additional threonine up to 68 d of age supplemented as crystalline AA at the expense of dietary wheat.
3 4 df.
4 Percentage of eviscerated carcass without feet, head and giblets.
5 Relative to the high temperature treatment and AA supplementation.
6 Significant effects ($P < 0.05$) are printed in bold.

In the period from 69 to 105 d of age, a significant interaction effect was also observed. Turkeys fed the AA-supplemented diets at high T had significantly higher feed:gain ratio than those fed the basal diets (2.89 vs. 2.59), but this difference was not observed among turkeys at low T (2.88 vs. 2.84).

Average mortality rate throughout the 134-d experimental period was 9.5%. There were no significant treatment effects on mortality or culling rates.

Carcass Yields and Quality

Carcass yield data are presented in Table 3. Breast meat yield was significantly higher ($P < 0.05$), and drum yield was significantly lower ($P < 0.05$), in birds subjected to low T than to high T. None of other carcass yields were significantly affected by the experimental treatments. Carcass quality parameters did not differ significantly between treatments because of a large variation among replicate rooms.

Litter Quality

Litter quality measurement values are presented in Table 4. The rooms at the higher temperature had litter with a somewhat higher DM content than the rooms at the lower temperature (*P* < 0.10). There were no other treatment effects observed on litter DM values. Nitrogen content in the DM of the litter was significantly lower for high T.

Table 4. Effects of ambient temperature and diet supplementation on litter quality of male turkeys determined at 135 d of age[1].

	Low temperature		High temperature		Source of variation[4]			
Variable	Basal	+AA[2]	Basal	+AA[2]	T	Diet	T * Diet	SEM[3]
					P			
DM (%)	65.9	67.1	70.2	83.5	0.088	0.190	0.259	2.3
N content (%)	5.0	4.9	4.2	4.1	0.142	0.783	0.956	0.2
N content (kg DM per delivered turkey)	1.16	1.10	0.79	0.87	**0.038**	0.944	0.506	0.05

[1] Mean values are expressed as an average of two replicate rooms.
[2] AA = amino acid. Dietary treatments were either a basal diet or basal diet with 10% additional lysine, and methionine up to 134 d and 10% additional threonine up to 68 d of age supplemented as crystalline AA at the expense of dietary wheat.
[3] 4 df.
[4] Significant effects (*P* < 0.05) are printed in bold.

DISCUSSION

The effect of ambient temperature on growth performance in the present experiment is in agreement with results published in literature. Feed consumption was influenced by temperature. Cumulative feed intake of turkeys subjected to high T was 11.1% lower than of turkeys subjected to low T. This observation corresponds to a 1.1% decrease in feed consumption for each degree Celsius increase in temperature. Rose and Michie (1987) reported a similar decrease of 1.2% per degree Celsius temperature increase.

Body weight gain from 1 to 21 d of age was significantly higher in poults subjected to high T than in poults subjected to low T. Ambient room temperature for low T during this period was below the turkey's thermal neutral zone as more calories of energy were diverted from growth to maintain body temperature in the cooler environment. Cold stress was evident in the low T groups as indicated by the crowding behavior of the poults under the heat lamps during the first few days after placement. In contrast, poults subjected to the high T spread out very well over the area within the ring; many avoided the radiant heat from the heat lamps during the first days after placement.

Although poults subjected to low T had retarded growth during the starter period, BW between the temperature treatments was similar by 42 d of age. Evidently, the poults subjected to high T experienced some growth suppression relative to the poults subjected to low T between 22 and 41 d of age. Beginning at 42 d of age, turkeys at high T showed panting behavior, regardless of dietary treatment, indicating that the ambient temperature of 25°C exceeded the thermal comfort of poults. Grimes et al. (1995) estimated that 25°C exceeds thermal comfort of turkeys beginning at 49 d of age. Thermoneutrality of male turkeys 63 d of age and older is estimated between 15 and 23°C.

By 134 d of age, BW of turkeys subjected to low T were approximately 8.9 % higher than those of turkeys subjected to high T. In agreement with these observations, Halvorson et al. (1991), and Noll et al. (1991) observed that male turkeys exposed to temperatures of 7°C had a higher growth rate than those exposed to an ambient temperature of 21°C after 12 wk of age. In a former trial at our laboratory, we found that final BW of turkeys at 14°C were 700 g higher than BW of turkeys at 20°C (Veldkamp, 1990).

We hypothesized that turkeys exposed to high ambient temperatures require higher dietary AA content to compensate for the reduced protein intake associated with the reduced feed consumption. Supplementation of AA, however, did not improve growth performance in turkeys subjected to high T as hypothesized. This observation is in contrast to the findings reported by Cowan and Michie (1978) and may be due to the fact that the basal diet contained sufficient AA to achieve the maximal growth response under high T, even with the limitation of a decreased feed intake. Dietary concentrations of lysine, methionine, and threonine in this study (as recommended by the breeder) exceeded NRC (1994) recommendations.

Turkeys at low T that were fed the AA-supplemented diet had lower feed:gain ratio than did turkeys fed the unsupplemented diet from 22 to 41 d of age. This result may suggest that the unsupplemented turkey poults at low T during this period had a lack of protein to sustain processes of net protein synthesis. Apparently, extra AA were used for BW gain.

From 69 to 105 d of age, turkeys at high T that were fed the supplemented diets had higher feed:gain ratio. A possible explanation for the lack of benefit for AA supplementation of the diet of birds subjected to the high T is that AA supplementation results in extra heat increment in these birds. The extra AA have to be deaminated because AA intake of birds fed the unsupplemented diet was already adequate.

Breast meat yields were higher, and drum yields were lower, for turkeys at low T than for turkeys at high T. Standing activity is increased in birds exposed to high T because of panting behavior, and birds need to develop muscles for locomotion purposes. In agreement, Halvorson et al. (1991) and Rose and Michie (1987) reported that turkeys reared in cool conditions had more breast meat than those reared at warmer ambient temperatures. In previous research, Veldkamp (1990) showed that turkeys at 14°C had 2.1% more breast meat per 100 g BW than did turkeys at 20°C.

Carcass yields in this study were not affected by diet, indicating that either the basal diet supplied sufficient AA or the supplementation of synthetic lysine caused an imbalance with other AA, such as arginine (Brake et al., 1994).

Dry Matter of the litter from birds subjected to high T was higher than that of litter from birds subjected to low T. This observation was likely due to more evaporation from the litter in the high T rooms than in the low T rooms. Nitrogen content in the DM of the litter was 26.5% lower in the high T than in the low T ($P < 0.038$), which might be due to evaporation losses or an overall higher N efficiency of these birds.

In conclusion, ambient temperature had a marked effect on feed intake, BW gain, feed:gain ratio, and carcass yields. Feed intake of turkeys subjected to the high T was decreased throughout the experiment. Consequently, turkeys subjected to the high T had lower final BW at 134 d of age than did those subjected to the low T. The reduced growth rate among the high T-treated birds corresponded with reduced breast meat and higher drum yields compared with the low T-treated birds. Up to 42 d of age, feed:gain ratio among the low T-treated turkeys was significantly impaired, which is most likely due to the effects of cold stress.

The hypothesis of this experiment could be rejected, as production performance did not respond positively to extra crystalline AA supplementation (lysine, methionine, and threonine) when subjected to a high ambient temperature regimen. This result is probably because the control basal diets already had sufficient AA to satisfy nutritional demands.

ACKNOWLEDGMENT

We wish to thank British United Turkeys Ltd., Hockenhull Hall, Tarvin, Chester CH3 8LE, UK, for their financial support in this project.

REFERENCES

Brake, J., P. Ferket, J. Grimes, D. Balnave, I. Gorman, and J. J. Dibner, 1994. Optimum arginine: lysine ratio changes in hot weather. Pages 82-104 in Proceedings of the 21st Carolina Poultry Nutrition Conference, Charlotte, NC.

Centraal Veevoederbureau. 1995. Veevoedertabel: Gegevens over Voederwaarde, Verteerbaarheid en Samenstelling. Centraal Veevoederbureau in Nederland, Lelystad, The Netherlands.

Cowan, P. J., W. Michie 1978. Environmental temperature and turkey performance: The use of diets containing increased levels of protein and use of a choice-feeding system. Ann. de Zootech. (Paris) 27:175-180.

Genstat 5 Committee. 1993. Genstat 5 Reference Manual. Release 3. Clarendon Press, Oxford, UK.

Grimes, J. L., P. R. Ferket, R. W. Bottcher, 1995. Hot weather management of turkeys. Turkey World 71(3):11-14.

Halvorson, J. C., P. E. Waibel, E. M. Oju, S. L. Noll, M. E. El Halawani, 1991. Effect of diet and population density on male turkeys under various environmental conditions. 2. Body composition and meat yield. Poultry Sci. 70:935-940.

Hurwitz, S. M. Weisselberg, U. Eisner, I. Bartov, G. Risenfeld, M. Sharvit, A. Niv, S. Bornstein, 1980. The energy requirements and performance of growing chickens and turkeys as affected by environmental temperature. Poultry Sci. 59:2290-2299.

Lehmann, D., M. Pack, H. Jeroch, 1996. Responses of growing and finishing turkey toms to dietary lysine. Poultry Sci. 75:711-718.

National Research Council. 1994. Nutrient Requirements for Poultry. 9th rev. ed. National Academy Press, Washington, DC.

Noll, S. L., M. E. El Halawani, P. E. Waibel, P. Redig, K. Janni, 1991. Effect of diet and population density on male turkeys under various environmental conditions. 1. Turkey growth and health performance. Poultry Sci. 70:923-934.

Rose, S. P., and W. Michie, 1987. Environmental temperature and dietary protein concentrations for growing turkeys. Br. Poult. Sci. 28:213-218.

Veldkamp, T., 1990. Effect of relative humidity and ambient temperature on performance and carcass quality in commercial male turkeys (in Dutch). Onderzoekverslag 3:1-24.

Chapter 3

EFFECTS OF AMBIENT TEMPERATURE, ARGININE TO LYSINE RATIO, AND ELECTROLYTE BALANCE ON PERFORMANCE, CARCASS AND BLOOD PARAMETERS IN COMMERCIAL MALE TURKEYS

T. Veldkamp

Centre for Applied Poultry Research, "Het Spelderholt",

Spelderholt 9, PO Box 31, 7360 AA Beekbergen, The Netherlands

R. P. Kwakkel

Wageningen Institute of Animal Sciences, Animal Nutrition Group,

Wageningen University, Marijkeweg 40, 6709 PG Wageningen, The Netherlands

P. R. Ferket

North Carolina State University, Department of Poultry Science,

Scott Hall, Campus Box 7608, Raleigh, North Carolina 27695, USA

P.C.M. Simons

Centre for Applied Poultry Research, "Het Spelderholt",

Spelderholt 9, PO Box 31, 7360 AA Beekbergen, The Netherlands

J.P.T.M. Noordhuizen and A. Pijpers

University Utrecht, Department of Herd Health and Reproduction,

Yalelaan 7, 3584 CL Utrecht, The Netherlands

Published in: Poultry Science (2000) 79: 1608-1616

EFFECTS OF AMBIENT TEMPERATURE, ARGININE TO LYSINE RATIO, AND ELECTROLYTE BALANCE ON PERFORMANCE, CARCASS AND BLOOD PARAMETERS IN COMMERCIAL MALE TURKEYS

T. Veldkamp, R.P. Kwakkel, P.R. Ferket, P.C.M. Simons, J.P.T.M. Noordhuizen, and A. Pijpers

ABSTRACT

The effects of ambient temperature (T; 15°C vs. 30°C from 6 wk of age onwards), dietary Arg:Lys ratio (Arg:Lys ratio; 1.00 vs. 1.25), dietary electrolyte balance (DEB; 164 vs. 254 meq/kg), and their interactions on growth performance and carcass yields of male turkeys were studied. The experiment was designed as a split plot, including T * DEB as the main plot and Arg:Lys ratio as the sub-plot, with 24 pens containing 35 male turkeys each. Feed consumption, BW gain, mortality, and processing yields were measured. Temperature had a clear effect on performance during all age periods. Feed intake was significantly lower for the high T group compared with the low T group (322.7 vs. 432.3 g/bird per d; $P < 0.001$). Consequently, BW gain during the experimental period (28 to 140 d of age) was significantly lower for the high T group compared with the low T group (14.54 vs. 18.74 kg; $P < 0.001$). Feed:gain ratio during the period 28 to 140 d of age was significantly lower for the high T group compared with the low T group (2.51 vs. 2.61; $P < 0.001$). The high dietary Arg:Lys ratio increased feed intake significantly until 56 d of age (200.6 vs. 197.6; $P = 0.034$). A high Arg:Lys ratio resulted in significantly higher BW gain until 98 d of age (10.03 vs. 9.84 kg; $P = 0.024$). The Arg:Lys ratio did not affect feed:gain ratio throughout the experiment. Dietary electrolyte balance did not affect performance parameters. No consistent two- or three-way interactions were observed. Processing yields were only affected significantly by T and not by Arg:Lys ratio or DEB main effects. High T resulted in lower cold carcass (73.2 vs. 74.9%) and breast meat yields (33.5 vs. 36.0%), and higher thigh (18.9 vs. 18.1%), drumstick (14.5 vs. 13.2%), and wing yields (11.7 vs. 10.6%) compared with low T. We concluded that growth performance is compromised by higher T and altering Arg:Lys ratio or DEB does not alleviate this impaired performance. Dietary Arg levels seem to be important when dietary Lys is marginal relative to the requirement.

Keywords: turkey, temperature, arginine to lysine ratio, electrolyte balance.

INTRODUCTION

Nutrient requirements of turkeys have generally been determined under conditions of moderate environmental temperatures (NRC, 1994). These requirements, however, were assessed at adequate feed intake levels that may change at higher ambient temperatures (T). High environmental temperatures decrease feed intake of broilers and turkeys (Cowan and Michie, 1978; Oju et al., 1987; Rose and Michie, 1987; Balnave and Oliva, 1990; Noll et al., 1991; Cooper and Washburn, 1998; Veldkamp et al., 2000). Moreover, a decreased digestibility of some amino acids (AA) has also been noted due to high environmental temperatures (Wallis and Balnave, 1984; Balnave and Oliva, 1991; Zuprizal et al., 1993). It has been suggested that high temperatures might alter relative gut absorption of certain AA and induce a plasma imbalance of AA that might decrease broiler and turkey performance and thermal tolerance (Brake et al., 1994). The same authors suggested that dietary Arg is important during hot weather because its availability from dietary sources is decreased or its metabolic requirement is increased.

Kroon and Balnave (1996) concluded that broilers must be fed higher Arg:Lys ratios in order to maintain optimal feed utilization during heat stress. Brake et al. (1994) reported that turkeys reared during hot weather had better feed conversion, a lower mortality rate, and higher breast meat yield when fed a diet with an Arg:Lys ratio of 1.30 rather than 1.05. Arginine is a precursor of nitric oxide (NO), which is important for the bactericidal and tumorcidal activity of mononuclear cells, including monocytes and macrophages. For that reason, a dietary Arg:Lys ratio above 1.10 was advised for maintaining a good health status, especially during warm weather conditions (Qureshi et al.,1998).

Data from literature indicate that dietary electrolyte balance (DEB) can influence the tolerance of poultry to heat stress. A proper DEB is important to maintain physiological functions in poultry during hot weather. Increased respiration rates necessary for evaporative cooling in broilers and turkeys result in carbon dioxide loss, which can cause acid and base perturbations (Teeter et al., 1985; Brake et al., 1994). Supplementation of electrolytes to diets may affect these perturbations. Sodium supplementation to a high-Lys diet (i.e., a reduced Arg:Lys ratio) in combination with a buffer such as bicarbonate, has been reported to affect the broiler performance in a way similar to supplementation with Arg (account of O'Dell and Savage, 1966). Including sodium bicarbonate or ammonium chloride in diets of broilers subjected to chronic heat stress improved BW gains (Teeter et al., 1985).

For the present experiment, we hypothesized that an increased dietary Arg:Lys ratio could alleviate the adverse effects of high T in turkeys, and DEB may modulate this effect.

MATERIALS AND METHODS

Birds and Housing

Nine-hundred twenty, day-old commercial male turkeys[1] were reared under practical conditions in four pens of 20 m^2 each until 28 d of age. Turkeys were reared in wired rings during the first week of life. Infrared heat lamps were used for supplemental local heating during the first 4 wk. Birds were provided 23 h light and 1 h dark on Day 1 and the photoperiod was gradually decreased 1 h per d to 8 d of age. From 8 d of age onwards, this lighting schedule of 16 h of light:8 h of dark was maintained.

At 28 d of age, 840 turkey poults were randomly selected and distributed among 12 identical individually controlled rooms of 20 m^2 each. A room was divided in two pens of 10 m^2 each and contained 35 birds. Soft pine wood shavings were used as litter material, and a certain amount of wood shavings was added to all pens if the litter condition in one pen required additional shavings. Feed and water were provided *ad libitum* throughout the experiment.

Climate

Local temperature below the heat lamps was decreased stepwise by about 3°C each week, from 36 to 23°C, from 0 to 28 d of age. Ambient room temperature from 0 to 28 d of age was decreased stepwise (about 1.7°C each week) from 26 to 19°C. The experimental period started at 28 d of age, and the two gradual temperature regimens were set for the period of 29 to 42 d of age. The high T increased from 19 to 30°C, and the low T decreased from 19 to 15°C in this period. Thereafter, the high and low T were maintained at 30 and 15°C, respectively, throughout the entire experiment. Each temperature regimen was applied to six rooms. Relative air humidity was 70% throughout the experiment. Temperature and humidity were maintained constant over the day, and ventilation rate was equal for all pens.

Dietary Treatments

Five wheat-, corn-, and soybean-based feed phases were provided to the birds *ad libitum* from 0 to 14, 15 to 28, 29 to 70, 71 to 112, and 113 to 140 d of age, respectively.

---

[1] British United Turkeys Ltd., Hockenhull Hall, Tarvin, Chester CH3 8LE, UK.

The diets during the first two periods were identical for all groups. From 28 d of age onwards, the experimental diets were similar except for the Arg content and DEB. Experimental diets within a room contained one DEB level, and in each pen within a room, two different Arg:Lys ratios were fed to the birds. All diets were based on wheat and soybean meal and fed as pellets (3 mm). The two Arg:Lys ratios were adjusted by adding L-Arg and the two DEB levels were adjusted by adding sodium bicarbonate ($NaHCO_3$) or ammonium chloride (NH_4Cl). The calculated compositions of the diets are presented in Table 1. Analyzed values for DM, CP, crude fiber, crude fat, Na, K, Cl, Ca, P, and AA in all four experimental diets are presented in Table 2. These values were in agreement with the calculated levels.

Traits Measured

Body weight (BW) gain and feed consumption data per pen were recorded biweekly, and feed:gain ratio per pen was calculated from these data. Any bird that died or had to be culled was weighed, and its BW gain was included in the calculation of feed:gain ratio per pen. Dead birds were subjected to postmortem dissection on the day of death. At 140 d of age, eight male turkeys per pen were selected on the basis of average pen weight and killed for processing. After the carcasses were chilled for 20 h, the meat was dissected from the carcasses. Per bird, weights of eviscerated carcass, breast meat (pectoralis major and pectoralis minor), thighs, drums, and wings were recorded, and pen means were calculated for statistics.

Haemagglutination Inhibition (HI) tests using Newcastle Disease Virus antigen (*LaSota* strain) were performed as described by De Jong (1978). All HI titers were expressed as $\log_2$ of the reciprocal of the highest serum dilution showing complete HI. At 63 d of age, birds were vaccinated, and one day prior to vaccination and 10 and 20 d after vaccination, blood was sampled from seven randomly chosen and marked birds per pen to determine the HI titers.

Hematocrit, pH, pO_2, pCO_2, and HCO_3^- in blood plasma as measures of respiratory alkalosis indicating hyperthermic panting (Siegel et al., 1974) were analyzed using a pH-gas analyzer[2] at 62, 73, and 83 d of age.

[2] ABL 605 Radiometer A/S, Åkandevej 21, DK-2700 Bronshoj, Denmark.

Table 1. Composition and calculated nutrient content of the diets[1].

Ingredient	0 to 14 d	15 to 28 d	29 to 70 d	71 to 112 d	113 to 140 d
	(%)				
Wheat	34.973	34.990	(39.824 to 39.164)	(44.153 to 43.453)	(49.993 to 49.003)
Corn	14.600	19.200	11.400	22.000	19.000
Soybean meal	32.100	26.700	25.000	18.500	12.500
Soybeans (heat-treated)	1.000	0.000	0.000	0.000	0.000
Rapeseed meal 00	3.000	3.000	3.000	4.000	4.000
Tapioca 109	0.000	0.000	7.300	0.000	6.000
Sunflower meal	0.000	3.600	0.000	0.000	0.000
Fish meal	4.000	2.900	2.000	0.000	0.000
Meat and bone meal	5.000	5.000	5.000	5.000	4.400
Animal fat	1.270	0.810	2.270	2.710	1.770
Soybean oil	0.000	0.100	0.150	0.350	0.000
L-lysine HCl	0.230	0.300	0.510	0.530	0.480
L-arginine	0.000	0.000	(0.000 to 0.440)	(0.000 to 0.370)	(0.000 to 0.320)
DL-methionine	0.237	0.190	0.419	0.321	0.230
L-threonine	0.000	0.000	0.160	0.133	0.098
Tryptophan	0.000	0.000	0.017	0.013	0.009
Ammonia chloride	0.000	0.000	(0.000 to 0.410)	(0.000 to 0.200)	(0.000 to 0.070)
Sodium bicarbonate	0.000	0.000	(0.040 to 0.230)	(0.010 to 0.540)	(0.000 to 0.740)
Limestone	0.930	0.770	0.330	0.410	0.130
Monocalcium phosphate	1.160	0.940	0.890	0.670	0.320
Vitamin-mineral premix[2]	1.000	1.000	1.000	1.000	1.000
Anticoccidial Avatec 310	0.500	0.500	0.500	0.000	0.000
ME (MJ/kg)	12.0	11.9	12.4	12.9	12.7
Calculated composition					
DM	87.8	87.6	87.8	87.5	87.3
Lys	1.63	1.49	1.46	1.24	1.04
Arg	1.79	1.64	1.46	1.24	1.04
Met	0.68	0.60	0.78	0.63	0.51
Met+Cys	1.10	1.01	1.15	0.98	0.82
Thr	1.02	0.93	0.99	0.84	0.70
Trp	0.32	0.29	0.28	0.24	0.20
Digestible Lys	1.42	1.29	1.28	1.08	0.90
Digestible Arg	1.58	1.46	1.29	1.09	0.91
Digestible Met	0.62	0.55	0.73	0.59	0.47
Digestible Met+Cys	0.97	0.88	1.02	0.87	0.72
Digestible Thr	0.84	0.77	0.83	0.71	0.58
Digestible Trp	0.28	0.25	0.24	0.20	0.17
Ca	1.29	1.15	0.94	0.77	0.59
P	0.86	0.79	0.71	0.62	0.51
Available P	0.52	0.46	0.42	0.34	0.26
Na	0.15	0.14	0.14	0.13	0.12
K	1.04	0.96	0.90	0.76	0.68
Cl	0.27	0.27	0.27	0.27	0.26
Arg:Lys ratio	1.1	1.1	(1.0 - 1.3)	(1.0 - 1.3)	(1.0 - 1.3)
DEB (meq/kg) [3]	261	238	(150 - 250)	(150 - 250)	(150 - 250)

[1] Changes in the diets due to Arg:Lys ratios or dietary electrolyte balance (DEB) are given between parenthesis.

[2] Supplied the following per kilogram of feed: retinyl acetate, 12,500 IU; cholecalciferol, 2,500 IU; DL-α-tocopheryl acetate, 25 IU; riboflavin, 7.0 mg; pantothenic acid, 15.0 mg; niacine, 70.0 mg; pyridoxine, 3.0 mg; folic acid, 0,8 mg; cyanocobalamin, 0.02 mg; biotin, 0.12 mg; menadione sodium bisulphite, 2.0 mg; choline, 400 mg; selenium, 0.1 mg; Cu (as copper sulfate), 10 mg; Fe (as ferrous sulfate), 40 mg; Mn (as manganese sulfate), 80 mg; Zn (as zinc sulfate), 50 mg; I (as ethylenediamine dihyriodide), 0.8 mg.

[3] DEB was calculated as Na + K - Cl in meq/kg.

Table 2. Analyzed nutrient contents in the diets.

			29 to 70 d				71 to 112 d				113 to 140 d			
			DEB[1] 164		DEB 254		DEB 164		DEB 254		DEB 164		DEB 254	
Item	0 to 14 d	15 to 28 d	AL[2] 1.00	AL 1.25	AL 1.00	AL 1.25	AL 1.00	AL 1.25	AL 1.00	AL 1.25	AL 1.00	AL 1.25	AL1.00	AL 1.25
	(%)													
Moisture	12.3	11.9	12.5	12.3	12.2	11.5	11.6	11.6	11.4	11.7	11.5	11.6	11.0	11.7
Crude protein	27.2	25.6	23.9	24.8	23.1	24.6	21.0	21.6	20.3	21.0	18.1	18.3	17.3	17.8
Crude fiber	3.4	3.5	2.9	2.9	2.9	3.2	3.0	2.8	2.8	2.8	3.1	3.0	3.0	3.0
Crude fat	4.1	3.9	4.8	4.7	4.9	4.7	5.9	5.9	6.1	6.3	4.6	4.6	4.7	4.7
Na	0.15	0.14	0.16	0.16	0.22	0.19	0.12	0.12	0.27	0.26	0.12	0.11	0.30	0.31
K	1.07	1.00	0.91	0.93	0.92	0.97	0.80	0.80	0.77	0.79	0.74	0.71	0.70	0.68
Cl	0.26	0.25	0.50	0.51	0.29	0.25	0.34	0.32	0.22	0.21	0.25	0.25	0.20	0.19
P	0.81	0.81	0.72	0.71	0.72	0.67	0.62	0.64	0.63	0.63	0.52	0.52	0.52	0.52
Ca	1.21	1.13	0.99	0.93	0.97	0.84	0.79	0.82	0.86	0.85	0.66	0.64	0.65	0.77
Lys	1.62	1.47	1.41	1.38	1.41	1.45	1.21	1.23	1.21	1.18	1.03	1.00	1.00	1.01
Met	0.63	0.60	0.72	0.71	0.75	0.76	0.61	0.58	0.58	0.59	0.50	0.50	0.51	0.50
Cys	0.39	0.37	0.33	0.34	0.33	0.35	0.34	0.34	0.33	0.32	0.29	0.29	0.28	0.29
Met+Cys	1.03	0.97	1.04	1.05	1.08	1.11	0.94	0.91	0.91	0.90	0.79	0.79	0.80	0.79
Thr	1.03	0.96	0.98	0.99	1.00	1.03	0.87	0.86	0.86	0.85	0.72	0.71	0.72	0.72
Trp	0.35	0.33	0.32	0.31	0.32	---	0.26	0.26	0.26	0.25	0.23	0.23	0.23	0.23
Arg	1.72	1.59	1.39	1.75	1.44	1.76	1.22	1.51	1.21	1.46	1.02	1.28	0.99	1.25
Ala	1.23	1.18	1.04	1.03	1.04	1.03	0.93	0.95	0.94	0.90	0.80	0.78	0.78	0.79
Asp	2.53	2.31	2.02	2.02	2.04	2.05	1.75	1.72	1.71	1.63	1.43	1.34	1.36	1.39
Glu	4.58	4.34	3.96	3.95	4.04	4.02	3.70	3.70	3.67	3.51	3.36	3.25	3.28	3.32
Gly	1.28	1.22	1.11	1.09	1.10	1.07	0.98	0.98	0.97	0.94	0.85	0.84	0.83	0.84
His	0.71	0.68	0.57	0.57	0.57	0.56	0.53	0.53	0.53	0.50	0.44	0.44	0.44	0.43
Ile	1.12	1.03	1.02	1.05	1.01	1.00	0.90	0.87	0.87	0.86	0.74	0.73	0.74	0.73
Leu	1.98	1.88	1.65	1.63	1.65	1.63	1.51	1.51	1.49	1.43	1.29	1.24	1.25	1.26
Phe	1.22	1.07	1.01	0.98	0.98	0.99	0.89	0.89	0.88	0.84	0.76	0.73	0.74	0.72
Ser	1.21	1.13	1.00	1.00	1.01	1.02	0.92	0.90	0.91	0.87	0.80	0.75	0.76	0.77
Tyr	0.73	0.65	0.62	0.59	0.55	0.52	0.56	0.52	0.52	0.51	0.44	0.44	0.46	0.43
Val	1.30	1.20	1.17	1.17	1.17	1.15	1.05	1.05	1.05	1.00	0.86	0.86	0.86	0.86
Free Lys Base	0.12	0.11	0.22	0.18	0.20	0.21	0.22	0.22	0.22	0.24	0.21	0.21	0.22	0.20
Free Lys HCl	0.15	0.14	0.28	0.22	0.25	0.27	0.27	0.28	0.27	0.30	0.27	0.26	0.28	0.26
Free Met	0.21	0.19	0.42	0.40	0.43	0.39	0.32	0.31	0.30	0.33	0.23	0.24	0.26	0.23
Free Thr	0.00	0.00	0.14	0.16	0.17	0.17	0.14	0.14	0.14	0.15	0.11	0.11	0.12	0.11
Free Trp	0.00	0.00	0.01	0.01	0.01	----	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01
DEB (meq/kg)[1]	266	246	161	164	249	260	161	167	252	256	171	159	253	255
AL	1.06	1.08	0.99	1.27	1.02	1.21	1.01	1.23	1.00	1.24	0.99	1.28	0.99	1.24

[1] DEB = dietary electrolyte balance; calculated as Na + K - Cl in meq/kg.

[2] AL = Arg:Lys ratio.

Statistical Analyses

The experiment was set up as a split-plot design including T * DEB as the main plot and Arg:Lys ratio as the sub-plot. Analysis of variance of data was performed using the Genstat 5 procedure (Genstat 5 Committee, 1993), using pen as the experimental unit for BW, BW gain, feed intake, feed:gain, carcass yields, and blood parameters.

The following model was used to assess 1) the effect of T: 15 vs. 30°C; 2) the effect of DEB: 164 vs. 254 meq/kg; 3) the interaction between T and DEB; 4) the effect of Arg:Lys ratio: 1.00 vs. 1.25; 5) the interaction between T and Arg:Lys; 6) the interaction between T and DEB; and 7) the three-way interaction between T, DEB and Arg:Lys:

$$Y_{ijkl} = \mu + T_i + DEB_j + T_i{*}DEB_j + e_{ijk} + Arg{:}Lys_k + T{*}Arg{:}Lys_{ik} + DEB{*}Arg{:}Lys_{jk} + T{*}DEB{*}Arg{:}Lys_{ijk} + e_{ijkl}$$

where Y_{ijkl} = observed trait; μ = overall mean; T_i = effect of T (i=15 or 30°C); DEB_j = effect of DEB (j=164 or 254 meq/kg); $T_i{*}DEB_j$ = interaction of T_i and DEB_j; e_{ijk} = random effect for k^{th} room with i^{th} T and j^{th} DEB; Arg:Lys $ratio_k$ = effect of Arg:Lys ratio (k=1.00 or 1.25); T_i x Arg:Lys $ratio_k$ = interaction of T_i and Arg:Lys $ratio_k$; DEB_j * Arg:Lys $ratio_k$ = interaction of DEB_j and Arg:Lys $ratio_{jk}$; T_i * DEB_j * Arg:Lys $ratio_k$ = interaction of T_i, DEB_j, and Arg:Lys $ratio_k$; and e_{ijkl} = random error.

RESULTS

Average mortality rate during the experiment was 8.1%, and was not affected by any of the experimental treatments.

Performance Traits

Results on feed intake, BW gain, and feed:gain ratio are summarized in Tables 3, 4, and 5, respectively.

Temperature had a clear effect on performance in all periods. Feed intake in all periods was significantly ($P < 0.001$) lower for the high T compared with the low T, with, on average, a decrease in feed intake of 25%. Body weight gain in each period was significantly ($P < 0.001$) lower for the high T compared with the low T, with, on average, a decrease in gain of about 22%. On average, feed:gain ratio was significantly lower for the high compared with the low T (2.51 vs. 2.61; $P < 0.001$).

Table 3. Effects of ambient temperature (T; in °C), Arg:Lys ratio, and dietary electrolyte balance (DEB[1]; in meq/kg) on feed intake at different age intervals.

Treatment			Age interval, d							
T	Arg:Lys	DEB	28-42	28-56	28-70	28-84	28-98	28-112	28-126	28-140
						(g/d)				
15	1.00	164	164	215	263	308	340	374	406	427
15	1.00	254	168	218	266	310	346	382	414	436
15	1.25	164	171	220	268	312	344	380	409	432
15	1.25	254	171	223	269	311	347	382	413	434
30	1.00	164	146	179	211	241	264	286	306	324
30	1.00	254	148	179	209	240	263	284	304	323
30	1.25	164	146	178	210	241	263	283	303	321
30	1.25	254	150	182	214	243	265	283	301	322
						P				
Source of variation[2]										
T			**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
Arg:Lys			**0.009**	**0.034**	0.057	0.254	0.482	0.838	0.669	0.926
DEB			0.135	0.245	0.786	0.730	0.230	0.270	0.210	0.168
T * Arg:Lys			**0.040**	0.099	0.387	0.747	0.578	0.238	0.350	0.444
T * DEB			0.805	0.908	0.786	0.832	0.281	0.103	**0.019**	0.221
Arg:Lys * DEB			0.640	0.491	0.387	0.867	0.966	0.608	0.586	0.661
T * Arg:Lys * DEB			0.111	0.384	0.176	0.328	0.363	0.376	0.680	0.375

[1] Calculated as Na + K - Cl in meq/kg.
[2] Significant effects ($P < 0.05$) are printed in bold.

Table 4. Effects of ambient temperature (T; in °C), Arg:Lys ratio, and dietary electrolyte balance (DEB[1]; in meq/kg) on BW gain at different age intervals.

Treatment			Age interval, d							
T	Arg:Lys	DEB	28-42	28-56	28-70	28-84	28-98	28-112	28-126	28-140
						(kg)				
15	1.00	164	1.23	3.37	5.94	8.37	10.80	13.32	15.96	18.49
15	1.00	254	1.25	3.41	6.00	8.33	10.92	13.59	16.30	18.88
15	1.25	164	1.30	3.51	6.13	8.61	11.19	13.74	16.26	18.93
15	1.25	254	1.30	3.50	6.08	8.39	11.04	13.55	16.07	18.67
30	1.00	164	1.19	2.97	5.03	6.82	8.91	10.90	12.75	14.62
30	1.00	254	1.18	2.93	4.95	6.75	8.73	10.67	12.50	14.37
30	1.25	164	1.17	2.98	5.04	6.94	8.96	10.95	12.93	14.73
30	1.25	254	1.21	2.99	5.05	6.86	8.91	10.73	12.59	14.42
						P				
Source of variation[2]										
T			**0.007**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
Arg:Lys			**0.005**	**0.004**	**0.016**	**0.043**	**0.024**	0.199	0.348	0.247
DEB			0.534	0.939	0.750	0.076	0.587	0.471	0.544	0.583
T*Arg:Lys			**0.027**	0.057	0.227	0.778	0.306	0.447	0.565	0.813
T*DEB			0.844	0.728	0.697	0.639	0.651	0.317	0.326	0.381
Arg:Lys*DEB			0.442	0.964	0.836	0.420	0.638	0.243	0.100	**0.047**
T*Arg:Lys*DEB			0.097	0.239	0.149	0.450	0.182	0.211	0.230	0.084

[1] Calculated as Na + K - Cl in meq/kg.
[2] Significant effects ($P < 0.05$) are printed in bold.

A high dietary Arg:Lys ratio increased feed intake significantly from 28 to 56 d of age (by about 1.5%). This effect was most pronounced (2.8%) in the low T groups, as indicated by the significant T * Arg:Lys ratio interaction (*P* = 0.040) in the first period. The Arg:Lys ratio had no effect on feed intake after 56 d of age. A high Arg:Lys ratio increased BW gain significantly by about 1.9% until 98 d of age (*P* = 0.024).

The DEB did not affect any of the performance parameters.

Table 5. Effects of ambient temperature (T; in °C), Arg:Lys ratio, and dietary electrolyte balance (DEB[1] in meq/kg) on feed:gain ratio at different age intervals.

Treatment			Age interval, d							
T	Arg:Lys	DEB	28-42	28-56	28-70	28-84	28-98	28-112	28-126	28-140
			(g:g)							
15	1.00	164	1.87	1.78	1.87	2.07	2.22	2.38	2.51	2.61
15	1.00	254	1.88	1.79	1.86	2.08	2.22	2.37	2.51	2.61
15	1.25	164	1.84	1.76	1.85	2.07	2.19	2.36	2.50	2.59
15	1.25	254	1.85	1.78	1.87	2.09	2.21	2.38	2.54	2.62
30	1.00	164	1.73	1.69	1.77	2.00	2.09	2.22	2.38	2.50
30	1.00	254	1.75	1.71	1.77	1.99	2.11	2.25	2.39	2.52
30	1.25	164	1.75	1.70	1.77	1.97	2.08	2.20	2.33	2.46
30	1.25	254	1.73	1.71	1.78	1.99	2.09	2.24	2.38	2.54
			P							
Source of variation[2]										
T			**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
Arg:Lys			0.154	0.258	0.664	0.479	**0.017**	0.229	0.284	0.576
DEB			0.787	0.322	0.339	0.183	0.253	0.210	0.218	0.072
T*Arg:Lys			0.323	0.169	0.086	0.560	0.543	0.399	**0.044**	0.553
T*DEB			0.865	0.922	0.906	0.351	0.812	0.542	0.751	0.291
Arg:Lys*DEB			0.258	0.946	**0.025**	0.565	0.627	0.174	0.104	0.073
T*Arg:Lys*DEB			0.391	0.090	0.195	0.725	0.195	0.475	0.942	0.521

[1] Calculated as Na + K - Cl in meq/kg.
[2] Significant effects (*P* < 0.05) are printed in bold.

Carcass Yields

Carcass yields are presented in Table 6. Temperature had a large effect on processing yields of cold carcass, breast meat, thighs, drumsticks, and wings. A high T resulted in a relative decrease of 2.3% in cold carcass yields, a decrease of 6.9% in breast meat yields, an increase of 4.6% in thigh yields, an increase of 1.0% in drumstick yields, and an increase of 1.0% in wing yields, compared with the low T. The main factors Arg:Lys ratio and DEB had no effect on carcass yields. A few interaction terms were significant. A small but significant T * DEB interaction was observed on wing yields (*P* = 0.043). The high DEB at high T resulted in a significant increase in wing yields, whereas the high DEB at low T resulted in a significant decrease in wing yields.

Table 6. Effects of ambient temperature (T; in °C), Arg:Lys ratio, and dietary electrolyte balance (DEB[1]; in meq/kg) on processing yields.

Treatment T	Arg:Lys	DEB	Live BW	Cold carcass	Cold carcass yield	Breast[2]	Thighs	Drum-sticks	Wings
			(kg)		(% of cold carcass)				
15	1.00	164	19.88	14.97	75.32	36.36	17.99	13.09	10.76
15	1.00	254	20.18	15.06	74.65	36.00	18.11	13.08	10.51
15	1.25	164	20.24	15.12	74.70	35.82	18.04	13.08	10.64
15	1.25	254	20.30	15.22	74.97	35.74	18.18	13.40	10.45
30	1.00	164	15.89	11.67	73.44	34.14	18.75	14.33	11.51
30	1.00	254	15.37	11.21	72.98	32.77	19.03	14.66	11.94
30	1.25	164	15.40	11.23	72.87	33.53	19.10	14.33	11.61
30	1.25	254	15.83	11.61	73.34	33.54	18.77	14.57	11.53
			P						
Source of variation[3]									
T			**< 0.001**	**< 0.001**	**0.006**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
Arg:Lys			0.405	0.541	0.562	0.696	0.755	0.642	0.380
DEB			0.690	0.733	0.840	0.175	0.708	0.202	0.778
T*Arg:Lys			0.365	0.415	0.906	0.558	0.950	0.398	0.819
T*DEB			0.509	0.490	0.832	0.465	0.575	0.670	**0.043**
Arg:Lys*DEB			0.208	0.065	0.057	0.316	0.404	0.613	0.419
T*Arg:Lys*DEB			0.051	0.072	0.997	0.496	0.379	0.377	0.300

1 Calculated as Na + K - Cl in meq/kg.
2 Skinless and boneless pectoralis major and pectoralis minor as a percentage of cold carcass.
3 Significant effects ($P < 0.05$) are printed in bold.

Blood Parameters

The HI-NCD titers, hematocrit, pH, pO_2, pCO_2 and HCO_3^- are presented in Table 7. The HI-NCD titers were not affected by any of the treatments. A high T resulted in lower hematocrit values at 62, 73, and 83 d of age compared with low T. The Arg:Lys ratio and DEB did not affect hematocrit consistently at every age, and no interaction term was found to be significant. A high T resulted in significantly lower pO_2 and pCO_2 values compared with the low T at 62 d of age. No significant effects were observed at 73 and 83 d of age. A high Arg:Lys ratio did not affect pO_2 and pCO_2, whereas a high DEB resulted in significant lower pCO_2 values at 83 d of age. A significant Arg:Lys ratio * T interaction was found for pCO_2 at 73 and 83 d of age; i.e., a higher Arg:Lys ratio at the high T resulted in significantly lower pCO_2 values ($P = 0.040$ and $P = 0.013$, respectively), but not at the low T. A high DEB resulted in a higher HCO_3^- value at 73 d of age ($P < 0.001$).

Table 7. Effects of ambient temperature (T; in °C), Arg:Lys ratio, and dietary electrolyte balance (DEB[1] in meq/kg) on hematocrit, pH, blood gas values, and HI-NCD titers at 62, 73, and 83 d of age.

Treatment			Hematocrit, age, d			pH, age, d			pO_2, age, d			pCO_2, age, d			HCO_3^-, age, d			HAR-NCD, age, d		
T	Arg:Lys	DEB	62	73	83	62	73	83	62	73	83	62	73	83	62	73	83	62	73	83
			(%)						(mm Hg)						(meq)					
15	1.00	164	28.8	29.5	31.0	7.433	7.349	7.393	40.4	47.4	43.7	44.9	53.1	47.6	29.4	28.0	28.2	3.0	7.2	7.0
15	1.00	254	28.9	29.2	29.6	7.429	7.393	7.421	43.2	47.6	42.6	45.7	49.7	46.3	29.5	29.5	29.5	3.0	7.4	7.3
15	1.25	164	29.1	29.5	30.9	7.417	7.357	7.391	42.1	46.8	42.6	46.5	52.3	48.6	29.4	28.5	28.7	3.3	6.2	6.7
15	1.25	254	29.4	29.9	30.6	7.432	7.371	7.417	41.9	44.8	41.3	45.3	51.7	46.7	29.6	29.1	29.4	3.1	7.0	7.3
30	1.00	164	27.2	28.6	29.6	7.444	7.348	7.384	36.9	46.1	40.5	42.7	52.0	51.6	28.8	27.7	28.5	3.0	7.3	7.1
30	1.00	254	27.5	27.1	29.1	7.448	7.382	7.399	39.4	44.4	44.4	44.4	51.6	47.2	30.2	29.8	28.5	2.9	7.5	7.4
30	1.25	164	28.0	28.6	29.5	7.449	7.380	7.409	41.9	44.8	41.7	42.7	48.2	46.5	29.1	27.7	28.9	2.6	7.4	7.4
30	1.25	254	26.5	27.5	28.3	7.456	7.400	7.422	40.5	43.7	41.1	42.4	48.8	45.2	29.4	29.2	28.8	2.9	7.2	7.6
											P									
Source of variation[2]																				
T			**0.009**	**0.013**	**<0.001**	0.062	0.574	0.826	**0.024**	0.109	0.587	**0.046**	0.394	0.660	0.776	0.474	0.288	0.314	0.441	0.368
Arg:Lys			0.703	0.517	0.912	0.971	0.456	0.237	0.128	0.229	0.392	0.789	0.121	0.069	0.663	0.753	0.340	1.000	0.120	0.838
DEB			0.683	0.199	**0.010**	0.586	0.117	**0.048**	0.251	0.298	0.839	0.814	0.599	**0.018**	0.188	**0.001**	0.100	0.947	0.594	0.270
T*Arg:Lys			0.629	0.895	0.150	0.375	0.187	0.134	0.175	0.753	0.934	0.265	**0.040**	**0.013**	0.393	0.695	0.801	0.060	0.210	0.241
T*DEB			0.287	0.406	0.180	1.000	0.993	0.892	0.459	0.625	0.837	0.233	0.674	0.549	0.415	0.383	0.178	0.068	0.743	0.571
Arg:Lys*DEB			0.378	0.464	0.742	0.439	0.272	0.913	0.103	0.718	0.385	0.204	0.270	0.358	0.242	0.376	0.597	0.651	0.942	0.838
T*Arg:Lys*DEB			0.328	0.895	0.177	0.588	0.768	0.945	0.805	0.523	0.433	1.000	0.597	0.206	0.124	0.906	0.758	0.196	0.320	0.544

1 Calculated as Na + K - Cl in meq/kg.

2 Significant effects ($P < 0.05$) are printed in bold.

DISCUSSION

Feed intake was particularly influenced by temperature; cumulative feed intake decreased by 1.6% per degree C increase in the temperature range 15 to 30°C. In an earlier study, we found that feed intake decreased by 1.3% for each degree C increase in temperature in the range 15 to 25°C (Veldkamp et al.,2000). This result indicates a larger decrease in feed intake per degree temperature increase at higher temperatures. Feed:gain ratio was lowest at 30°C. It is suggested that the extra maintenance costs in the high T birds (panting behavior and lower gain) were compromised by a better energy-to-protein ratio available for protein growth (and less for fat accretion), which was confirmed by the observation of less abdominal fat in the high T groups (data not shown).

Feed intake was significantly higher at a high dietary Arg:Lys ratio, but only in the starter period from 28 to 56 d of age, and mainly at low T. A high Arg:Lys ratio resulted in significantly higher BW gain until 98 d of age. This greater gain may be due to the higher feed intake at the high Arg:Lys ratio until 56 d of age. The higher feed intake in the starter period could have had a long lasting effect on BW gain. These results, however, seem to contradict those reported by Brake et al. (1994) and those of Kidd and Kerr (1998). Brake et al. (1994) conducted a similar study during the summer season in North Carolina, in which male turkeys were subjected to periodic episodes of heat stress. These researchers reported a tendency of lower feed:gain ratio and higher 20-wk BW at an Arg:Lys ratio of 1.3 compared with a ratio of 1.0. Kidd and Kerr (1998) evaluated two Arg:Lys ratios (0.98 vs. 1.22) under more thermoneutral circumstances. Increasing the Arg:Lys ratio improved 20-wk BW (P = 0.027) and 8- to 20-wk BW gain (P = 0.023). Feed:gain ratio in the period of 0 to 20 wk of age was also improved by increasing the Arg:Lys ratio; however, feed:gain ratio from 8 to 20 wk did not differ. Ferket et al. (1998) reported, also in broilers, that contradictory results have been found. During heat stress, broilers must be fed higher Arg:Lys ratios to maintain optimal feed utilization (Brake et al., 1994; Kroon and Balnave, 1996). In contrast, Mahmoud et al. (1996) and Mendes et al. (1996) found no effect of Arg:Lys ratio larger than 1.0 on the performance of broilers raised under thermoneutral or heat stress conditions. Ferket et al. (1998) reported that the major difference among studies that observed a positive response to higher dietary Arg:Lys ratios in heat-stressed birds and those that did not may be related to the source of Arg in the diets. Brake et al. (1994) (for broilers and turkeys) and Kroon and Balnave (1996) (for broilers) increased dietary Arg:Lys ratios by adjusting (inclusion levels of) basal ingredients, whereas Mahmoud et al. (1996) and Mendes et al. (1996) used the supplement L-Arg. In the present experiment and that of Kidd and Kerr (1998), L-Arg was used to increase dietary Arg:Lys ratios as well. Time-lag phenomena, indicating a differential rate of absorption between free and protein-bound AA, might have had a major impact in the utilization of arginine. Another explanation for the lack of an Arg:Lys effect may be the absolute amount of absorbable lysine per day, which may have been insufficient for proper growth at the low T regimen. Waldroup et al. (1998) suggested that "increasing Arg:Lys ratios improves performance of turkeys only if the diets contain insufficient amounts of Arg in relation to low levels of Lys". The NRC (1994) periods do not correspond exactly with the periods used in these studies. It appears, however, that the formulas for the 29 to 70 d age group just met the Lys and Arg levels of NRC, but lysine was borderline in this regard. This period was actually the one in which significant effects of Arg:Lys ratios were observed.

The DEB as a main factor did not affect any of these traits in any period, and no consistent effects of DEB-related interactions could be determined in the present study. Brake et al. (1994) reported that 20-wk BW was not influenced by DEB, but turkeys fed diets containing 250 meq/kg had significant higher feed:gain ratio than turkeys fed diets with 150 meq/kg. Kidd and Kerr (1998) evaluated two DEB levels (148 vs. 202 meq/kg) under more thermoneutral circumstances and found that feed:gain ratio (0 to 20 wk of age) was slightly decreased by an increasing DEB (3.01 vs. 2.95, $P = 0.045$), contradicting the results of Brake et al. (1994). In the present experiment, no effect of DEB was observed on feed:gain ratio under either T-regimen.

Processing yields were affected by T. A high T resulted in lower cold carcass and breast meat yields and higher thigh, drumstick, and wing yields compared with the low T. Neither Arg:Lys ratio nor DEB affected processing yields at all. Brake et al. (1994) reported a 3% increase in pectoralis major yield and a 4% increase in pectoralis minor yield due to the higher Arg:Lys ratio ($P < 0.05$). Kidd and Kerr (1998), however, reported a small, nonsignificant, increase in breast meat yield of 1% in male turkeys fed diets containing high Arg:Lys ratios under thermoneutral conditions. These two studies suggest that breast muscle yield is more sensitive to Arg:Lys ratios under heat stress circumstances than under more moderate temperatures. This difference was not evident in the present experiment.

It was expected that the high Arg:Lys ratio at the high T would enhance the immunity of the turkeys (Qureshi, 1998). The HI-NCD titers in this experiment were not affected by any of these treatments. Literature on blood parameters related to T or dietary factors in turkeys is very scarce. In the present experiment, the high T resulted in significantly lower hematocrit values compared with the low T, possibly due to a lower metabolic rate. Parker and Boone (1971) also found significantly lower hematocrit levels in heat-stressed adult turkeys, and reported no effect on blood pH when birds were exposed to heat stress for more than 21 d. Kohne and Jones (1975a) reported that acute hyperthermia produced profound alkalosis, but that chronic hyperthermia (Kohne and Jones (1975b) had no effect. This experiment, by design, involved a chronic thermal stress. The lack of an alkalosis is consistent with the results of Kohne and Jones (1975b). A lowering effect of heat stress on pCO_2 and HCO_3^- values in the blood was not noticed in the present experiment. This is in contradiction with a study by Siegel et al. (1974). Adding NH_4Cl or HCO_3^- to the diets in the present experiment did not affect any of the blood parameters.

In conclusion, an increased dietary Arg:Lys ratio did not alleviate the adverse effects of high T on performance of turkeys in this experiment. It is suggested that a beneficial effect of a high dietary Arg:Lys ratio is only significant under the condition of deficient dietary lysine levels. Dietary electrolyte balance did not modulate the influence of dietary Arg:Lys ratio. On the basis of this study, it seems that the relationship between Arg:Lys ratio and DEB in heat stress situations is more complicated than the literature suggests.

ACKNOWLEDGMENT

We wish to thank Eurolysine, 153 rue de Courcelles, 75817 Paris Cedex 17, France, for their financial support in this experiment.

REFERENCES

Balnave, D., and A. G. Oliva, 1990. Responses of finishing broilers at high temperatures to dietary methionine source and supplementation levels. Aust. J. Agric.Res. 41:557-564.

Balnave, D., and A. G. Oliva, 1991. The influence of sodium bicarbonate and sulfur amino acids on the performance of broilers at moderate and high temperatures. Aust. J. Agric. Res. 42:1385-1397.

Brake, J., P. Ferket, J. Grimes, D. Balnave, I. Gorman, and J. J. Dibner, 1994. Optimum arginine:lysine ratio changes in hot weather. Pages 82-104 in Proceedings of the 21st Carolina Poultry Nutrition Conference, Charlotte, NC.

Cooper, M. A., and K. W. Washburn, 1998. The relationships of body temperature to weight gain, feed consumption, and feed utilization in broilers under heat stress. Poultry Sci. 77:237-242.

Cowan, P. J., and W. Michie, 1978. Environmental temperature and turkey performance: the use of diets containing increased levels of protein and use of a choice-feeding system. Ann. Zootech. 27:175-180.

De Jong, W. A., 1978. The influence of the incubation period and the amount of antigen on the haemagglutination inhibition titres to Newcastle Disease Virus. Tijdschr. Diergeneeskd. 103:104-109.

Ferket, P. R., J. D. Garlich, R. Kuiper, and M. T. Kidd, 1998. Dietary arginine requirement of growing and finishing turkey toms. Pages 6-14 in Proceedings of Turkey Nutrition Workshop, North Carolina State University, Raleigh, NC.

Genstat 5 Committee. 1993. Genstat 5 Reference Manual. Release 3. Clarendon Press, Oxford, UK.

Kidd, M. T., and B. J. Kerr, 1998. Dietary arginine and lysine ratios in large white toms. 2. Lack of interaction between arginine:lysine ratios and electrolyte balance. Poultry Sci. 77:864-869.

Kohne, H. J., and J. E. Jones, 1975a. Changes in plasma electrolytes, acid-base balance and other physiological parameters of adult female turkeys under conditions of acute hyperthermia. Poultry Sci. 54:2034-2038.

Kohne, H. J. and J. E. Jones, 1975b. Acid base balance, plasma electrolytes and production performance of adult turkey hens under conditions of increasing ambient temperature. Poultry Sci. 54:2038-2045.

Kroon, J. M. M., and D. Balnave, 1996. Heat stress in broilers. Msc. Thesis, Wageningen Agricultural University, Wageningen, The Netherlands, and University of Sidney, Sidney, Australia.

Mahmoud, H. A., and R. G. Teeter, 1996. Arginine:lysine ratio effects on performance and carcass variables of broilers in thermoneutral and heat stress environments. Poultry Sci. 75:(Suppl. 1)88.

Mendes, A. A., S. E. Watkins, E. A. Saleh, J. A. England, A. L. Waldroup, P. W. Waldroup, 1996. Influence of dietary lysine and arginine:lysine ratios on performance of broilers exposed to heat or cold stress from 3 to 6 weeks of age. Poultry Sci.75:(Suppl. 1)130.

National Research Council. 1994. Nutrient Requirements of Poultry. National Academy Press, Washington, DC.

Noll, S. L., M. E. El Halawani, P. E. Waibel, P. Redig, and K. Janni, 1991. Effect of diet and population density on male turkeys under various environmental conditions. 1. Turkey growth and health performance. Poultry Sci. 70:923-934.

O'Dell, B. L., and J. E. Savage, 1966. Arginine-lysine antagonism in the chick and its relationship to dietary cations. J. Nutr. 90:364-370.

Oju, E. M., P. E. Waibel, and S. L. Noll, 1987. Protein, methionine, and lysine requirements of growing hen turkeys under various environmental temperatures. Poultry Sci. 66:1675-1683.

Parker, J. T., and M. A. Boone, 1971. Thermal stress effects on certain blood characteristics of adult male turkeys. Poultry Sci. 50:1287-1295.

Qureshi, M. A., P. R. Ferket, and G. B. Havenstein, 1998. Turkey immune system as affected by dietary and environmental factors. Proceedings of Turkeys 21st Technical Turkey Conference, Cheshire, UK.

Rose, S. P., and W. Michie, 1987. Environmental temperature and dietary protein concentrations for growing turkeys. Br. Poultry. Sci. 28:213-218.

Siegel, H. S., L. N. Drury, and W. C. Patterson, 1974. Blood parameters of broilers grown in plastic coops and on litter at two temperatures. Poultry Sci. 53:1016-1024.

Teeter, R. G., M. O. Smith, F. N. Owens, S. C. Arp, S. Sangiah, and J. E. Breazile, 1985. Chronic heat stress and respiratory alkalosis: occurrence and treatment in broiler chicks. Poultry Sci. 64:1060-1064.

Veldkamp, T., C. Nixey, R. P. Kwakkel, and J. P. T. M. Noordhuizen, 2000. Interaction between ambient temperature and supplementation of synthetic amino acids on performance and carcass parameters in commercial male turkeys. Poultry Sci. 79:1472-1477.

Waldroup, P. W., J. A. England, M. T. Kidd, and B. J. Kerr, 1998. Dietary arginine and lysine in large white toms. 1. Increasing arginine:lysine ratios does not improve performance when lysine levels are adequate. Poultry Sci. 77:1364-1370.

Wallis, I. R., and D. Balnave, 1984. The influence of environmental temperature, age and sex on the digestibility of amino acids in growing broiler chickens. Br. Poult. Sci. 25:401-407.

Zuprizal, M. Larbier, A. M. Chagneau, and P. A. Geraert, 1993. Influence of ambient temperature on true digestibility of protein and amino acids of rapeseed and soybean meals in broilers. Poultry Sci. 72:289-295.

Chapter 4

GROWTH RESPONSES TO DIETARY LYSINE AT HIGH AND LOW AMBIENT TEMPERATURE IN MALE TURKEYS

T. Veldkamp

Research Institute for Animal Husbandry, Runderweg 6, P.O. Box 2176, 8203 AD Lelystad, The Netherlands

R. P. Kwakkel

Wageningen Institute of Animal Sciences, Animal Production Systems, Wageningen University, Marijkeweg 40, 6709 PG Wageningen, The Netherlands

P. R. Ferket

North Carolina State University, Department of Poultry Science, Scott Hall, Campus Box 7608, Raleigh, North Carolina 27695, USA

J. Kogut

Institute for Animal Science and Health (ID-Lelystad BV), P.O. Box 65, 8200 AB Lelystad, The Netherlands

M.W.A. Verstegen

Wageningen Institute of Animal Sciences, Animal Nutrition Group, Wageningen University, Marijkeweg 40, 6709 PG Wageningen, The Netherlands

Submitted to: Poultry Science

GROWTH RESPONSES TO DIETARY YSINE AT HIGH AND LOW AMBIENT TEMPERATURE IN MALE TURKEYS

T. Veldkamp, R.P. Kwakkel, P.R. Ferket, J. Kogut, and M.W.A. Verstegen

ABSTRACT

Several researchers have postulated that dietary lysine requirements for turkeys are dependent upon ambient temperature (T) during the growing period. To test and quantify this hypothesis, a factorial experiment was designed with four dietary lysine levels (LYS; 75, 90, 105, and 120% of NRC (1994) lysine recommendations) from one day of age onward and two ambient temperatures (T; 15 vs. 30°C) from 4 wk of age onward. Treatment effects were measured on growth performance and carcass yield characteristics and requirements were derived from the fitted exponential response curves at 95% of the maximum possible response above that of the basal diet. The dietary lysine for the starter period (0 to 28 d of age) was estimated to be 2.03±0.18% for optimal BW gain. During the growing and finishing period, high T decreased feed intake and BW gain ($P < 0.001$) and this effect increased as age increased. Feed:gain ratio was significantly lower for turkeys exposed to high T until 85 d of age ($P < 0.001$). In the entire experiment no significant interaction effects between T and LYS have been observed for feed intake, BW gain, and feed:gain ratio. Exponential curves gave a very good fit to the responses for feed intake and BW gain to dietary lysine concentrations as demonstrated by high R^2-values ($R^2 > 0.89$) in all age intervals. The estimated 95%-requirements for BW gain, were 1.67±0.09, 1.19±0.13, 1.08, and 0.94±0.35% dietary lysine from 29 to 56 d, 57 to 84 d, 85 to 114 d, and 115 to 140 d of age, respectively. High T decreased all absolute processing yields in kg but relative cold carcass (as a proportion of live weight), and relative yields of thighs, drums, and wings (as proportions of cold carcass) were increased by high T. Breast meat yield and abdominal fat (as proportion of cold carcass) were decreased by high T. The only interaction effect of T and LYS observed was for absolute breast meat weight: turkeys at low T responded with more breast meat to high LYS than at high T.

Keywords: turkey, ambient temperature, dietary lysine, growth performance, carcass yields.

INTRODUCTION

Lysine is the first limiting amino acid in most commercial diets for growing turkeys (Balloun, 1962). Estimates of lysine requirements of turkeys vary considerably in literature (Potter et al., 1981; Nixey, 1989; Noll and Waibel, 1989; Plavnik and Hurwitz, 1993; and Lehmann et al., 1996). This variability could be partially due to differences in ambient conditions inherent in the different studies (Noll and Waibel, 1989). As observed in earlier studies with turkeys, high ambient temperatures depressed feed intake, resulting in reduced BW gain and breast meat yield (Veldkamp et al., 2000a,b).

Several researchers recommended increased dietary protein concentrations in growing and finishing turkeys as ambient temperature (T) increased (Waibel et al., 1975, 1976; Oju et al, 1987, and Ferket, 1995). Waibel et al. (1975) found that maximal BW gain of turkeys reared at 22.2°C from 4 to 20 wk was reached at a higher dietary protein concentration than those reared at 10.6°C. Waibel et al. (1976) also showed in another study that higher dietary protein levels were required for male turkeys reared at 20 or 27°C than at 9.4 or 14.4°C from 6 to 20 wk of age.

Lysine and methionine are limiting amino acids in corn-soybean meal diets for turkeys. Noll and Waibel (1989) suggested that thermal conditions affect lysine requirements of growing and finishing turkeys. A greater percentage of lysine was required to maximize growth when T was over 20°C than below 10°C, as well in the period from 8 to 12 as from 16 to 20 wk of age. The benefit of higher lysine levels was expressed more during the period of 8 to 12 wk of age than during 16 to 20 wk of age. Waldroup et al. (1997) stated that protein and amino acid requirements relative to dietary energy depends on ambient temperature. They demonstrated that turkeys require higher amino acid levels than the NRC (1994) recommendations in a study in which T frequently exceeded 27°C. The higher dietary amino acid content seem to be necessary to compensate for the reduced feed intake that occurs during chronic exposure to high T.

Dietary amino acid requirements as reported in literature may be insufficient for optimum growth performance in modern commercial turkey strains reared under high ambient T conditions because these requirements were usually estimated under thermoneutral conditions. The NRC (1994) recommends dietary lysine requirements of 1.6, 1.5, 1.3, 1.0, and 0.8%, respectively corresponding with 1.37, 1.24, 1.03, 0.77, and 0.60 g/MJ ME during the sequential four-week intervals from 0 to 20 wk of age. Lehmann et al. (1996) studied responses of growing and finishing male turkeys fed different levels of dietary lysine and reared in moderate T conditions from 8 to 12 and 16 to 20 wk of age. From 8 to 12 wk of age, about 1.2% (0.96 g/MJ ME) lysine in the diet was found to be adequate for optimum BW gain and feed:gain ratio. From 16 to 20 wk of age, 0.96% (0.72 g lysine/MJ ME) lysine in the diet, which exceeds the NRC (1994) recommendations by 20%, was insufficient to maximize BW gain. Waldroup et al. (1998) suggested that performance of turkeys is increased by elevated arginine to lysine ratios only when diets contain insufficient lysine levels, indicating a deficiency of arginine per se rather than a true response to an arginine to lysine ratio. Veldkamp et al. (2000b) demonstrated a positive effect of increasing dietary arginine to lysine ratio during the period of 4 to 8 weeks of age. During the first eight wk of this experiment, dietary lysine concentrations were below the NRC (1994) recommendations.

The objective of this experiment was to evaluate growth responses of male turkeys to different dietary lysine levels under different ambient conditions.

MATERIALS AND METHODS

Birds, Housing and Experimental Design

A total of 640 day-old commercial male turkeys[1] were randomly distributed over four identical, individually controlled rooms of 20 m^2 each. Each room, serving as a statistical block, was divided into four pens of 5 m^2, and each pen served as one experimental unit containing 40 birds. In each room, the four pens were assigned to one of four dietary lysine levels (75, 90, 105, or 120% of NRC (1994) recommendation for 0 to 4 wk of age) in a randomized block design. Poults were reared in wired rings during the first week of age. Infrared heat lamps were used as supplemental heat during the first 4 wk. Birds were provided 23 h light and 1 h dark on Day 1, and the photoperiod was gradually decreased 1 h per d to 8 d of age. From 8 d of age onwards, this lighting schedule of 16 h of light and 8 h of dark was maintained.

At 29 d of age, 600 turkeys within the same dietary lysine treatment were randomly reassigned to one of two additional temperature treatments (15 and 30 °C). Out of 10 identical, individually controlled rooms of 20 m^2 each, five rooms were randomly assigned to 15 °C and

[1] British United Turkeys Ltd., Hockenhull Hall, Tarvin, Chester CH3 8LE, UK.

five to 30 °C. Each room was divided into four pens of 5 m^2, containing 15 birds each. Again in each room (the whole-plot experimental unit), the four pens (the sub-plot experimental units) were assigned at random to one of the four dietary lysine levels (75, 90, 105, or 120% of NRC (1994) recommendations). Therefore, this part of our study was a split-plot design with temperature as whole-plot and dietary lysine levels as sub-plot treatments.

Soft pine wood shavings were used as litter material, and additional shavings were added to all pens within the room if it was found necessary to maintain satisfactory litter condition in any one of the pens.

Climate

In accordance to best management practices, the turkeys were subjected to a common temperature regimen from 0 to 28 d and then the two temperature regimens were applied subsequently until 140 d of age. Temperature below the heat lamps was decreased by about 3 °C each week from 36 to 23 °C during the period from 0 to 28 d. Ambient room temperature (T) decreased by about 1.7 °C each week from 26 °C at 1 d to 19 °C at 28 d of age. The two different T regimens were gradually imposed during the period of 29 to 42 d of age. The high T regimen increased from 19 to 30 °C (i.e. about 0.8 °C increase per d) and the low T regimen decreased from 19 to 15 °C (i.e. about 0.3 °C decrease per d) during this period. After 42 d of age, the high and low T regimen were maintained at 30 and 15 °C, respectively, throughout the experiment. Relative air humidity was maintained at 70% throughout the experiment. Ambient temperature and humidity were maintained constant over the day, and ventilation rate was set similar for all rooms.

Dietary Treatments

The composition and calculated nutrient contents of the diets and the analyzed nutrient contents are presented in Table 1a and 1b. Five different successive corn and soybean-based diets were provided ad libitum from 0 to 28 d, 29 to 56 d, 57 to 84 d, 85 to 114 d, and 115 to 140 d of age, respectively. Each experimental diet was formulated to provide 110% of NRC (1994) recommended amino acid levels except for lysine, methionine+cystine, and arginine. Methionine+cystine was maintained at 100% of NRC (1994) for all diets. The four experimental diets were formulated to contain 75, 90, 105, and 120% dietary lysine relative to NRC (1994) recommendations. Dietary lysine levels in the diets were adjusted by adding L-lysine HCl to the basal 75%-diet. Based on the results of Veldkamp et al. (2000), the four experimental diets within each feed phase were supplemented with free-base L-arginine to achieve the same arginine-to-lysine ratio: 1.3:1 from 0 to 28 d of age and 1.0:1 from 29 d of age onwards. All experimental diets per age interval were formulated to be isocaloric and met or exceeded NRC (1994) recommendations for vitamins and minerals. The feed was provided to the birds from 0 to 28 d of age in the form of 2-mm pellets and 3- mm pellets were provided subsequently.

Table 1a. Composition of diets for turkeys from 0 to 140 d of age formulated to provide different percentages of dietary lysine.

	0 to 28 d				29 to 56 d				57 to 84 d				85 to 114 d				115 to 140 d			
Item	75[1]	90	105	120	75	90	105	120	75	90	105	120	75	90	105	120	75	90	105	120
Ingredient	(%)																			
Corn (8.2% CP)	48.3	47.7	47.0	46.4	66.9	66.3	65.7	65.1	75.2	74.7	74.2	73.7	79.0	78.6	78.2	77.8	85.5	85.2	84.9	84.6
Soybean meal (47.2% CP)	32.00				11.00				9.00				6.00				1.00			
Corn glutenmeal (62.0% CP)	14.00				7.50				2.75				4.00				3.75			
Fish meal (72.7% CP)	0.00				5.00				4.50				0.00				0.00			
Potato protein (77.0% CP)	0.00				5.00				4.50				5.00				5.00			
Soybean oil	0.00				0.00				0.00				1.45				0.50			
Premix[2,3]	1.00 [2]				1.00 [3]				1.00 [3]				1.00 [3]				1.00 [3]			
Limestone	2.02				1.65				1.40				1.35				1.25			
Monocalcium phosphate	2.10				1.30				1.00				1.25				1.00			
Salt (NaCl)	0.40				0.24	0.16	0.08	0.00	0.24	0.16	0.08	0.00	0.21	0.14	0.07	0.00	0.18	0.12	0.06	0.00
Sodium bicarbonate ($NaHCO_3$)	0.00				0.00	0.12	0.24	0.36	0.00	0.11	0.22	0.33	0.17	0.27	0.37	0.47	0.22	0.30	0.38	0.46
Potassium bicarbonate ($KHCO_3$)	0.00				0.09	0.11	0.13	0.15	0.15	0.16	0.17	0.18	0.29	0.28	0.27	0.26	0.46	0.45	0.44	0.43
DL-methionine	0.08				0.10				0.10				0.05				0.00			
L-threonine	0.08				0.13				0.11				0.18				0.09			
L-tryptophan	0.02				0.04				0.03				0.04				0.05			
L-isoleucine	0.00				0.02				0.00				0.00				0.00			
L-valine	0.00				0.05				0.00				0.00				0.00			
L-lysine HCl	0.00	0.31	0.62	0.93	0.00	0.29	0.58	0.87	0.00	0.25	0.50	0.75	0.06	0.25	0.44	0.63	0.04	0.19	0.35	0.50
L-arginine	0.00	0.32	0.64	0.96	0.00	0.24	0.48	0.72	0.00	0.21	0.42	0.63	0.00	0.16	0.32	0.48	0.00	0.13	0.26	0.39

1 Lysine level is relative to NRC (1994) recommendations.

2 Supplied per kg of diet: vitamin A, 16,000 IU (retinyl acetate); vitamin D_3, 4,200 IU (cholecalciferol); vitamin E, 38 IU (dl-α-tocopherol); thiamin, 4 mg; riboflavin, 8 mg; pyridoxine, 4 mg; niacin, 75 mg; Ca-D-Pantothenic acid, 17 mg; choline chloride, 1040 mg; cobalamin, 23 μg; menadione, 4 mg; ascorbic acid, 10 mg; folic acid, 1 mg; biotin, 130 μg, cobalt (as $CoSO_4.7H_2O$), 0.2 mg; selenium (as Selpex-50 (organic Se)), 0.1 mg; iodine (as KI), 0.8 mg; zinc (as $ZnSO_4.H_2O$), 60 mg; iron (as $FeSO_4.7H_2O$), 52 mg; copper (as $CuSO_4.5H_2O$), 11 mg; manganese (as MnO_2), 90 mg; flavomycin, 5 mg; lasalocid-Na, 90 mg; dimetridazol, 125 mg.

3 Supplied per kg of diet: vitamin A, 12,000 IU (retinyl acetate); vitamin D_3, 2,500 IU (cholecalciferol); vitamin E, 25 IU (dl-α-tocopherol); thiamin, 3 mg; riboflavin, 7 mg; pyridoxine, 3 mg; niacin, 70 mg; Ca-D-Pantothenic acid, 15 mg; choline chloride, 1000 mg; cobalamin, 20 μg; menadione, 2 mg; folic acid, 1 mg; biotin, 120 μg; cobalt (as $CoSO_4.7H_2O$), 0.2 mg; selenium (as Selpex-50 (organic Se)), 0.1 mg; iodine (as KI), 0.8 mg; zinc (as $ZnSO_4.H_2O$), 50 mg; iron (as $FeSO_4.7H_2O$), 40 mg; copper (as $CuSO_4.5H_2O$), 10 mg; manganese (as MnO_2), 80 mg; flavomycin, 5 mg; lasalocid-Na, 90 mg (until 85 d of age); dimetridazol, 125 mg (until 85 d of age).

Table 1b. Calculated and analyzed nutrient contents of the diets.

	0 to 28 d				29 to 56 d				57 to 84 d				85 to 114 d				115 to 140 d			
Item	75[1]	90	105	120	75	90	105	120	75	90	105	120	75	90	105	120	75	90	105	120
Calculated Analysis										(g/kg)										
ME (MJ/kg)[2]	11.8	11.8	11.9	11.9	12.9	12.9	12.9	12.9	13.0	13.0	13.0	13.0	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4
Calcium	12.0				10.1				8.5				7.5				6.6			
Available phosphorus[2]	6.0				5.0				4.2				3.8				3.2			
Determined Analysis																				
Crude Protein	283	294	304	312	230	237	243	254	194	199	202	208	157	165	171	175	136	146	150	152
Crude fat	32	32	32	35	38	38	37	36	39	38	38	37	48	48	47	48	40	41	40	41
Crude fiber	22	21	22	24	17	21	21	21	20	20	20	20	17	17	19	20	18	20	20	23
Ash	67	69	65	65	51	54	50	51	48	45	45	45	42	42	41	39	39	38	37	37
Starch	348	347	345	345	467	455	452	450	507	503	502	495	532	526	529	533	562	564	553	560
Lysine	11.8	14.3	17.0	18.6	11.2	13.7	16.1	17.8	9.8	12.0	14.1	15.2	7.6	9.2	10.4	11.8	6.2	7.4	8.5	9.3
Arginine	15.8	18.8	22.8	24.7	11.5	14.4	17.0	18.7	9.9	12.7	14.9	16.2	8.5	10.3	11.4	13.2	7.0	8.4	9.3	11.0
Arginine:Lysine ratio (g:g)	1.34	1.31	1.34	1.33	1.03	1.05	1.06	1.05	1.01	1.06	1.06	1.07	1.12	1.12	1.10	1.12	1.13	1.14	1.09	1.18
Methionine	5.8	5.7	5.7	5.3	5.7	5.7	5.7	5.5	4.9	4.9	5.1	5.0	3.6	3.7	3.8	3.6	3.1	3.0	2.9	3.0
Cystine	4.7	4.7	4.7	4.4	3.6	3.6	3.6	3.6	2.9	2.9	3.0	2.9	2.9	2.9	2.9	2.9	2.7	2.7	2.6	2.7
Threonine	11.2	11.2	11.2	10.8	10.5	10.5	10.6	9.7	8.8	8.9	9.1	8.9	8.2	8.3	8.4	8.1	6.8	6.8	6.7	6.8
Isoleucine	11.8	11.7	11.9	11.4	9.7	9.9	10.0	9.7	7.9	8.0	8.1	7.9	6.8	6.8	7.0	6.6	5.8	5.7	5.6	5.7
Leucine	32.3	32.3	32.7	31.2	25.8	25.8	26.0	25.3	20.0	20.0	20.3	20.2	18.9	19.0	18.9	18.7	17.4	17.6	17.1	17.5
Valine	13.1	12.0	12.3	13.4	12.4	10.8	12.5	12.0	10.1	8.9	10.4	9.8	8.2	8.2	8.3	8.2	7.3	7.4	7.3	7.5
Histidine	7.7	6.8	6.8	6.8	5.4	5.3	5.4	5.4	4.4	4.5	5.1	4.6	4.1	4.2	4.1	4.1	3.6	3.6	3.6	3.7

1 Lysine level is relative to NRC (1994) recommendations.

2 Available phosphorus, and ME-content in the ingredients was calculated, based on official Dutch standards (CVB, 1999).

Traits Measured

Pen means of body weight (BW) gain and feed intake were recorded at 0, 28, 56, 84, 114, and 140 d of age and pen means of feed:gain ratio were calculated from these data. Birds that died or had to be culled were weighed and their BW gains were included in the calculation of feed:gain ratio per pen. Dead birds were examined by post mortem dissection on the day of death to determine cause of mortality.

At 140 d of age, five turkeys per pen that represented the average BW were selected and processed at a commercial abattoir to determine the yield of carcass parts. After air chilling for 20 h, cold carcasses were weighed and expressed as a percentage of live BW, and were cut into commercial-type cut parts. Each part was weighed, and expressed as a percentage of cold carcass weight. Again pen means of cold carcass and all carcass parts (as well absolute weights (kg) as relative (%)) were used in the statistical analysis of this data.

Statistical Analyses

This experiment was subdivided into two experimental phases. From 0 to 28 d of age, the turkeys were treated with only four dietary lysine concentrations (LYS; 75, 90, 105, and 120% of NRC (1994)), and from 29 to 140 d of age, they were treated with a factorial combination of LYS and two ambient temperatures (T; 15 and 30°C). Therefore, these two phases differed in experimental design (see: Birds, Housing and Experimental Design) and analysis.

The growth performance responses observed during 0 to 28 d of age were subjected to analysis of variance according to the following model for a randomized block design:

$$Y_{ijk} = \mu + block_i + LYS_j + e_{ijk}$$

where Y_{ijk} = the observed mean pen responses (feed intake, BW gain, and feed:gain ratio); μ = overall mean; $block_i$ = effect of room (i = 1…4); LYS_j= effect of LYS (j = 1…4); e_{ijk} = random error assumed to be normally distributed with zero mean and a constant variance. The growth performance observed during each successive four-week period from 29 to 140 d of age (5 to 8 wk, 9 to 12 wk, 13 to 16 wk, and 17 to 20 wk of age), and carcass results were subjected to analysis of variance according to the following model for a split-plot design:

$$Y_{lmj} = \mu + T_l + e_{lm} + LYS_j + T * LYS_{lj} + e_{lmj}$$

where additionally: T_l = effect of ambient temperature (l = 1,2); T * LYS_{lj} = interaction effect of T and LYS; e_{lm} = random whole-plot error associated with rooms (m = 1…5) and e_{lmj} = random sub-plot error associated with pens (j = 1…4), both assumed to be normally distributed with zero mean and a constant variance.

Significance of differences between means of LYS, T, and T * LYS were tested with the Student's t-test. The effects of LYS and the interaction of T * LYS were split into orthogonal polynomial contrasts to test for linearity of the response across the four dietary lysine percentages.

Exponential curves after examples of Schutte and Pack (1995) and Lehmann et al. (1996) were used to fit the growth responses. These authors used the model:

$$y = a + b\,(1 - e^{-c(x-d)})$$

where: y = predicted response; a = intercept (i.e., feed intake, BW gain, or feed:gain ratio on basal diet); b = maximum response to dietary lysine level; c = curvature steepness; d = lysine content of basal diet (%); and x = dietary lysine content (%).

For the present study, this model was reparameterized into:

$$y = y_0 + m_{y0} * (1 - e^{(-\ln(2)/lys½ * (lys\%-x0))}) \qquad \textbf{[1]}$$

where: y = predicted response; x_0 = lowest used lysine % dependent on the age interval (which was always equal to the 75% of the NRC (1994) recommendations; y_0 = response at x_0; m_{y0} = maximum possible response due to lysine % above that of x_0; $lys_{½}$ = lysine % step by which the half of the remaining maximum of the estimated response is realized (lysine half-dose); ln(2) = 0.6931. From this model it can be derived that: dietary lysine % = x_0 + n * $lys_{½}$ results in the percentage remaining response up to the asymptote equal to $(½)^n$. Thus, with addition of 1, 2, 3, 4, and 5 * $lys_{½}$, the percentages of remaining response were calculated to be 50, 25, 12.5, 6.25, and 3.12, respectively. Usually, additions of up to 5 * $lys_{½}$ are economically interesting because then just only 3.12% of the remaining response is still remain to be achieved.

Only significant nonlinear responses on performance parameters for each four-wk age interval separately and for carcass yields at 20 wk of age were fitted by model **[1]**. When T * LYS interaction effects were not significant, parallel response curve analyses was performed.

Dietary lysine requirements were calculated at 95% of m_{y0}. This is relative to the basal response. From model **[1]** it resulted in:

$$95\%lysreq = x_0 - \ln(1\text{-}0.95)/\ln(2) * lys_{½} = x_0 + 4.322 * lys_{½} \qquad \textbf{[2]}$$

which due to our reparameterization, enables nutritionists to directly calculate the 95% relative requirements from the estimates of $lys_{½}$-parameters.

The effects, means and estimated values of fitted parameters were declared significant at $P < 0.05$. All calculations and analyses were done with Genstat 5 (Genstat 5 Committee, 1993); in particular ANOVA, FIT, RPAIR, FITCURVE, FITNONLINEAR and RFUNCTION procedures were used.

RESULTS

Average mortality rates in turkeys that were fed 75, 90, 105, and 120% dietary lysine relative to NRC (1994) were 14.4, 13.8, 17.5, and 20.6% respectively, from 0 to 140 d of age. From 85 to 114 d of age, mortality rate was higher in the LYS-groups that were fed 120% dietary lysine at low T (15.3% compared to about 4.0% for the lower levels).

Starter Period (0 to 28 d of age)

Results on feed intake, BW gain, and feed:gain ratio are reported in Table 2.

Table 2. Performance of male turkeys from 0 to 28 d of age at different dietary lysine levels (LYS; % of NRC (1994) recommendations).

LYS (% of NRC)	Dietary Lysine (%)	Feed intake[1] g/d	BW gain[1] g/d	Feed:gain ratio[1] g:g
75	1.18	26.9 [c]	19.1 [c]	1.41 [a]
90	1.43	40.3 [b]	30.7 [b]	1.31 [b]
105	1.70	47.9 [a]	36.8 [a]	1.30 [b]
120	1.86	47.6 [a]	37.1 [a]	1.28 [b]
	LSD[2]	2.2	1.9	0.03
		P		
Source of variation[3]				
Dietary lysine % effects		**< 0.001**	**< 0.001**	**< 0.001**
Linear[4]		**< 0.001**	**< 0.001**	**< 0.001**
Quadratic[4]		**< 0.001**	**< 0.001**	**0.012**
Cubic[4]		0.476	0.856	0.087

[1] Means are average of four replicate pens with 40 birds each.
[2] Least significant difference ($P = 0.05$) between two means.
[3] Significant effects ($P < 0.05$) are printed in bold.
[4] Orthogonal polynomial contrast across dietary lysine %.
[a-c] Means within columns with no common superscript differ significantly ($P < 0.05$).

Feed intake and BW gain increased by a quadratic function ($P < 0.001$) as LYS increased. Feed:gain ratio decreased quadratically ($P = 0.012$) as LYS increased. The significantly inferior growth performance of turkeys fed at the 75% level of LYS clearly indicated that this diet was deficient in lysine. The 105% and 120% LYS response were almost equivalent and seemed to be within a plateau range.

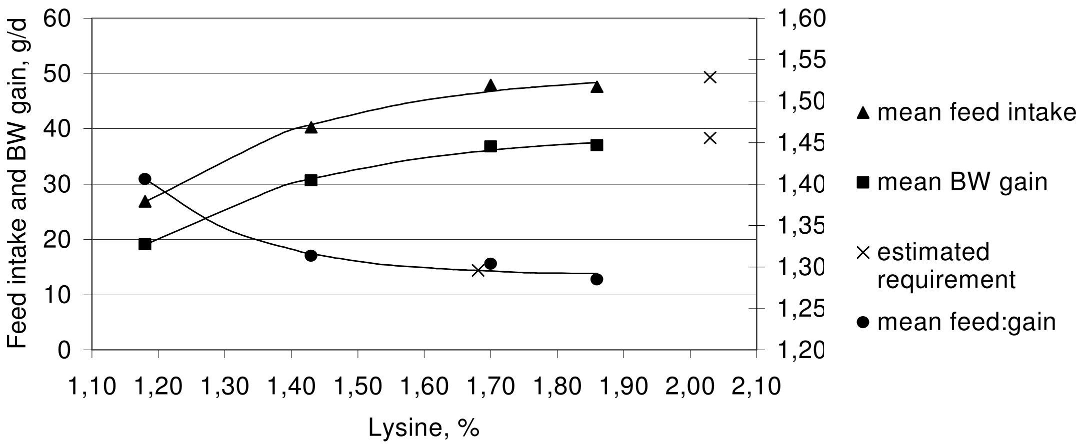


Figure 1. Feed intake, BW gain, and feed:gain ratio responses of male turkeys to dietary lysine (0 to 28 d of age). Curved lines = exponential fit.

The exponential curves for feed intake, BW gain, and feed:gain ratio are presented in Table 3 and Figure 1. Each successive addition of about 0.196 and 0.197% dietary lysine ($lys_{½}$ in Table 3) resulted in 50% improvement of the remaining possible response for feed intake and BW gain, respectively. However, for 50% improvement of the remaining possible response for feed:gain ratio an addition of only 0.116% dietary lysine was necessary.

Table 3. Performance of male turkeys from 0 to 28 d of age; Parameter estimates of exponential fits and lysine requirements.

Response	Parameter estimates of exponential fit [1]				R^2	Dietary lysine requirement[2]
	y_0	m_{y0}	$lys_{½}$	x_0[3]		
	(g/d)		(% in diet)			(% in diet)
Feed intake	26.8±0.96	23.7±2.0	0.196±0.044	1.18	0.95	2.03±0.19
BW gain	19.1±0.78	20.3±1.7	0.197±0.042	1.18	0.96	2.03±0.18
Feed:gain ratio	1.41±0.01	–0.116±0.014	0.116±0.046	1.18	0.84	1.68±0.20

1 estimated values of parameters ± SE of model **[1]**: $y = y_0 + m_{y0} * (1 - e^{(-\ln(2)/lys½ \ * \ (lys\% - x0))})$
2 estimated value ± SE calculated from equation **[2]**: $95\%lysreq = x_0 + 4.322 * lys_{½}$.
3 fixed lowest used dietary lysine %.

The turkeys used the added dietary lysine very efficiently for body accretion. This appears from the relatively high $lys_{½}$ - parameter. The R^2-values for the exponential fit for feed intake, BW gain, and feed:gain ratio were 0.95, 0.96, and 0.84, respectively. The dietary lysine requirement was estimated as 2.03±0.19% for feed intake, 2.03±0.18% for BW gain, and 1.68±0.20% for feed:gain ratio.

Growing and Finishing Period (29 to 140 d of age)

Tables 4, 5, and 6 summarize the respective observations for feed intake, BW gain, and feed:gain ratio for each age period and corresponding feed phase and the cumulative 29 to 140 d period. The estimated dietary lysine requirements are presented in Table 7.

Feed Intake

The main treatment effects were highly significant but interaction effects between T and LYS were not observed (Table 4).

Feed intake was depressed by high T during all age intervals ($P < 0.001$). This adverse effect on feed intake of turkeys in high T conditions increased as age increased, resulting in 23.4, 32.0, 37.2, and 39.5% lower feed intake during the successive age intervals than those reared in the low T conditions. Feed intake increased by an exponential function as LYS was increased ($P < 0.001$), except during the age interval from 115 to 140 d of age. The data fitted the parallel exponential response curves well as demonstrated by the adjusted R^2-values in the succeeding four-week age intervals: $R^2 = 0.97$, 0.96, 0.97, and 0.96, respectively (Figure 2).

Because parallel exponential curves were fitted for both T, the common dietary lysine requirements determined from equation **[2]** were estimated to be: 1.66±0.08, 1.33±0.11, 0.84±0.62, and 0.76±0.20% for the age periods of 29 to 56 d, 57 to 84 d, 85 to 114 d, and 115 to 140 d of age, respectively.

Table 4. Feed intake (g/d) of male turkeys as affected by ambient temperature (T; °C) and dietary lysine levels (LYS; % of NRC (1994)) in different age intervals.

Treatment		Age interval, d				
T	LYS	29 to 56	57 to 84	85 to 114	115 to 140	29 to 140
		(g/d)				
T Main Effect Means[1]						
15		188.4 [a]	374.8 [a]	530.8 [a]	590.1 [a]	412.0 [a]
30		144.3 [b]	254.7 [b]	333.6 [b]	356.9 [b]	270.1 [b]
	LSD[3]	3.6	5.6	12.4	16.7	7.2
LYS Main Effect Means[2]						
	75 [4]	130.8 [c]	266.3 [b]	391.7 [b]	448.6 [b]	305.3 [b]
	90	170.5 [b]	324.3 [a]	445.8 [a]	480.3 [a]	351.1 [a]
	105	182.1 [a]	336.6 [a]	443.9 [a]	480.6 [a]	353.8 [a]
	120	182.1 [a]	332.0 [a]	447.5 [a]	484.4 [a]	354.1 [a]
	LSD[3]	5.4	12.5	17.5	22.1	9.1
		P				
Source of variation[5]						
T		**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
Dietary lysine %		**< 0.001**	**< 0.001**	**< 0.001**	**0.009**	**< 0.001**
Linear[6]		**< 0.001**	**< 0.001**	**< 0.001**	**0.003**	**< 0.001**
Quadratic[6]		**< 0.001**	**< 0.001**	**< 0.001**	0.102	**< 0.001**
Cubic[6]		0.210	0.603	0.076	0.397	**0.008**
T * Dietary lysine %		0.723	0.095	0.181	0.718	0.093

1 Means are an average of 20 replicate pens of 15 birds each.
2 Means are an average of 10 replicate pens of 15 birds each.
3 Least significant difference ($P = 0.05$) between two means.
4 % lysine of NRC (1994) recommendations in all age intervals, but dietary lysine % was decreasing in the succeeding age intervals.
5 Significant effects ($P < 0.05$) are printed in bold.
6 Orthogonal polynomial contrast across dietary lysine %.
a-c Means within columns with no common superscript differ significantly ($P < 0.05$).

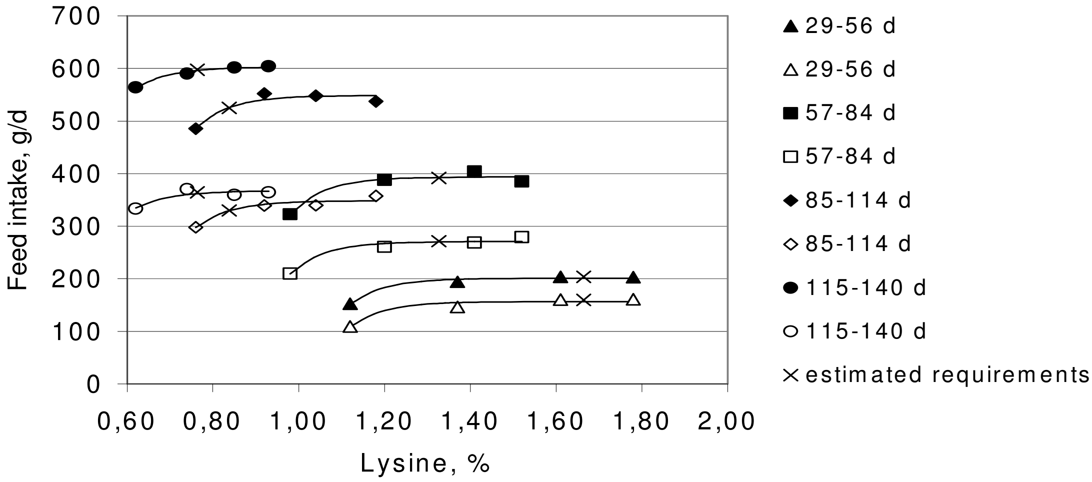


Figure 2. Feed intake response of growing male turkeys to dietary lysine per age interval at high (open signs) and low (closed signs) ambient temperature (curved lines = exponential fit).

Body weight gain

Significant temperature and lysine levels effects were observed in BW gain, but significant T * LYS interaction effects were not found (Table 5).

Table 5. Body weight gain (g/d) of male turkeys as affected by ambient temperature (T; ℃) and dietary lysine levels (LYS; % of NRC (1994)) in different age intervals.

Treatment			Age interval, d				
T	LYS		29 to 56	57 to 84	85 to 114	115 to 140	29 to 140
			(g/d)				
T Main Effect Means[1]							
15			118.4 [a]	177.9 [a]	182.0 [a]	162.9 [a]	160.6 [a]
30			93.5 [b]	126.6 [b]	119.4 [b]	96.1 [b]	109.3 [b]
		LSD[3]	3.1	4.0	6.6	9.5	3.2
LYS Main Effect Means[2]							
	75 [4]		79.1 [c]	129.4 [b]	140.5 [c]	118.5 [b]	117.3 [c]
	90		108.6 [b]	158.9 [a]	150.2 [b]	130.6 [a]	137.5 [b]
	105		119.0 [a]	161.3 [a]	151.1 [b]	133.2 [a]	141.5 [a]
	120		117.0 [a]	159.3 [a]	160.9 [a]	135.6 [a]	143.7 [a]
		LSD[3]	3.9	5.4	6.7	10.5	3.2
			P				
Source of variation[5]							
T			**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
Dietary lysine %			**< 0.001**	**< 0.001**	**< 0.001**	**0.012**	**< 0.001**
Linear[6]			**< 0.001**	**< 0.001**	**< 0.001**	**0.002**	**< 0.001**
Quadratic[6]			**< 0.001**	**< 0.001**	0.878	0.263	**< 0.001**
Cubic[6]			0.762	0.157	0.156	0.629	**0.008**
T * Dietary lysine %			0.206	0.055	0.502	0.169	0.366

1, 2,3,4,5,6, and a-c See Table 4.

The high T treatment resulted in a significant depression in BW gain ($P < 0.001$) as compared to the low T. Relative to low T, the high T treatment decreased BW gain by 21.0, 28.8, 34.4, and 41.0% during the successive age intervals. Body weight gain increased by an exponential function as LYS was increased ($P < 0.001$) until 85 d of age and increased by a linear function from 85 to 114 d ($P < 0.001$) and 115 to 140 d of age ($P = 0.002$). From 29 to 140 d of age, BW gain increased by an exponential function as dietary LYS was increased ($P < 0.001$). The data fitted the parallel exponential curves well as demonstrated by the adjusted R^2-values in the succeeding four-week age intervals: $R^2 = 0.95$, 0.96, 0.94, and 0.89, respectively (Figure 3 and Table 7).

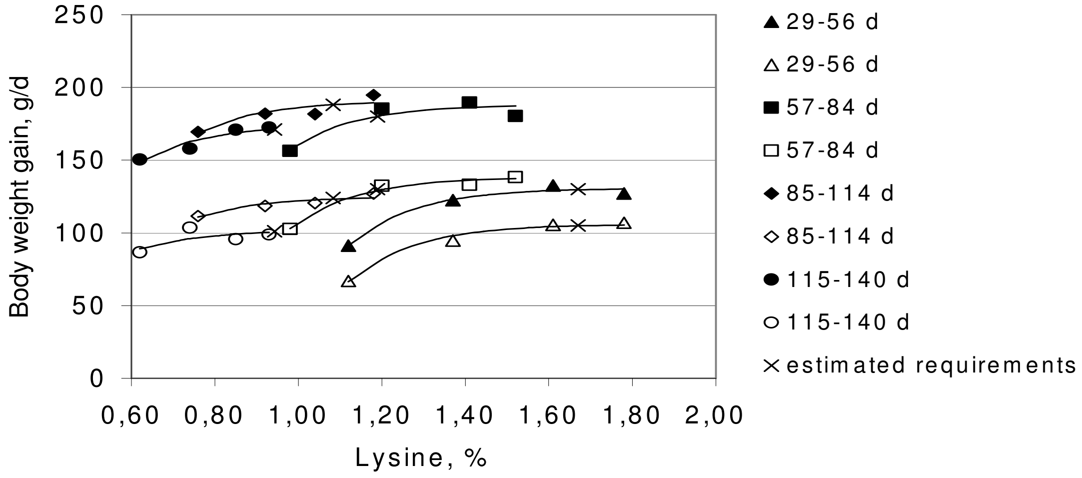


Figure 3. Body weight gain response of growing male turkeys to dietary lysine per age interval at high (open signs) and low (closed signs) ambient temperature (curved lines = exponential fit).

The dietary lysine requirements were estimated to be: 1.67±0.09, 1.19±0.13, 1.08, and 0.94±0.35% during the periods of 29 to 56 d, 57 to 84 d, 85 to 114 d, and 115 to 140 d of age, respectively.

Feed:gain ratio

Temperature * LYS interaction effects on feed:gain ratio were not found to be significant (Table 6). Highly significant T effects were observed on feed:gain ratio from 29 to 84 d of age. Feed:gain ratio of birds exposed to high T was 2.9% ($P = 0.001$) and 4.4% ($P < 0.001$) lower than of those birds exposed to the low T during 29 to 56 d and 57 to 84 d of age, respectively. On average, feed:gain ratio of birds reared in the high T conditions was 3.6% ($P < 0.001$) lower than those reared in the low T. Feed:gain ratio decreased by an exponential function as LYS was increased during the periods of 29 to 56 d ($P < 0.001$) and 85 to 114 d of age ($P = 0.001$). However, the cumulative feed:gain ratio observed during the composite 29 to 140 d period of age decreased linearly ($P < 0.001$) as the level of dietary LYS was increased. The inconsistent variability in the data resulted in a poor fit of the exponential model, except for the 29 to 56 d of age interval ($R^2 = 0.65$)(Figure 4 and Table 7). Therefore, only the dietary lysine requirement for the 29 to 56 d age interval was estimated to be 1.60±0.23%.

Table 6. Feed:gain ratios (g:g) of male turkeys as affected by ambient temperature (T; ℃) and dietary lysine levels (LYS; % of NRC (1994)) in different age intervals.

Treatment			Age interval, d			
T	LYS		29 to 56	57 to 84	85 to 114	115 to 140	29 to 140
			(g:g)				
T Main Effect Means[1]							
15			1.60 [a]	2.11 [a]	2.92	3.64	2.57 [a]
30			1.55 [b]	2.02 [b]	2.80	3.74	2.48 [b]
		LSD[3]	0.02	0.03	0.13	0.18	0.03
LYS Main Effect Means[2]							
	75 [4]		1.65 [a]	2.06	2.77 [b]	3.81	2.60 [a]
	90		1.57 [b]	2.03	2.95 [a]	3.68	2.54[ab]
	105		1.53 [c]	2.08	2.93 [a]	3.65	2.49[bc]
	120		1.55[bc]	2.08	2.79 [b]	3.62	2.46 [c]
		LSD[3]	0.03	0.06	0.13	0.23	0.06
					P		
Source of variation[5]							
T			**0.001**	**< 0.001**	0.060	0.220	**< 0.001**
Dietary lysine %			**< 0.001**	0.386	**0.013**	0.337	**0.001**
Linear[6]			**< 0.001**	0.287	0.801	0.084	**< 0.001**
Quadratic[6]			**< 0.001**	0.323	**0.001**	0.624	0.570
Cubic[6]			0.472	0.336	0.785	0.822	0.909
T * Dietary lysine %			0.141	0.260	0.164	0.275	0.177

1, 2,3,4,5,6, and a-c See Table 4.

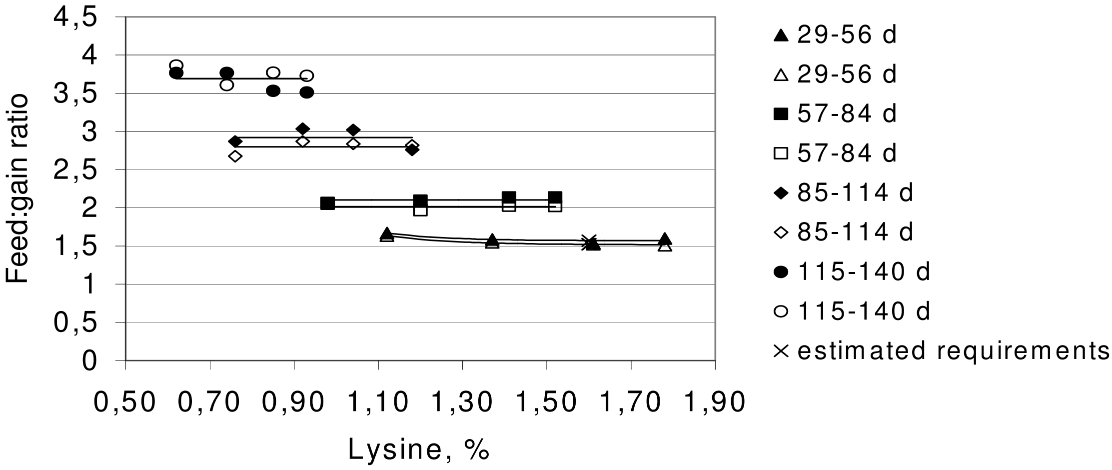


Figure 4. Feed:gain ratio response of growing male turkeys to dietary lysine per age interval at high (open signs) and low (closed signs) ambient temperature (curved lines = exponential fit).

Table 7. Performance of male turkeys from 29 to 140 d of age at low and high ambient temperature (°C); Parameter estimates of exponential fits and lysine requirements.

Response	Parameter estimates of parallel exponential fits[1] y_0 15°C	y_0 30°C	m_{y0}	$lys_{½}$	x_0[3]	Adj. R^2	Dietary lysine requirement[2]
	(g/d)			(% in diet)			(% in diet)
Feed intake							
29 to 56 d	152.8	108.7	53.70	0.1258	1.12	0.97	1.66±0.08
57 to 84	326.3	206.2	68.93	0.0803	0.98	0.96	1.33±0.11
85 to 114	490.2	293.1	54.09	0.0180	0.76	0.97	0.84±0.62
115 to 140	565.2	332.1	34.19	0.0333	0.62	0.96	0.76±0.20
BW gain							
29 to 56	91.45	66.56	40.61	0.1266	1.12	0.95	1.67±0.09
57 to 84	155.1	103.8	30.87	0.0486	0.98	0.96	1.19±0.13
85 to 114	171.2	108.6	16.15	0.0747 [4]	0.76	0.94	1.08 [4]
115 to 140	151.9	85.11	17.60	0.0747	0.62	0.89	0.94±0.35
Feed:gain ratio							
29 to 56	1.674	1.629	-0.1116	0.1110	1.12	0.65	1.60±0.23
57 to 84	2.105	2.016	n.d. [5]	n.d.	0.98	0.30	n.d.
85 to 114	2.860	2.860	n.d. [6]	n.d.	0.76	0.13	n.d.
115 to 140	3.691	3.691	n.d. [6]	n.d.	0.62	0.06	n.d.

[1] estimated values of parameters ± SE of model **[1]**: $y = y_0 + m_{y0} * (1 - e^{(-ln(2)/lys½ \; * \; (lys\% - x0))})$

[2] estimated value ± SE calculated from equation **[2]**: $95\%lysreq = x_0 + 4.322 * lys_{½}$.

[3] fixed lowest used dietary lysine %.

[4] $lys_{½}$ taken from the age interval from 115 to 140 d of age because of convergency problems otherwise.

[5] no differences in response to dietary lysine %.

[6] not estimated due to low adjusted R^2-values.

Carcass Yields

Results of carcass yields are presented in Tables 8a and 8b. Ambient temperature significantly affected all the carcass parameters measured.

Table 8a. Processing yields (kg) as affected by ambient temperature (T; °C) and dietary lysine levels (LYS; % of NRC (1994).

Treatment T	LYS	Live BW	Cold Carcass	Breast[1]	Thighs	Drums	Wings	Fat[2]
		(kg)						
T Main Effect Means[1]								
15		19.18^{a}	14.21^{a}	4.69^{a}	2.72^{a}	1.86^{a}	1.57^{a}	0.15^{a}
30		13.40^{b}	9.97^{b}	2.97^{b}	1.94^{b}	1.50^{b}	1.25^{b}	0.07^{b}
	LSD[3]	0.69	0.52	0.24	0.08	0.05	0.04	0.01
LYS Main Effect Means[2]								
	75	14.06^{c}	10.24^{c}	2.92^{c}	2.01^{c}	1.51^{c}	1.25^{c}	0.11
	90	16.45^{b}	12.18^{b}	3.82^{b}	2.36^{b}	1.70^{b}	1.43^{b}	0.12
	105	17.38^{a}	13.03^{a}	4.31^{a}	2.48^{a}	1.77^{a}	1.49^{a}	0.11
	120	17.27^{a}	12.92^{a}	4.27^{a}	2.46^{a}	1.75^{ab}	1.46^{ab}	0.10
	LSD[3]	0.57	0.42	0.18	0.08	0.06	0.05	0.02
T * LYS Effect Means[3]								
15	75	16.68^{c}	12.15^{c}	3.61^{c}	2.39^{c}	1.67^{c}	1.41^{c}	0.14^{a}
15	90	19.14^{b}	14.09^{b}	4.62^{b}	2.71^{b}	1.87^{b}	1.57^{b}	0.15^{a}
15	105	20.67^{a}	15.46^{a}	5.32^{a}	2.90^{a}	1.97^{a}	1.67^{a}	0.15^{a}
15	120	20.24^{a}	15.14^{a}	5.23^{a}	2.87^{a}	1.94^{ab}	1.62^{ab}	0.13^{a}
30	75	11.44^{e}	8.33^{e}	2.23^{e}	1.63^{e}	1.35^{e}	1.09^{e}	0.07^{b}
30	90	13.77^{d}	10.27^{d}	3.03^{d}	2.01^{d}	1.53^{d}	1.30^{d}	0.08^{b}
30	105	14.10^{d}	10.60^{d}	3.30^{c}	2.05^{d}	1.56^{d}	1.31^{d}	0.07^{b}
30	120	14.30^{d}	10.70^{d}	3.33^{c}	2.05^{d}	1.55^{d}	1.31^{d}	0.06^{b}
	LSD[3]	0.93(0.81)	0.68(0.59)	0.31(0.26)	0.12(0.11)	0.08(0.08)	0.07(0.07)	0.03(0.03)
		P						
Source of variation[4]								
T		**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
LYS		**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	0.213
Linear		**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	0.204
Quadratic		**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	0.108
Cubic		0.648	0.841	0.737	0.414	0.764	0.565	0.563
T * LYS		0.094	**0.044**	**0.005**	0.265	0.343	0.339	0.768
T * Linear		0.071	0.034	**0.002**	0.206	0.147	0.625	0.768
T * Quadratic		0.349	0.476	0.200	0.917	0.585	0.763	0.483
T * Cubic		0.113	0.061	0.177	0.125	0.341	0.087	0.467

1 Skinless and boneless Pectoralis major and Pectoralis minor.
2 Abdominal fat.
3 Least significant difference (P = 0.05) between two means. Comparing means with the same level of temperature use LSD in parenthesis.
4 Significant effects (P < 0.05) are printed in bold.
a-e Effect means within columns with no common superscript differ significantly (P < 0.05).

The turkeys reared in the high T had higher percentages yields of cold dressed carcass (74.4 vs. 73.9%; *P* = 0.032), thigh (19.4 vs. 19.2%; *P* = 0.011), drum (15.1 vs. 13.2%; *P* < 0.001), and wing (12.6 vs. 11.1%; *P* < 0.001) than those reared in the low T. Percentage breast meat yield of birds reared in the high T was lower than those reared in low T (29.6 vs. 32.8%; *P* < 0.001).

Table 8b. Relative processing yields (%) as affected by ambient temperature (T; °C) and dietary lysine levels (LYS; % of NRC (1994).

Treatment T	LYS	Cold carcass yield	Breast[1]	Thighs	Drums	Wings	Fat[2]
		(%)					
T Main Effect Means[1]							
15		73.9 b	32.8 a	19.2 b	13.2 b	11.1 b	1.0 a
30		74.4 a	29.6 b	19.4 a	15.1 a	12.6 a	0.7 b
	LSD[3]	0.4	0.6	0.2	0.3	0.3	0.1
LYS Main Effect Means[2]							
	75	72.6 c	28.2 c	19.6 a	15.0 a	12.3 a	1.0 a
	90	74.3 b	31.1 b	19.4 ab	14.1 b	11.9 b	0.9 ab
	105	75.0 a	32.7 a	19.1 b	13.8 c	11.6 c	0.8 bc
	120	74.8 ab	32.7 a	19.1 b	13.7 c	11.5 c	0.7 c
	LSD[3]	0.6	0.5	0.4	0.3	0.3	0.2
T * LYS Effect Means[3]							
15	75	72.5 c	29.6 d	19.6 a	13.8 c	11.6 d	1.2 a
15	90	73.6 b	32.7 b	19.3 abc	13.3 d	11.1 e	1.1 ab
15	105	74.8 a	34.4 a	18.8 c	12.8 e	10.8 ef	1.0 abc
15	120	74.8 a	34.4 a	18.9 bc	12.8 e	10.8 f	0.9 b
30	75	72.7 bc	26.7 e	19.6 a	16.2 a	13.1 a	0.9 c
30	90	74.9 a	29.5 d	19.5 a	14.9 b	12.7 ab	0.8 cd
30	105	75.1 a	31.1 c	19.3 ab	14.7 b	12.4 bc	0.6 de
30	120	74.8 a	31.0 c	19.2 abc	14.6 b	12.2 c	0.6 e
	LSD[3]	0.8(0.9)	0.8(0.7)	0.5(0.6)	0.4(0.4)	0.4(0.4)	0.2(0.2)
		P					
Source of variation[4]							
T		**0.032**	**< 0.001**	**0.011**	**< 0.001**	**< 0.001**	**< 0.001**
LYS		**< 0.001**	**< 0.001**	**0.020**	**< 0.001**	**< 0.001**	**0.003**
Linear		**< 0.001**	**< 0.001**	**0.003**	**< 0.001**	**< 0.001**	**< 0.001**
Quadratic		**< 0.001**	**< 0.001**	0.452	**< 0.001**	0.111	0.997
Cubic		0.980	0.682	0.434	0.461	0.864	0.502
T * LYS		0.162	0.758	0.492	**0.032**	0.928	0.894
T * Linear		0.385	0.300	0.359	0.062	0.831	0.909
T * Quadratic		0.114	0.813	0.250	0.138	0.538	0.750
T * Cubic		0.158	0.946	0.642	0.051	0.908	0.491

[1] Skinless and boneless Pectoralis major and Pectoralis minor.
[2] Abdominal fat.
[3] Least significant difference (*P* = 0.05) between two means. Comparing means with the same level of temperature use LSD in parenthesis.
[4] Significant effects (*P* < 0.05) are printed in bold.
[a-f] Effect means within columns with no common superscript differ significantly (*P* < 0.05).

The birds reared in the high T had significantly lower proportion of abdominal fat than those reared in the low T (0.7 vs. 1.0%; $P < 0.001$)). For the absolute weight of cold carcass and breast meat and for the relative drum yield, significant T * LYS interaction effect was observed. Turkeys reared in the low T responded to the higher dietary LYS with higher breast meat than those reared in the high T.

Live BW, cold carcass weight, and the absolute weights of all carcass parts increased by an exponential function ($P < 0.001$) as the level of dietary LYS was increased. Relative cold carcass and relative breast meat yields increased by an exponential function ($P < 0.001$) whereas drum yields decreased exponentially ($P < 0.001$) as LYS was increased. Relative thigh and wing yields and abdominal fat decreased linearly ($P = 0.003$, < 0.001, and < 0.001 respectively) as the level of dietary LYS was increased.

DISCUSSION

Mortality rate in this experiment was relatively high, mainly due to ompholitis, liver cirrhosis, heart deformities, and ascites. From 85 to 114 d of age, turkeys fed the highest level of dietary lysine (120% of NRC 1994) and reared in the low T had a mortality rate of 15%, primarily due to heart deformities, liver cirrhosis, and ascites. This high mortality rate influenced the performance results. In the beginning of this period, the lighter birds that suffered from ascites belonged to this treatment group and only the well-growing birds remained in these pens; consequently the average BW gain apparently increased (Table 5 and Figure 3), and feed:gain ratio decreased.

The requirement of dietary lysine from 0 to 28 d of age was determined to be 2.03±0.18% (1.71±0.15 g/MJ ME), which was higher than recommended by NRC (1994) recommendations and the requirement reported by Waldroup et al. (1997a,b).

At 29 d of age, each LYS treatment started with different BW due to the treatment effects in the first four-wk period. This may have influenced the results after 29 d of age by carry-over effects. For interpreting results in the period after 29 d of age this should be kept in mind. Turkeys that were fed the lowest levels of dietary lysine from 29 to 56 d of age gained less weight than those birds fed the higher levels of dietary lysine. This disadvantage in weight gain could have been associated with a reduced capacity of feed intake and consequently adversely affected the ability to estimate dietary lysine requirements during the succeeding age intervals. However, the present study was done to answer the question if different lysine concentrations should be fed at high and low T. This question could still be answered, regardless of carry-over effects.

In the present experiment no T * LYS interaction effects were observed. Turkeys responded to dietary lysine supplementation similarly in both high and low T treatments. This result is in contrast to other researchers who recommended higher levels of dietary amino acid to support optimum growth performance of turkeys reared under high ambient temperatures (Waibel et al., 1975 and 1976; Oju et al, 1987, and Ferket, 1995). A possible explanation for the lack of a T * LYS interaction observed in this study may be associated with the birds being continuously exposed to 30°C at the high T treatment. Except for the 29 to 56 d age period, this continuous exposure to high ambient temperature may have had such a negative impact on feed intake that the birds consuming the highest level of dietary lysine could hardly achieve the same lysine intake as the birds consuming the lowest level of dietary lysine while exposed to the low T treatment.

Previous studies demonstrated that feed intake was influenced significantly by T (Veldkamp et al, 2000a,b). In temperature ranges from 15 to 25°C and 15 to 30°C, cumulative feed intake from 29 d to slaughter decreased by 1.3 and 1.6% for each degree C increase in ambient T, respectively. In the present experiment, two T regimens (15 or 30°C after 28 d of age) were maintained. Turkeys subjected to the high T regimen consumed 23.4, 32.0, 37.2, and 39.5% less feed during the succeeding four age intervals after 28 d of age than birds in the low T regimen. Evidently, the cumulative effect of heat stress on feed intake increased as birds grew older. From 29 to 140 d of age, feed intake decreased about 2.3% for each degree C increase above 15°C, which was a greater heat stress effect than observed in earlier studies. Turkeys subjected to the high T regimen had 31.9% lower BW gain than those in the low T regimen. Moreover, the negative effect of high T on BW gain increased as turkeys got older. Cumulative feed:gain ratio was lowest among birds subjected to the high T regimen. Apparently, at the high T regimen more dietary lysine was used for production than for maintenance or the amount of protein deposited relative to fat was higher than in turkeys in the low T regimen.

During each age interval, feed intake increased by an exponential function as the level of LYS was increased ($P < 0.001$; $R^2 > 0.96$). Lysine requirements, expressed as g dietary lysine per MJ ME for optimal feed intake were 1.29±0.06, 1.02±0.08, 0.63±0.46, and 0.57±0.15 g/MJ ME from 29 to 56 d, 57 to 84 d, 85 to 114 d, and 115 to 140 d of age, respectively.

Body weight gain also increased by an exponential function as LYS was increased ($P <$ 0.001; $R^2 > 0.89$). The lysine requirements expressed as g dietary lysine per MJ ME for optimal BW gain were: 1.29±0.07, 0.92±0.10, 0.81, and 0.70±0.26 g/MJ ME from 29 to 56 d, 57 to 84 d, 85 to 114 d, and 115 to 140 d of age, respectively.

Feed:gain ratio decreased by an exponential function from 29 to 56 d of age as LYS was increased (P < 0.001; $R^2 = 0.65$). The lysine requirement expressed as g dietary lysine per MJ ME for optimal feed:gain ratio was 1.24±0.18 g/MJ ME from 29 to 56 d of age. From 57 to 84 d of age, only a T effect was observed and the turkeys did not respond significantly to the level of dietary lysine. As mentioned earlier, the mortality rate from 85 to 114 d of age was high in turkeys that were fed the highest level of LYS (120% of NRC (1994) recommendations) and in the low T regimen. When this treatment group was removed from the analyses of variance, only a significant T effect was detected. From 115 to 140 d of age, neither T nor LYS effects were observed. After 84 d of age, fitted curves had very low adjusted R^2-values ($R^2 = 0.13$).

Absolute and relative carcass yields were strongly affected by T. Turkeys subjected to the high T regimen had higher cold carcass yield relative to slaughter weight, and higher yields of thigh, drum, and wing relative to cold carcass than turkeys subjected to the low T regimen. Percentage breast meat yield of turkeys in the high T treatment group was lower than those in the low T group, agreeing with other studies (Rose and Michie, 1987; and Halvorson et al., 1991). Relative weight of abdominal fat in turkeys subjected to the high T was lower than those in the low T group. It is also likely that these high T turkeys had less visceral fat depots than the low T birds because they had a higher percentage yield of eviscerated cold carcass.

Body weight, cold carcass weight, and the absolute weights of all carcass parts increased by an exponential function as the level of dietary LYS was increased. Relative cold carcass and relative breast meat yields increased also exponentially, whereas drum yields decreased exponentially as LYS was increased. Relative thigh and wing yields and abdominal fat decreased linearly as LYS was increased. Lehmann et al. (1996) also found an increase in breast meat yield and a decrease in fat content with increasing LYS.

A significant T * LYS interaction effect was observed for cold carcass weight, for absolute breast meat weight, and for relative drum yield. The maximal possible response for breast meat weight to dietary lysine was lower among turkeys subjected to the high T than those subjected to the low T.

The dietary lysine requirements in the present study were determined to be consistent within the range of 15 to 30 °C because no interaction effects between T and dietary lysine were observed. In general, the response to increasing level of dietary LYS on birds reared in the high

T regimen of the present experiment was different from that reported by Noll and Waibel (1989). These authors used dietary energy contents that exceed NRC (1994) by 10 to 20% and found a positive growth performance response to extra dietary lysine when birds were reared at high ambient T. However, they used a lower lysine to energy ratio in comparison to our study. Feed intake was decreased by high T and moreover by use of high-density diets. When feed intake was decreased by high-density diets also lysine intake decreased and maybe therefore a response to extra dietary lysine at high T has been observed in the study of Noll and Waibel (1989). In the present experiment, energy contents in the diets after 28 d of age were only about 5% higher than NRC (1994). This may explain why lysine intake of turkeys subjected to the high T was still adequate to support maximal growth and no T * LYS interaction effect was observed. More research on the energy to lysine relationship in turkeys should be conducted at different temperatures.

REFERENCES

Balloun, S. L., 1962. Lysine, arginine and methionine balance of diets for turkeys to 24 weeks of age. Poultry Sci. 41:417-424.

Boling, S. D., and J. D. Firman, 1998. Digestible lysine requirement of female turkeys during the starter period. Poultry Sci. 77:547-551.

Centraal Veevoederbureau, 1999. Veevoedertabel: Gegevens over Voederwaarde, Verteerbaarheid en Samenstelling. Centraal Veevoederbureau in Nederland, Lelystad, The Netherlands.

Ferket, P. R., 1995. Nutrition of turkeys during hot weather. Proceedings of the Eighteenth Technical Turkey Conference. Renfrew, Scotland.

Genstat 5 Committee, 1993. Genstat 5 Reference Manual. Release 3. Clarendon Press, Oxford, UK.

Halvorson, J. C., P. E. Waibel, E. M. Oju, S. L. Noll, and M. E. El Halawani, 1991. Effect of diet and population density on male turkeys under various environmental conditons. 2. Body compositon and meat yield. Poultry Sci. 70:935-940.

Hurwitz, S., Y. Frisch, A. Bar, U. Eisner, I. Bengal, and M. Pines, 1983. The amino acid requirements of growing turkeys. 1. Model construction and parameter estimation. Poultry Sci. 62:2208-2217.

Lehmann, D., M. Pack, and H. Jeroch, 1996. Responses of growing and finishing turkey toms to dietary lysine. Poultry Sci. 75:711-718.

National Research Council, 1994. Nutrient Requirements of Poultry. 9th rev. ed. National Academy Press, Washington, DC.

Nixey, C., 1989. Nutritional responses of growing turkeys. Pages 183-189 in Recent Advances in Turkey Science. C. Nixey and T. C. Grey, ed. Butterworth, London, UK.

Noll, S. L., and P. E. Waibel, 1989. Lysine requirements of growing turkeys in various temperature environments. Poultry Sci. 68:781-794.

Oju, E. M., P. E. Waibel, and S. L. Noll, 1987. Protein, methionine, and lysine requirements of growing hen turkeys under various environmental temperatures. Poultry Sci. 66:1675-1683.

Plavnik, I., and S. Hurwitz, 1993. Amino acids and protein requirement in turkeys. Pages 300-308 in 9th European Symposium on Poultry Nutrition. Jelenia Gòra, Poland.

Potter, L. M., J. R. Shelton, and J. P. McCarthy, 1981. Lysine and protein requirements of growing turkeys. Poultry Sci. 60:2678-2686.

Rose, S. P., and W. Michie, 1987. Environmental temperature and dietary protein concentrations for growing turkeys. Br. Poultry Sci. 28:213-218.

Schutte, J. B., and M. Pack, 1995. Sulfur amino acid requirement of broiler chicks from fourteen to thirty-eight days of age. 1. Performance and carcass yield. Poultry Sci. 74:480-487.

Veldkamp, T., P. R. Ferket, R. P. Kwakkel, C. Nixey, and J. P. T. M. Noordhuizen, 2000a. Interaction between ambient temperature and supplementation of synthetic amino acids on performance and carcass parameters in commercial male turkeys. Poultry Sci. 79:1472-1477.

Veldkamp, T., R. P. Kwakkel, P. R. Ferket, P. C. M. Simons, J. P. T. M. Noordhuizen, and A. Pijpers, 2000b. Effects of ambient temperature, arginine-to-lysine ratio, and electrolyte balance on performance, carcass, and blood parameters in commercial male turkeys. Poultry Sci. 79:1608-1616.

Waibel, P. E., M. E. El Halawani, and B. R. Behrends, 1975. Ambient temperature and protein requirements of turkeys. Minn. Agric. Exp. Stn. Misc. Rep. 134:77-84.

Waibel, P. E., M. E. El Halawani, and B. R. Behrends, 1976. Growth and efficiency of large white turkeys in relation to dietary protein and environmental temperatures. Pages 119-127 in Proceedings of the 37th Minn. Nutr. Conf., St. Paul, MN.

Waldroup, P. W., M. H. Adams, and A. L. Waldroup, 1997. Evaluation of national research council amino acid recommendations for large white turkeys. Poultry Sci. 76:711-720.

Waldroup, P. W., J. A. England, M. T. Kidd, and B. J. Kerr, 1998. Dietary arginine and lysine in large white toms. 1. Increasing arginine:lysine ratios does not improve performance when lysine levels are adequate. Poultry Sci. 77:1364-1370.

Chapter 5

GROWTH RESPONSES TO DIETARY ENERGY AND LYSINE AT HIGH AND LOW AMBIENT TEMPERATURE IN MALE TURKEYS

T. Veldkamp

Research Institute for Animal Husbandry, Runderweg 6, P.O. Box 2176, 8203 AD Lelystad, The Netherlands

R. P. Kwakkel

Wageningen Institute of Animal Sciences, Animal Production Systems, Wageningen University, Marijkeweg 40, 6709 PG Wageningen, The Netherlands

P. R. Ferket

North Carolina State University, Department of Poultry Science, Scott Hall, Campus Box 7608, Raleigh, North Carolina 27695

M. W. A. Verstegen

W*ageningen Institute of Animal Sciences, Animal Nutrition Group, Wageningen University, Marijkeweg 40, 6709 PG Wageningen, The Netherlands*

Sumitted to: Poultry Science

GROWTH RESPONSES TO DIETARY ENERGY AND LYSINE AT HIGH AND LOW AMBIENT TEMPERATURE IN MALE TURKEYS

T. Veldkamp, R.P. Kwakkel, P.R. Ferket, and M.W.A. Verstegen

ABSTRACT

The effects of ambient temperature (T; 18°C vs. 28°C from 6 wk of age onwards), dietary energy level (E; 90, 100, and 110% of NRC (1994) recommendations), and dietary lysine level (LYS; 105 vs. 120% of NRC (1994) recommendations), and their interactions on growth performance and carcass yields of male turkeys were studied from 29 to 140 d of age. The experiment was designed as a split plot, including T as the main plot and E and LYS as the sub-plot, with 60 pens containing 10 male turkeys each. Temperature had a clear effect on performance during all age periods. Overall, feed intake was significantly lower at high T than at low T (335.9 vs. 435.1 g/bird per d, $P < 0.001$). Consequently, BW gain was significantly lower at high T (132.5 vs. 165.0 g/d, $P < 0.001$). Feed:gain was significantly lower at high T than at low T (2.54 vs. 2.64, $P = 0.01$). Feed intake decreased linearly during all age intervals as dietary energy levels increased, but this response was more pronounced at low T than at high T. Consequently, metabolizable energy intake increased more at high than at low T as E level increased. Turkeys that were fed the highest E level gained less weight until 84 d of age than those that were fed the lower E levels. Lysine was not the limiting amino acid in the diet because birds showed no response to extra lysine. Feed:gain decreased linearly in all age intervals as E level increased. Until 84 d of age, feed:gain was decreased more at low than at high T as dietary E increased. Breast meat yields were lower, and thigh, drum, and wing yields were higher at high T than at low T. The highest energy level resulted in lower cold carcass and breast meat yields and higher thigh and drum yields than the lowest energy level. Dietary lysine level did not affect carcass yields.

(*Key words*: ambient temperature, energy, lysine, performance, carcass yields, turkeys)

INTRODUCTION

Turkeys exposed to high ambient temperatures reduce their feed intake to minimize the amount of body heat generated from digestion and energy metabolism (Ferket, 1995). The reduction in feed intake at high ambient temperatures usually makes caloric energy the limiting nutrient. The first priority for dietary energy is for basal metabolism and maintenance with the remaining energy for growth and tissue accretion. Therefore, any limitation in dietary energy intake results in reduced growth and tissue accretion.

Hurwitz et al. (1980) studied the energy requirements in relatively young (4.5 to 9.5 wk of age) turkeys at different ambient temperatures. When exposed to constant temperatures ranging from 12 to 24°C, metabolic heat production was reduced with the lowest level between 24 and 28°C. Metabolic heat production increased as the ambient temperature increased above 28°C. However, the data obtained by Hurwitz et al. (1980), were from a genetic strain of turkeys having lower feed intake and BW gain than the modern commercial strains of turkeys. In older birds with higher rates of gain, however, lowest level of heat production will occur at a lower ambient temperature.

Turkeys show panting behavior when having difficulties to dissipate the heat generated by digestion and energy metabolism, and this requires more energy than they are exposed to thermal neutral temperatures. Most studies reported in the literature about the relationship of dietary energy and ambient temperature have been conducted with broilers and the results vary considerably. In general, a response to dietary energy concentration occurred when adequate lysine levels were fed to broilers in a hot environment (Fuller and Mora, 1973; Dale and Fuller, 1979, 1980; and Fuller, 1981). Sinurat and Balnave (1985) found that the optimum amino acid:ME ratio for broilers varied with dietary ME-concentration in hot (25 to 35°C), but not in moderate (18 to 26°C) environment temperatures. Relatively greater increases in feed intake and BW gain occurred in the hot environment when dietary ME was increased and thereby reducing the amino acid:ME ratio. However, when inadequate levels of lysine were fed, growth response to dietary energy was not observed (Dale and Fuller, 1980; Reece and McNaughton, 1982; and McNaughton and Reece, 1984). Bacon et al. (1981) reported that broilers did not respond to increasing energy or protein when reared in a hot environment (26°C). Plavnik et al. (1997) did not find any differences in the performance responses to dietary fat or carbohydrate supplementation neither in broiler chickens of different ages nor in growing turkeys. Noll et al. (1991) did not find any performance response of adding up to 8% animal fat to the diet of turkeys reared in different ambient temperature regimens.

Ferket (1995) explained that supplemental fat can improve energetic efficiency of a diet fed during hot weather in three ways. First, dietary fat has 2.25 times more energy per unit of weight than carbohydrate or protein. Therefore, fat can be used to increase flexibility of feed formulation by allowing more inclusion possibilities for other crucial nutrients. Second, digestion and metabolism of dietary fat generates less body heat per g when absorbed and used for growth than dietary carbohydrate and protein. The reduction of metabolic heat from dietary fat compared to other forms of energy increases the performance of broilers fed high energy diets in hot temperatures (Mickelberry et al., 1966; Olson et al., 1972; and Reece and McNaughton, 1982). Third, the rate of food passage is reduced by dietary fat, which may increase the digestibility of other ingredients (Mateos et al., 1982).

The objective of this study was to evaluate the growth response and meat yield of male turkeys reared at high and low ambient temperatures and fed diets containing different energy levels at relatively high dietary lysine concentrations.

MATERIALS AND METHODS

Birds, Housing and Experimental Design

A total of 700 commercial male turkeys[1] were raised under standard management practices from day-old to 28 d of age. Out of 10 identical, individually controlled 20 m^2 rooms, five rooms were randomly assigned to a constant 18°C and five to 28°C. Each room was divided into six 3.7 m^2 pens containing 10 birds each. In each room (whole-plot experimental unit), the six pens (sub-plot experimental units) were assigned at random to one of six dietary treatments. The experimental diets contained three levels of dietary energy (90, 100, or 110% of NRC (1994)), and two dietary lysine levels (105 or 120% of NRC (1994)) recommendations corresponding to ages of 5 to 8, 9 to 12, 13 to 16, and 17 to 20 wk).

Feed and water were supplied ad libitum, and the turkeys received 16 h light/d from 8 to 140 d of age. Soft wood shavings were used as litter material.

---

[1] British United Turkeys Ltd., Hockenhull Hall, Tarvin, Chester CH3 8LE, UK.

Climate

In accordance to best management practices, the turkeys were subjected to a common temperature regimen from 0 to 28 d and then the two temperature regimens were applied subsequently until 140 d of age. The two different T regimens were gradually imposed during the period of 29 to 42 d of age. The high T regimen was increased from 19 to 28°C by about 0.6°C increase per day, whereas the low T regimen was set on a constant 18°C at 29 d of age. After 42 d, the ambient temperature on the high and low T regimens maintained constant throughout the experiment at 28°C and 18°C, respectively. Relative air humidity was maintained at 70% throughout the experiment. Ventilation rate was set similar for all rooms.

Diets

The compositions of the diets are presented in Table 1a. Before the respective experimental period started at 29 d of age, the poults received commercial diets (2 mm-pellets) appropriate for the respective age. In the experimental period, six different corn and soybean-based diets with three levels of dietary energy (90, 100, or 110% of NRC (1994)) and two dietary lysine levels (105 or 120% of NRC (1994) recommendations) were provided to the birds *ad libitum* during four age intervals (29 to 52 d, 53 to 84 d, 85 to 112 d, and 113 to 140 d of age). Soybean oil was added to the 90% energy diet at the expense of cornstarch, and diamol[1] and cellulose was used to modify dietary energy levels of 100 and 110%. Supplementation of L-Lysine HCl to the 105% lysine diet at the expense of corn was done to prepare the dietary lysine level of 120% of NRC (1994) recommendations. All the experimental diets were manufactured as 3-mm pellets.

All experimental diets were formulated to provide a minimum of 110% of NRC (1994) recommendations for all amino acids except for lysine. Calculated values for CP, crude fiber, crude fat, Ca, available P, and analyzed values for amino acids in all experimental diets are presented in Table 1b. The analyzed values were in good agreement with the calculated levels.

---

[1] Bertram GmbH, Hamburg, Germany

Traits Measured

Pen means of body weight (BW) gain and feed intake were recorded at 0, 28, 52, 84, 112, and 140 d of age and pen means of feed:gain ratio were calculated from these data. Birds that died or had to be culled were weighed and their BW gain was included in the calculation of feed:gain ratio per pen. Dead birds were subjected to post mortem dissection on the day of death.

At 140 d of age, five turkeys per pen representing the average BW for that pen were selected and processed at a commercial abattoir to determine the yield of carcass parts. After air chilling for 20 h, cold carcasses were weighed and then cut into commercial-type parts and weighed. Cold carcass yield was expressed as a percentage of live BW and each part was expressed as a percentage of cold carcass weight. Pen means of cold carcasses and all carcass parts (as well absolute weights (kg) as relative (%) were used in the statistical analysis of this data.

Table 1a. Composition of diets for turkeys from 0 to 140 d of age formulated to provide different percentages of dietary energy and lysine.

	Age interval, d																							
Item	29 to 52						53 to 84						85 to 112						113 to 140					
Energy (% of NRC 1994)	90	100	110	90	100	110	90	100	110	90	100	110	90	100	110	90	100	110	90	100	110	90	100	110
Lysine (% of NRC 1994)	105	105	105	120	120	120	105	105	105	120	120	120	105	105	105	120	120	120	105	105	105	120	120	120
	(%)																							
Corn (8.4% CP)	46.4	46.4	46.4	46.1	46.1	46.1	56.5	56.5	56.5	56.2	56.2	56.2	62.7	62.7	62.7	62.5	62.5	62.5	68.1	68.1	68.1	68.0	68.0	68.0
Soybean meal (47.2% CP)	36.0						28.5						23.0						18.0					
Potato protein (76.9% CP)	5.0						3.0						2.0						1.5					
Corn starch	1.50	0.75	0.00	1.50	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soybean oil	0.75	4.00	7.25	0.75	4.00	7.25	1.20	4.20	7.20	1.20	4.20	7.20	1.90	4.90	7.90	1.90	4.90	7.90	2.40	5.50	8.60	2.40	5.50	8.60
Diamol	2.50	1.25	0.00	2.50	1.25	0.00	3.00	1.50	0.00	3.00	1.50	0.00	3.00	1.50	0.00	3.00	1.50	0.00	3.10	1.55	0.00	3.10	1.55	0.00
Cellulose (Arbocel)	2.50	1.25	0.00	2.50	1.25	0.00	3.00	1.50	0.00	3.00	1.50	0.00	3.00	1.50	0.00	3.00	1.50	0.00	3.10	1.55	0.00	3.10	1.55	0.00
Premix[2]	1.00						1.00						1.00						1.00					
Limestone	1.75						1.50						1.35						1.15					
Monocalcium phosphate	1.80						1.50						1.35						1.10					
Salt (NaCl)	0.35						0.30						0.30						0.20					
Sodium bicarbonate ($NaHCO_3$)	0.00						0.00						0.00						0.15					
L-lysine HCl	0.17	0.17	0.17	0.43	0.43	0.43	0.28	0.28	0.28	0.52	0.52	0.52	0.13	0.13	0.13	0.34	0.34	0.34	0.07	0.07	0.07	0.23	0.23	0.23
DL-methionine	0.27						0.19						0.12						0.07					
L-threonine	0.02						0.05						0.13						0.05					

[1] See Table 1b for analyzed values.

[2] Supplied per kg of diet: vitamin A, 12,000 IU (retinyl acetate); vitamin D_3, 2,500 IU (cholecalciferol); vitamin E, 25 IU (dl-α-tocopherol); thiamin, 3 mg; riboflavin, 7 mg; pyridoxine, 3 mg; niacin, 70 mg; Ca-D-Pantothenic acid, 15 mg; choline chloride, 1000 mg; cobalamin, 20 µg; menadione, 2 mg; folic acid, 1 mg; biotin, 120 µg, cobalt (as $CoSO_4.7H_2O$), 0.2 mg; selenium (as Selpex-50 (organic Se)), 0.1 mg; iodine (as KI), 0.8 mg; zinc (as $ZnSO_4.H_2O$), 50 mg; iron (as $FeSO_4.7H_2O$), 40 mg; copper (as $CuSO_4.5H_2O$), 10 mg; manganese (as MnO_2), 80 mg; flavomycin, 5 mg; lasalocid-Na, 90 mg (up to 12 wk of age); and dimetridazol, 125 mg (up to 12 wk of age).

Table 1b. Calculated and analyzed nutrient contents of the diets.

Item	Age interval, d																							
	29 to 52						53 to 84						85 to 112						113 to 140					
Energy(% of NRC 1994)	90	100	110	90	100	110	90	100	110	90	100	110	90	100	110	90	100	110	90	100	110	90	100	110
Lysine(% of NRC 1994)	105	105	105	120	120	120	105	105	105	120	120	120	105	105	105	120	120	120	105	105	105	120	120	120
	(g/kg)																							
<u>Calculated Analysis</u>																								
ME (MJ/kg)[1]	11.1	12.2	13.3	11.1	12.2	13.3	11.4	12.6	13.7	11.4	12.6	13.7	11.9	13.0	14.1	11.9	13.0	14.1	12.2	13.4	14.6	12.2	13.4	14.6
Calcium	10.6						9.0						8.0						6.7					
Available phosphorus[1]	5.3						4.5						4.1						3.5					
<u>Determined Analysis</u>																								
Crude Protein	254	250	252	254	250	249	210	209	209	211	209	210	180	179	180	175	174	173	150	149	148	152	150	150
Crude fat	28	59	89	28	58	90	35	65	89	36	64	90	46	77	107	48	78	107	53	68	113	52	83	113
Crude fiber	41	33	25	42	33	24	44	33	24	44	34	25	41	31	22	43	33	21	48	33	22	44	34	24
Ash	79	70	61	80	73	62	80	66	57	80	66	55	72	71	22	74	61	21	70	57	41	70	54	40
Starch	346	331	335	336	330	321	389	389	377	388	382	382	436	425	415	432	433	441	461	461	459	471	460	454
Lysine	16.5	16.2	16.3	18.3	18.0	18.3	14.2	14.2	14.6	15.7	15.8	15.8	11.2	11.0	10.9	12.2	12.3	11.8	8.1	8.1	8.3	9.6	9.5	9.4
Methionine	6.5	6.8	6.6	6.5	6.4	6.8	5.0	5.2	5.0	4.9	4.8	4.8	4.0	4.0	3.9	4.2	3.9	3.8	3.1	3.0	3.1	3.1	3.0	3.1
Cystine	4.0	4.0	4.3	3.9	4.0	4.2	3.5	3.7	4.0	3.5	3.6	3.7	3.4	3.3	3.5	3.0	3.4	3.3	2.6	2.7	2.8	2.7	2.8	2.8
Threonine	10.7	10.7	10.8	10.7	10.6	10.6	8.5	8.5	8.8	8.3	8.3	8.3	8.2	8.2	8.2	8.2	8.2	7.9	6.2	6.1	6.2	6.3	6.2	6.3
Isoleucine	11.7	11.3	11.3	11.4	11.3	11.3	8.8	8.8	9.1	8.7	8.7	8.9	8.0	7.7	7.4	7.1	7.3	6.7	5.9	6.0	6.2	5.9	5.7	5.7
Leucine	22.1	21.9	21.9	22.0	21.7	21.7	18.8	18.5	19.0	18.3	18.3	18.4	16.9	16.1	15.8	15.3	15.8	15.0	13.9	13.9	14.0	14.0	13.6	13.6
Valine	13.0	12.6	12.7	12.8	12.7	12.7	10.4	10.2	10.4	10.1	10.0	10.0	9.0	8.7	8.5	8.2	8.3	7.8	7.0	7.0	7.2	7.0	6.8	6.9
Arginine	17.7	17.5	17.7	17.5	17.3	17.6	15.2	15.1	15.5	14.7	14.9	14.7	11.7	11.5	11.4	10.9	11.2	10.7	9.1	9.1	9.3	9.2	9.1	9.2
Histidine	6.9	6.6	6.7	6.7	6.6	6.6	5.8	5.6	5.8	5.6	5.6	5.5	5.0	4.9	4.8	4.6	4.8	4.6	4.0	4.0	4.1	4.1	4.0	4.0

[1] Available phosphorus, and ME-content in the ingredients was calculated, based on official Dutch standards (CVB, 1999).

Statistical Analyses

From 29 to 140 d of age, turkeys were exposed to a factorial combination of three dietary energy levels (E; 90, 100, 110% of NRC (1994)), two dietary lysine levels (LYS; 105 or 120% of NRC (1994)), and two ambient temperatures (T; 15 and 30°C).

The performance results from 29 to 140 d of age, for each four-wk feed phase (29 to 52 d, 53 to 84 d, 85 to 112 d, and 113 to 140 d of age), and carcass yield results were subjected to analysis of variance according to the following model for a split-plot design:

$$Y_{ijkl} = \mu + T_i + e_{ij} + E_k + LYS_l + T * E_{ik} + T * LYS_{il} + E * LYS_{kl} + T * E * LYS_{ikl} + e_{ijklm}$$

where: Y_{ijkl} = observed trait; μ = overall mean; T_i = effect of T (i = 1,2); E_k = effect of E (k = 1…3); LYS_l = effect of LYS (l= 1,2); $T * E_{ik}$ = interaction of T_i and E_k; $T * LYS_{il}$ = interaction of T_i and LYS_l; $E * LYS_{kl}$ = interaction of E_k and LYS_l; $T * E * LYS_{ikl}$ = interaction of T_i, E_k, and LYS_l; e_{ij} = random whole-plot error associated with rooms (j = 1…5); and e_{ijklm} = random sub-plot error associated with pens (m = 1…6), both assumed to be normally distributed with zero mean and a constant variance. Significance of differences between means of T, E, LYS, T * E, T * LYS, E * LYS, and T * E * LYS were tested with the Student's t-test.

The effects and means of the parameters were declared significant at $P < 0.05$. All analyses were done with Genstat 5 (Genstat 5 Committee, 1993); in particular ANOVA, FIT, RPAIR, and PPAIR procedures were used.

RESULTS

Mortality rate was observed during 29 to 140 d of age averaged 8.9 %. Mortality rate among turkeys reared in the high T regimen was about twice as high as in the low T regimen (11.2 vs. 6.6%, $P < 0.05$). Most of the mortality among birds exposed to the high T regimen was related to airsaculitis.

Performance (28 to 140 d of age)

Feed intake, BW gain, and feed:gain data observed during the different age periods including the 29 to 140 d cumulative period are summarized in Tables 2, 3, and 4, respectively.

Table 2. Feed intake (g/d) of male turkeys as affected by ambient temperature (T; in°C), energy level (E; in % of NRC (1994) recommendations) and dietary lysine levels (LYS; in % of NRC (1994) recommendations) in different age intervals.

Treatment				Age interval, d				
T	E	LYS		29 to 52	53 to 84	85 to 112	113 to 140	29 to 140
				(g/d)				
T Main Effect Means								
18				205.1 [a]	391.7 [a]	582.2 [a]	541.2 [a]	435.1 [a]
28				177.0 [b]	318.7 [b]	427.9 [b]	407.5 [b]	335.9 [b]
			LSD [1]	3.4	10.2	24.6	17.6	9.2
E Main Effect Means								
	90			208.3 [a]	387.7 [a]	526.0 [a]	506.3 [a]	411.8 [a]
	100			190.6 [b]	356.9 [b]	509.7 [a]	459.6 [b]	383.7 [b]
	110			174.1 [c]	320.9 [c]	479.7 [b]	457.2 [b]	361.0 [c]
			LSD	3.6	10.1	24.1	21.6	10.6
LYS Main Effect Means								
		105		189.8	355.8	514.2	477.4	388.4
		120		192.2	354.5	496.1	471.3	382.6
			LSD	2.9	8.2	19.7	17.6	8.7
T * E Interaction Effect Means								
18	90			226.5 [a]	436.5 [a]	609.5 [a]	586.2 [a]	470.8 [a]
18	100			203.0 [b]	394.3 [b]	593.7 [a]	531.3 [b]	435.8 [b]
18	110			185.7 [c]	344.2 [c]	543.8 [b]	506.2 [b]	398.6 [c]
28	90			190.2 [c]	338.9 [c]	442.5 [c]	426.4 [c]	352.7 [d]
28	100			178.2 [d]	319.5 [d]	425.6 [c]	387.9 [cd]	331.7 [e]
28	110			162.5 [e]	297.6 [e]	415.6 [c]	408.3 [d]	323.3 [e]
			LSD	5.1	14.7	35.3	30.5	14.6
				P				
Source of variation[2]								
T				**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
E				**< 0.001**	**< 0.001**	**0.001**	**< 0.001**	**< 0.001**
LYS				0.101	0.752	0.071	0.491	0.184
T * E				**0.001**	**< 0.001**	0.177	**0.018**	**< 0.001**
T * LYS				0.060	0.558	0.100	0.321	0.372
E * LYS				0.463	0.261	**0.034**	0.353	**0.026**
T * E * LYS				0.641	0.819	0.342	0.705	0.835

[1] Least significant differences of means (5% level).
[2] Significant effects ($P < 0.05$) are printed in bold.

Feed Intake

The main effects of T and E on feed intake were highly significant (Table 2). High T reduced feed intake in all age intervals ($P < 0.001$) and this effect increased with age. Cumulative feed intake was depressed by 22.8% at high T and it decreased linearly as dietary energy content increased ($P \leq 0.001$). This effect of dietary energy was more pronounced during 29 to 84 d than during 85 to 140 d of age.

Table 3. Body weight gain (g/d) of male turkeys as affected by ambient temperature (T; in°C), energy level (E; in % of NRC (1994) recommendations) and dietary lysine levels (LYS; in % of NRC (1994) recommendations) in different age intervals.

Treatment				Age interval, d				
T	E	LYS		29 to 52	53 to 84	85 to 112	113 to 140	29 to 140
				(g/d)				
T Main Effect Means								
18				129.1 [a]	182.5 [a]	186.7 [a]	154.6 [a]	165.0 [a]
28				117.0 [b]	150.4 [b]	149.9 [b]	108.7 [b]	132.5 [b]
			LSD [1]	2.4	3.5	8.8	6.9	2.2
E Main Effect Means								
	90			127.0 [a]	167.3 [a]	165.4	130.9	148.9
	100			123.7 [b]	168.6 [a]	168.3	129.8	149.0
	110			118.5 [c]	163.5 [b]	171.0	134.4	148.3
			LSD	2.7	3.5	5.6	8.4	2.7
LYS Main Effect Means								
		105		122.6	166.9	170.8 [a]	131.8	149.4
		120		123.5	166.1	165.7 [b]	131.6	148.1
			LSD	2.2	2.8	4.5	6.9	2.2
T * E Interaction Effect Means								
18	90			133.8	184.9	183.6	153.4	165.6
18	100			128.5	183.4	185.9	154.7	165.0
18	110			124.8	179.2	190.4	155.8	164.4
28	90			120.1	149.7	147.2	108.3	132.2
28	100			118.8	153.7	150.8	104.9	133.1
28	110			112.2	147.9	151.6	112.9	132.2
			LSD	3.8	5.1	10.3	11.9	3.7
				P				
Source of variation[2]								
T				**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
E				**< 0.001**	**0.015**	0.143	0.460	0.858
LYS				0.378	0.568	**0.030**	0.956	0.240
T * E				0.321	0.279	0.792	0.656	0.842
T * LYS				0.082	0.515	0.812	0.321	0.994
E * LYS				0.482	0.922	0.154	0.720	0.862
T * E * LYS				0.763	0.985	0.937	0.652	0.642

[1] Least significant differences of means (5% level).
[2] Significant effects ($P < 0.05$) are printed in bold.

From 29 to 84 d of age, feed intake was decreased on average by 16.8% as E increased from 90 to 110% of NRC (1994) recommendations. Feed intake from 85 to 140 d of age was decreased on average by 9.3% as E increased from 90 to 110% of NRC (1994). Significant T * E interaction effects were observed during all age intervals except during 85 to 112 d of age. Overall, the depressing effect of increased dietary E was greater among turkeys subjected to the low T (15.3%) than the high T (8.3%). A significant E * LYS interaction effect was also observed during 85 to 112 d and 29 to 140 d of age.

Table 4. Feed:gain ratio of male turkeys as affected by ambient temperature (T; in °C), energy level (E; in % of NRC (1994) recommendations) and dietary lysine levels (LYS; in % of NRC (1994) recommendations) in different age intervals.

Treatment				Age interval, d				
T	E	LYS		29 to 52	53 to 84	85 to 112	113 to 140	29 to 140
				(g:g)				
T Main Effect Means								
18				1.59 [a]	2.15	3.13 [a]	3.51	2.64 [a]
28				1.51 [b]	2.12	2.86 [b]	3.79	2.54 [b]
			LSD [1]	0.02	0.07	0.09	0.34	0.07
E Main Effect Means								
	90			1.64 [a]	2.31 [a]	3.17 [a]	3.92 [a]	2.76 [a]
	100			1.54 [b]	2.11 [b]	3.01 [b]	3.58 [b]	2.57 [b]
	110			1.47 [c]	1.97 [c]	2.80 [c]	3.45 [b]	2.44 [c]
			LSD	0.03	0.06	0.15	0.22	0.07
LYS Main Effect Means								
		105		1.55	2.13	3.00	3.67	2.59
		120		1.55	2.13	2.99	3.63	2.58
			LSD	0.02	0.05	0.12	0.18	0.06
T * E Interaction Effect Means								
18	90			1.69 [a]	2.36 [a]	3.32	3.84	2.84 [a]
18	100			1.58 [b]	2.15 [c]	3.20	3.43	2.64 [b]
18	110			1.49 [c]	1.92 [e]	2.86	3.26	2.43 [c]
28	90			1.58 [b]	2.26 [b]	3.01	4.01	2.67 [b]
28	100			1.50 [c]	2.08 [cd]	2.83	3.73	2.49 [c]
28	110			1.45 [d]	2.01 [d]	2.75	3.64	2.45 [c]
			LSD	0.03	0.09	0.19	0.40	0.10
				P				
Source of variation [2]								
T				**< 0.001**	0.398	**< 0.001**	0.098	**0.010**
E				**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
LYS				0.448	0.899	0.849	0.620	0.640
T * E				**0.023**	**0.002**	0.190	0.623	**0.023**
T * LYS				0.857	0.873	0.206	0.981	0.451
E * LYS				0.717	0.168	**0.033**	0.752	0.051
T * E * LYS				0.839	0.817	0.363	0.799	0.690

[1] Least significant differences of means (5% level).
[2] Significant effects ($P < 0.05$) are printed in bold.

Feed intake of turkeys fed LYS levels of 120% instead of 105% of NRC (1994) was significantly decreased at dietary energy levels of 90 and 110%, whereas no LYS level effect was observed at the dietary energy level of 100%. There were no significant T * E * LYS interaction effects observed.

Body weight gain

The main effect of T on BW gain was highly significant throughout the experiment, and significant E and LYS effects were observed from 29 to 84 d, and 85 to 112 d of age, respectively (Table 3). In all age intervals, body weight gain was depressed as T increased ($P < 0.001$). Overall, BW gain was 19.7% lower among turkeys reared in high T than low T environment. From 29 to 84 d of age, BW gain decreased significantly by 4.5% as E increased from 90 to 110% of NRC (1994) recommendations. During the period of 85 to 112 d, turkeys consuming the 120% LYS diets had about 3% lower BW gain than those consuming the 105% LYS diets. There were no significant interaction effects observed on BW gain during the experiment.

Feed:gain ratio

Significant E main effects ($P < 0.001$) on feed:gain were observed throughout the experiment, and significant main effects of T ($P < 0.001$) were observed from 29 to 52 d, and 85 to 112 d of age (Table 4). Feed:gain ratios in these age intervals were improved at high T. Overall, feed:gain ratio at high T was also significantly lower than at low T (2.54 vs. 2.64, $P < 0.001$). In general, feed:gain ratios decreased linearly as E increased from 90 to 110% of NRC (1994). Feed:gain ratio of birds fed the lowest E level (90%) from 29 to 140 d of age was significantly higher than those fed the highest E level (110%) (2.76 vs. 2.44, $P < 0.001$). Significant T * E interaction effects were observed until 84 d of age and from 29 to 140 d of age. The benefit of higher E levels was more pronounced at the low than at the high T regimen. From 85 to 112 d, a significant E * LYS interaction effect was observed. Among birds fed diets containing the 90% level of E, the feed:gain ratio was lowest in the group fed at the 105% level of LYS, whereas there were no LYS level effects observed among birds fed diets containing the 100% and 110% levels of E. Three-way interaction effects on feed:gain ratio were not observed.

Carcass Yields

The results on carcass parts yields are presented in Tables 5a and 5b. Ambient temperature significantly affected all measured parameters except cold carcass yield (as a percentage of live BW). All absolute weights of parts were lower in birds reared in the high T regimen than in the low T ($P < 0.001$).

Relative breast meat yield decreased and thighs, drums, and wings (all as a percentage of cold carcass weight) increased as T increased. Cold carcass yield and absolute as well as relative breast meat yield decreased significantly as E increased, whereas relative thigh and drum yields significantly increased. Dietary lysine did not affect carcass yields and interaction terms were not significant.

Table 5a. **Processing yields (in kg) of male turkeys as affected by** ambient temperature (T; in°C), energy level (E; in % of NRC (1994) and dietary lysine levels (LYS; in % of NRC (1994)).

Treatment T	E	LYS		Live BW	Cold carcass	Breast[1]	Thighs	Drums	Wings
				(kg)					
T Main Effect Means									
18				19.64 [a]	14.36 [a]	4.54 [a]	2.67 [a]	1.94 [a]	1.59 [a]
28				16.14 [b]	11.73 [b]	3.42 [b]	2.25 [b]	1.71 [b]	1.41 [b]
			LSD [2]	0.45	0.37	0.14	0.07	0.04	0.04
E Main Effect Means									
	90			17.89	13.12	4.12 [a]	2.44	1.81	1.51
	100			18.05	13.16	4.02 [a]	2.47	1.84	1.50
	110			17.73	12.86	3.80 [b]	2.46	1.82	1.48
			LSD	0.40	0.30	0.12	0.07	0.05	0.04
LYS Main Effect Means									
		105		17.91	13.04	3.98	2.47	1.83	1.49
		120		17.87	13.05	3.98	2.45	1.82	1.51
			LSD	0.33	0.25	0.10	0.06	0.04	0.03
				P					
Source of variation[3]									
T				**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
E				0.285	0.103	**< 0.001**	0.725	0.381	0.366
LYS				0.833	0.946	0.862	0.641	0.725	0.382
T * E				0.343	0.333	0.943	0.485	0.179	**0.035**
T * LYS				0.343	0.701	0.472	0.547	0.352	0.333
E * LYS				0.575	0.592	0.652	0.788	0.968	0.434
T * E * LYS				0.452	0.138	0.179	0.605	0.354	0.663

[1] Skinless and boneless Pectoralis major and Pectoralis minor.
[2] Least significant differences of means (5% level).
[3] Significant effects ($P < 0.05$) are printed in bold.

Table 5b. Processing yields (%) of male turkeys as affected by ambient temperature (T; in°C), energy level (E; in % of NRC (1994) and dietary lysine levels (LYS; in % of NRC (1994)).

Treatment T	E	LYS		Cold carcass yield	Breast[1]	Thighs	Drums	Wings
				(%)				
T Main Effect Means								
18				73.1	31.6 [a]	18.6 [b]	13.5 [b]	11.1 [b]
28				72.7	29.1 [b]	19.2 [a]	14.6 [a]	12.1 [a]
			LSD [2]	0.8	0.5	0.2	0.3	0.2
E Main Effect Means								
	90			73.4 [a]	31.2 [a]	18.6 [b]	13.9 [b]	11.6
	100			72.9[ab]	30.4 [b]	18.8 [b]	14.1[ab]	11.5
	110			72.4 [b]	29.4 [c]	19.2 [a]	14.2 [b]	11.6
			LSD	0.7	0.5	0.3	0.2	0.2
LYS Main Effect Means								
		105		72.8	30.3	18.9	14.1	11.5
		120		73.0	30.3	18.8	14.0	11.6
			LSD	0.6	0.4	0.2	0.2	0.2
				P				
Source of variation[3]								
T				0.237	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
E				**0.038**	**< 0.001**	**0.002**	**0.019**	0.471
LYS				0.466	0.936	0.250	0.487	0.167
T * E				0.247	0.184	0.662	0.487	0.182
T * LYS				0.220	0.424	0.449	0.296	0.053
E * LYS				0.224	0.847	0.865	0.482	0.243
T * E * LYS				0.079	0.438	0.346	0.783	0.145

1 Skinless and boneless Pectoralis major and Pectoralis minor.
2 Least significant differences of means (5% level).
3 Significant effects ($P < 0.05$) are printed in bold.

DISCUSSION

Turkeys exposed to high T consumed 13.7, 18.6, 26.5, and 24.7% less feed during the respective four age intervals after 28 d of age than those exposed to low T. The effect of high T on feed intake increased as turkeys grew older. Overall, feed intake was 22.8% lower among birds exposed to the high T than at the low T. This corresponded with a 2.3% decrease in feed intake for each degree C of increase within the range from 18 to 28°C. This response of feed intake to ambient temperature was similar to one observed in an earlier study with male turkeys exposed to ambient temperatures from 15 to 30°C (Veldkamp et al., Chapter 4). The decrease in feed intake was due to a cumulative effect of T and associated effects on depressing BW gain. Overall, turkeys exposed to high T expressed 19.7% less BW gain than those exposed to low T. This effect of high T on BW gain increased with increasing age, resulting in 9.4, 17.6, 19.7, and 29.7% lower BW gain during the successive age intervals, respectively. Temperature had a greater relative effect on feed intake than on BW gain until 112 d of age. Feed:gain ratio at high T was on average 11.6% lower than at low T. This implies that turkeys exposed to the high T converted the diets more efficiently into BW gain than those exposed to the low T in all age intervals, except from 113 to 140 d of age.

Feed intake decreased linearly in all age intervals as dietary E increased, regardless of the T regimen. Turkeys need a certain amount of energy for maintenance and production purposes and are able to consume an amount of feed that will meet this requirement. When high energy diets are fed, turkeys will decrease their feed intake to the point that their energy requirement has been met. Increasing dietary energy levels decreased feed intake linearly in all age intervals at both T. This response was more pronounced at low T than at high T, especially during the age intervals of 29 to 52 d and 53 to 84 d of age. During these age intervals, metabolic rate is very high because average daily gain and feather growth is maximized. As a consequence, metabolizable energy intake increased more at high T than at low T as E level increased. This response is in part a consequence of lowered heat increment and heat burden associated with high energy diets (Black, 1995). From 29 to 52 d of age feed intake decreased 18.0% at low T and 14.5% at high T as E increased from 90 to 110% of NRC (1994). However, ME intake was 1.6% lower at low T and 2.6% higher at high T as E increased from 90 to 110%. From 53 to 84 d of age, the difference was even larger. Feed intake during this age interval decreased 21.2% at low T and 12.2% at high T as E increased from 90 to 110% of NRC (1994), resulting in 5.6% lower ME intake at low T and 5.1% higher ME intake at high T. From 85 to 112 d of age, ME intake of birds at both T was higher as E increased from 90 to 110%. From 113 to 140 d of age, ME intake at E levels of 90 and 100% was equal at both T but increased as E increased further to 110%.

Body weight gain only responded to higher E levels until 84 d of age. Turkeys that were fed the high E level gained less weight in this age interval than those that were fed the low E level. Lysine content, as the first limiting amino acid for protein accretion in turkeys, was in this experiment higher than NRC (1994) recommendations. Veldkamp et al. (Chapter 4) reported that dietary lysine requirements until 56 d of age were higher than NRC (1994) recommendations. Although turkeys did not respond to extra dietary lysine, intake of other amino acids may have been limited due to the reduced feed intake at high E levels. Lehmann et al. (1997) concluded that the requirement for dietary threonine was almost equal to NRC (1994) recommendations at normal feed intake. In comparison to turkeys fed the 90% NRC level of E from 29 to 52 d of age for example, turkeys fed at the 110% level of dietary energy consumed 14.6 and 18.0% less threonine at high and low T, respectively. From 53 to 84 d of age, these differences were 10.6 and 19.7%, respectively. All experimental diets were formulated to provide at least 110% of NRC (1994) recommended amino acid levels other than lysine. In the present experiment, lysine did not seem to be the limiting amino acid because birds did not respond to extra dietary lysine content. With the decreased feed consumption, turkeys may have had a lack of threonine.

Feed:gain was greatly improved during all age intervals as dietary E level increased. Evidently, a lysine content in the diet of 105% of NRC (1994) recommendations was adequate because extra dietary lysine to 120% of NRC (1994) did not result in extra BW gain, although other amino acids may have become limiting.

High T had a negative effect on carcass yields as observed in earlier studies (Halvorson et al., 1991; Ferket et al., 1995). Relative cold carcass yields were not affected by T. Relative breast meat yields of turkeys exposed to high T were lower (29.1 vs. 31.6%, $P < 0.001$), and relative thigh (19.2 vs. 18.6%, $P < 0.001$), drum (14.6 vs. 13.5%, $P < 0.001$), and wing (12.1 vs. 11.1%, $P < 0.001$) yields were higher than those exposed to low T. The high E diets (110% of NRC (1994)) resulted in lower absolute breast meat weight (3.80 vs. 4.12 kg, $P < 0.001$) than the low E diets (90% of NRC (1994)). When the 90% and 110% E main effect treatments were compared, relative cold carcass (73.4 vs. 72.4%, $P = 0.038$) and breast meat yields (31.2 vs. 29.4%, $P < 0.001$) decreased, whereas relative thigh (18.6 vs. 19.2%, $P = 0.002$) and drum yields (13.9 vs. 14.2%, $P = 0.019$) increased.

Changes in dietary lysine had no effect on carcass yields. The depressed BW gain observed among turkeys fed the high-energy diets until 84 d of age may be associated to the reduced breast meat yields. Furthermore, amino acids other than lysine may have been insufficient to maximize breast meat yields due to the decreased feed intake at high energy contents. Lehmann et al. (1997) suggested that dietary threonine requirement for optimal breast meat may be higher than for optimal BW gain. In our study, significant T * E interaction effects were not observed in the carcass yield results.

In conclusion, the high T regimen decreased feed intake and BW gain, and resulted in relatively lower breast meat yields as expected. Overall, turkeys that consumed the high-energy diets had lower feed intake, but their BW gain was only marginally affected, resulting in a greatly improved feed:gain ratio. The effect of extra dietary energy (in the form of soybean oil) on feed intake was more pronounced among turkeys exposed to the low T than the high T regimen. The decrease in feed intake due to high-energy diets probably resulted in a deficiency of amino acids other than lysine because breast meat yield was negatively affected by high-energy diets. These results imply that when dietary lysine levels are adequate, dietary energy may be increased above NRC (1994) in order to improve the feed efficiency, but some of the limiting amino acids after lysine should be increased in high density diets to optimize breast meat yields.

REFERENCES

Adams, R. L., F. N. Andrews, E. E. Gardiner, W. E. Fontaine, and C. W. Carrick, 1962. The effect of environmental temperature on the growth and nutritional requirements of the chick. Poultry Sci. 41: 588-594

Bacon, W. L., A. H. Cantor, and M. A. Coleman, 1981. Effect of dietary energy, environment, and sex of market broilers on lipoprotein composition. Poultry Sci. 60: 1282-1286

Black, J. L., 1995. Modelling energy metabolism in the pig – critical evaluation of a simple reference model. Pages 87-102 *In*: Modelling growth in the pig. EAAP Publication No. 78. Ed. P. J. Moughan, M. W. A. Verstegen, and M. I. Visser-Reyneveld. Wageningen Pers, Wageningen, The Netherlands.

Centraal Veevoederbureau, 1999. Veevoedertabel: Gegevens over Voederwaarde, Verteerbaarheid en Samenstelling. Centraal Veevoederbureau in Nederland, Lelystad, The Netherlands.

Dale, N. M., and H. L. Fuller, 1979. Effect of diet composition on feed intake and growth of chicks under heat stress. I. Dietary fat levels. Poultry Sci. 58: 1529-1534

Dale, N. M., and H. L. Fuller, 1980. Effect of diet composition on feed intake and growth of chicks under heat stress. II. Constant vs. Cycling temperature. Poultry Sci. 59: 1434-1441

De Albuquerque, K., A. T. Leighton Jr., J. P. Mason Jr., and L. M. Potter, 1978. The effects of environmental temperature, sex and dietary energy levels on growth performance of Large White turkeys. Poultry Science 57:353-362.

Ferket, P. R., 1995. Nutrition of turkeys during hot weather. *In:* Eighteenth Technical Turkey Conference. Renfrew, Scotland.

Fuller, H. L., and G. Mora, 1973. Effect of diet composition on heat increment, feed intake, and growth of chicks subjected to heat stress. Poultry Sci. 52: 2029 (Abs.)

Fuller, H. L., 1981. The importance of energy source in poultry rations. Proceedings of the Maryland Nutrition Conference. pp. 91-95

Genstat 5 Committee, 1993. Genstat 5 Reference Manual. Release 3. Clarendon Press, Oxford, UK.

Halvorson, J. C., P. E. Waibel, E. M. Oju, S. L. Noll, and M. E. El Halawani, 1991. Effect of diet and population density on male turkeys under various environmental conditions. 2. Body composition and meat yield. Poultry Science 70: 935-940.

Mateos, G. G., J. L. Sell, and J. A. Eastwood, 1982. Rate of food passage (transit time) as influenced by level of supplemental fat. Poultry Sci. 61: 94-100

McNaughton, J. L., and F. N. Reece, 1984. Response of broiler chickens to dietary energy and lysine levels in a warm environment. Poultry Sci. 63: 1170-1174

Mickelberry, W. C., J. C. Rogler, and W. J. Stadelman, 1966. The influence of dietary fat and environmental temperature upon chick growth and carcass composition. Poultry Sci. 45: 313-321

National Research Council, 1994. Nutrient requirements of poultry. National Academy Press, Washington, DC.

Noll, S. L., M. E. El Halawani, P. E. Waibel, P. Redig, and K. Janni, 1991. Effect of diet and population density on male turkeys under various environmental conditions. 1. Turkey growth and health performance. Poultry Sci. 70: 923-934

Olson, D. W., M. L. Sunde, and H. R. Bird, 1972. The effect of temperature on metabolizable energy determination and utilization by the growing chick. Poultry Sci. 51: 1915-1922

Plavnik, I., E. Wax, D. Sklan, and S. Hurwitz, 1997. The response of broiler chickens and turkeys to steam-pelleted diets supplemented with fat or carbohydrates. Poultry Sci. 76: 1006-1013

Reece, F. N., and J. L. McNaughton, 1982. Effect of dietary nutrient density on broiler performance at low and moderate environmental temperatures. Poultry Sci. 61: 2208-2211

Sinurat, A. P., and D. Balnave, 1985. Effect of dietary amino acids and metabolisable energy on the performance of broilers kept at high temperatures. British Poultry Sci. 26: 117-128

Veldkamp, T., P. R. Ferket, R. P. Kwakkel, C. Nixey, and J. P. T. M. Noordhuizen, 2000a. Interaction between ambient temperature and supplementation of synthetic amino acids on performance and carcass parameters in commercial male turkeys. Poultry Sci. 79:1472-1477.

Veldkamp, T., R. P. Kwakkel, P. R. Ferket, P. C. M. Simons, J. P. T. M. Noordhuizen, and A. Pijpers, 2000b. Effects of ambient temperature, arginine-to-lysine ratio, and electrolyte balance on performance, carcass, and blood parameters in commercial male turkeys. Poultry Sci. 79:1608-1616.

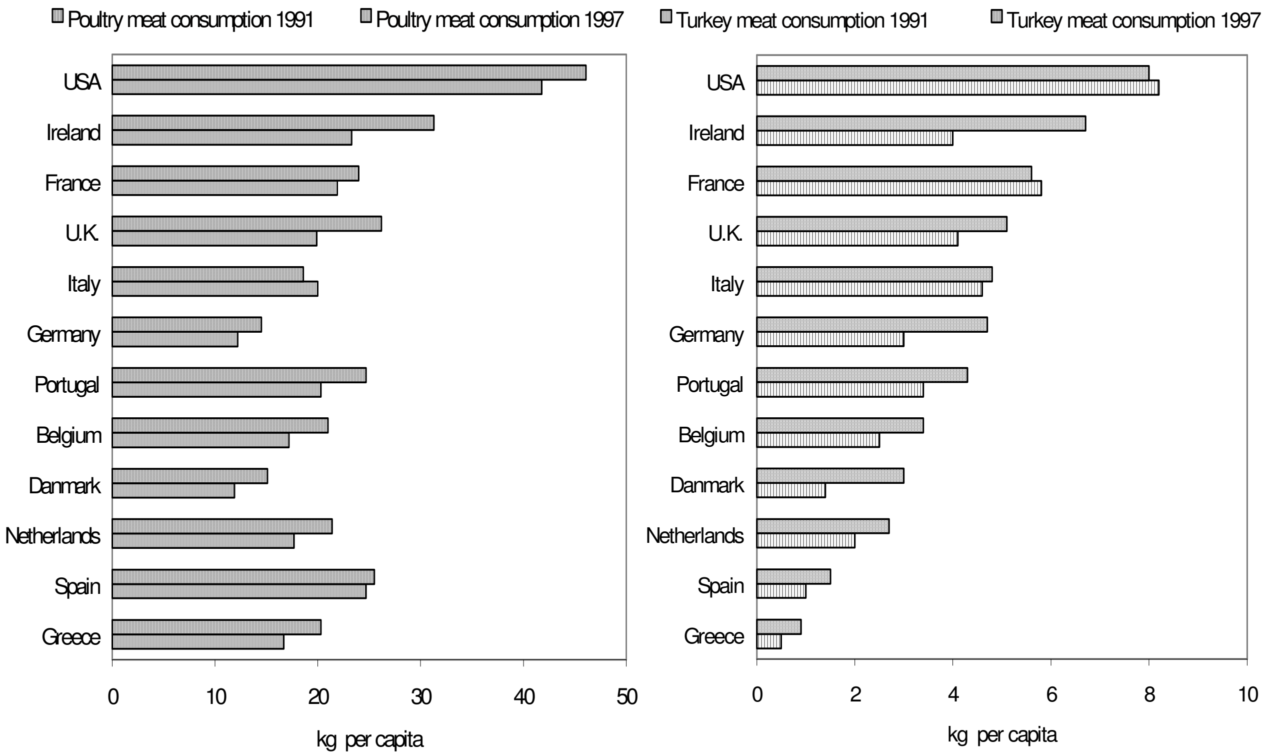
Veldkamp, T., R. P. Kwakkel, P. R. Ferket, M. W. A. Verstegen, 2002. Growth responses to dietary lysine at high and low ambient temperature in male turkeys. (Chapter 4 in this dissertation).

GENERAL DISCUSSION

GENERAL DISCUSSION

The world human population is expected to increase during the next twenty years by about 50 percent and individual income is expected to increase as well (Hudson, 1998). This population growth combined with the increased living standards and improvements of human diets will at least double the demand for food. Poultry meat consumption is increasing and world poultry production has doubled over the last 10 years. The changes in poultry and turkey meat consumption from 1991 to 1997 in different countries are presented in Figure 1. Turkey meat consumption follows the trend of poultry meat consumption.

Figure 1. Poultry and turkey meat consumption in different EU-countries and USA in 1991 and 1997 (Viandes, 1998).



The poultry industries will gradually move to regions of the world with low labor costs and less restrictive legislation in order to keep production costs competitive and food affordable. Many of these regions have long periods of high ambient temperatures that will have a negative effect on growth performance and carcass yield results. Also in established poultry areas with moderate temperatures, production efficiency during summer months is often decreased (Krueger, 2000).

Turkeys are very sensitive to ambient temperatures. In areas with high ambient temperatures throughout the year or in some seasons like spring, summer, or autumn, retarded body weight (BW) gain often occurs. Retarded BW gain results in lower breast meat yields (Veldkamp, 1990; Halvorson et al., 1991; Noll et al., 1991; and Krueger, 2000). Brake et al. (1995) observed a positive linear relationship between BW and breast meat yield. Therefore, it is very important to obtain high BW in turkeys to attain the maximum yield of breast meat, which is the most economically portion of the turkey.

Emmans (1989) calculated that turkeys would require temperatures between 10 to 12°C between 10 and 18 wk of age in order to dissipate heat produced by metabolism. However, temperatures in commercial turkey houses frequently exceed these values. Turkeys try to maintain body temperature constant and exhibit distinct behavior when temperature exceeds their thermal neutral zone. First of all, feed intake will decrease. This has a detrimental effect on BW gain and breast meat yield. A decrease in feed intake is a natural reaction to high ambient temperatures because activity of feeding and heat increment by digestion and anabolism of feed nutrients increases the birds' heat production (heat increment). Heat increment after feed consumption and during digestion depends on the chemical composition of the diet. For example, the average efficiency for energy utilization of different nutrients for different body functions is presented in Table 1.

Table 1. Estimates of the biochemical efficiency with which different nutrient classes are used for different metabolic purposes (adopted from Black, 1995).

Nutrient class	Energy yield (%)	
	ATP production	Lipid retention
Fatty acids	66	90
Glucose	68	74
Amino acids	58	53
Digested fiber	50	62

Also amino acid contents in the diet above requirement and imbalances between amino acids may increase heat increment. Minimizing excess dietary amino acids for turkeys is also desirable to reduce nitrogen emissions into the environment. Amino acid requirements should be known to adjust dietary formulations. In literature, only few studies investigated the effects of feed composition on performance and carcass yields when turkeys were grown under high temperature regimens. This dissertation will contribute to a better knowledge of how turkeys deal with high ambient temperatures and how they respond to differences in amino acid balances, lysine *per se*, and lysine to energy ratios, with the emphasis on performance and carcass composition. The objective is to derive from the results of the study more optimal amino acid compositions in the diet relative to energy at different ambient temperatures and weight ranges.

Ambient temperature during the rearing period (0-4 wk of age)

No information is available on the effect of temperature gradients at poult level during the rearing period. In Chapter 2, two different temperature (T) regimens were compared. In commercial practice, young turkeys are reared in a restricted area by use of wired rings to avoid poults easily moving away from feed and water sources. Moreover, the young turkey poult is not able to control its body temperature during the first days post hatching. Therefore, local heat devices above the middle of the rings provide supplemental heat. However, it is often questioned what temperature gradient should be provided from the center of the ring to the outside. In this experiment, a high or low T in the center of the ring was applied. The temperature in the center of the ring was equal for both temperature regimens from 0 to 21 d of age (gradually decreasing from 36 to 28°C). From 22 to 42 d of age, the center temperature at the high T treatment only decreased further to 27°C and at the low T treatment, the center temperature decreased to 22°C. Along the two center T regimens, two different T regimens outside the ring were applied. From 0 to 42 d of age, ambient temperature at the high T regimen, gradually decreased from 28 to 25°C and at the low T regimen from 23 to 15°C. This implies that on the first day of life, the ambient temperature gradient (from the center of the ring to the outside) at the low T regimen was 13°C and at the high T regimen only 8°C. The turkeys at the high T regimen had fewer opportunities to choose a temperature that met their requirement. During the first days after hatch, however, turkeys at the low T regimen showed crowding behavior below the heat device whereas turkeys at the high T regimen had spread out all over the ring. Apparently, the temperature gradient at the low T regimen decreased too much when moving from the center to the outside of the ring. Feed intake of turkeys at the high T regimen was lower and BW gain until 21 d of age was higher than turkeys at the low T regimen. This results in lower feed:gain ratios. Apparently, turkeys reared in the high T used less feed for maintenance than those reared in the low T regimen in order to maintain body temperature. The results from this study implied that poults preferred a temperature gradient of 8°C (36-28°C) above that of 13°C (36-23°C).

Ambient temperature during the growing and finishing period (5-20 wk of age)

In the Chapters 2 to 5, four different nutritional experiments with high and low ambient temperatures (T) were presented. When turkeys were exposed to high T for long periods, it was clear that this had a tremendous suppressing effect on feed intake and BW gain (Figures 2 and 3). Ambient temperatures and humidity were held constant throughout the day in all four experiments. It was assumed that the effects of nutrition would be more pronounced under constant than under diurnal cycling T regimens, because of a lack of adaptive capacity to recover from over-heating. One should consider this feature of the heat exposure when results from these studies are to be interpreted and applied to commercial practice.

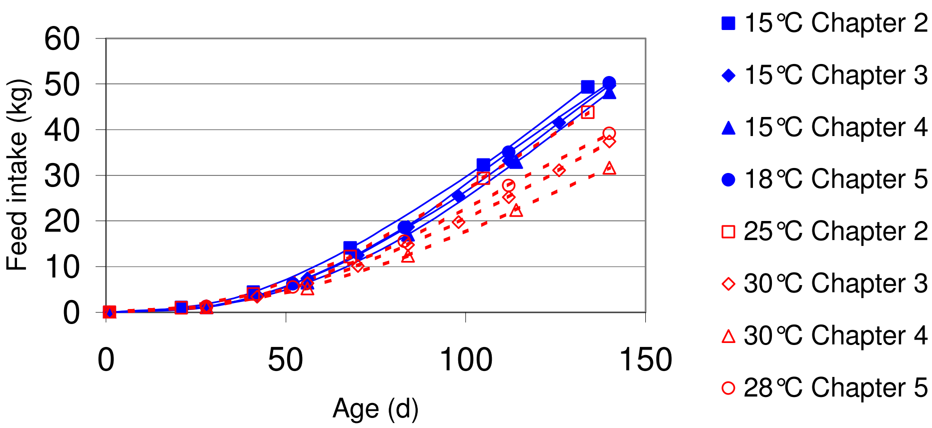


Figure 2. Cumulative feed intake of male turkeys from hatch to slaughter (134 or 140 d of age) at high and low ambient temperature.

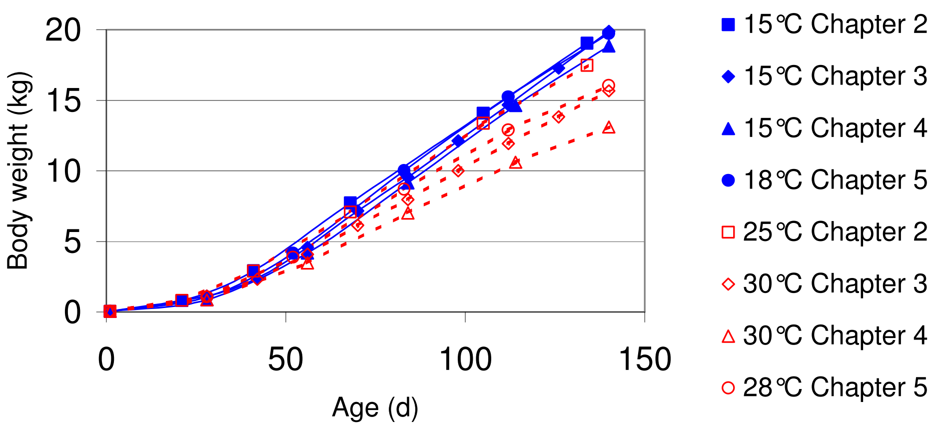


Figure 3. Cumulative BW of male turkeys from hatch to slaughter (134 or 140 d of age) at high and low ambient temperature.

In an experiment of Noll et al. (1991) and Halvorson et al. (1991), cycling temperatures resulted in intermediate performance results and carcass yields (the mean of constant high and low temperature) compared to constant high or constant low temperatures. These results agree with the observations by Hurwitz and Ben-Gal (1982), who suggested that the upper temperature should not exceed 30°C. Relative humidity in Chapter 2 was maintained at 60% by 25°C and at 80% by 15°C to simulate an average summer and winter condition in Western Europe. In Chapters 3 and 4, birds were subjected to severe heat stress by inducing a high ambient temperature of 30°C relative to a low ambient temperature of 15°C. In Chapter 5, the high and low ambient temperatures were 28 and 18°C, respectively, due to technical limitations of the climate-controlled house in relation to the season of the year during which the experiment was conducted. Relative humidity in Chapters 3 to 5 was maintained at a constant 70% at both temperatures. The higher relative humidity of 70% at high temperatures compared to that used in Chapter 2 (60% humidity) made it more difficult for the birds to dissipate heat. Literature is scarce on the effect of relative humidity on performance of turkeys. In 5 to 8-wk-old turkeys, no effect of relative humidity (40 to 75%) was observed at an ambient temperature of 30°C (Yahav et al., 2000).

The means for feed intake and BW of turkeys per temperature treatment in the Figures 2 and 3 were within each experiment averaged over the different nutritional treatments. It may be concluded that the smaller negative effect of a high T on feed intake and BW gain in Chapter 2 (15-25°C) as compared to the other Chapters (15-30°C; 18-28°C), may be due to the smaller difference between temperatures and the absolute temperature settings.

Feed intake was decreased by 1.1, 1.7, 2.3, and 2.3 % for each degree Celsius increase within the temperature ranges from 15 to 25°C, 15 to 30°C, 15 to 30°C, and 18 to 28°C, used in the Chapters 2 to 5, respectively. Apparently, temperatures above 25°C had a great effect on feed intake (see also Figure 2). Rose and Michie (1987) reported a decrease in feed intake of 1.2% per degree Celsius increase from 14 to 23°C. Noll and Waibel (1989) had observed a decrease in feed intake of 1.0% per degree Celsius increase from 7 to 20°C and 1.5% per degree Celsius increase from 20 to 26°C. This means that feed intake decreased more rapidly at higher temperatures (Figure 4).

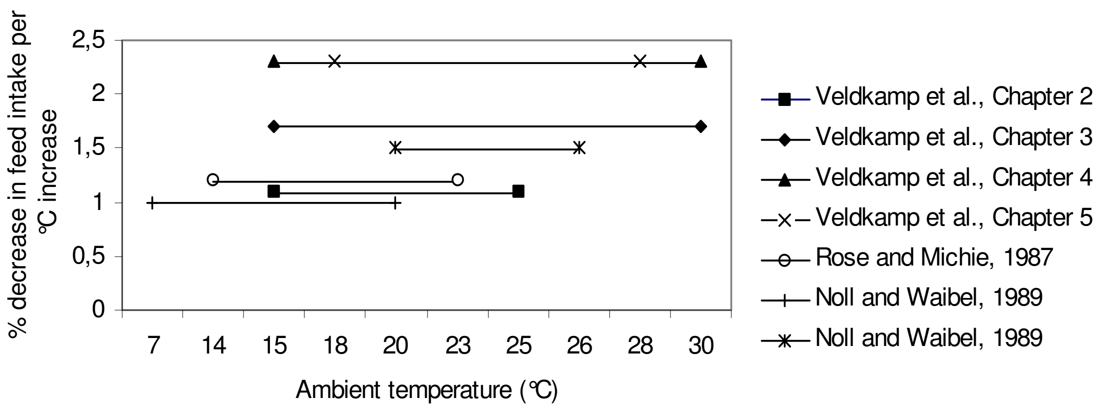


Figure 4. Decrease in feed intake (% per °C) as ambient temperature increases (°C), as observed in different studies.

The reduced feed intake resulted in a decrease in BW gain of 0.8, 1.5, 2.1, and 2.0 % for each degree Celsius increase in temperature in the subsequent Chapters. In general, the negative effect of high T on feed intake and BW gain increased as age increased. Overall, the decrease in BW gain per degree Celsius increase was less than the decrease in feed intake, which implies that turkeys at higher T had higher feed efficiencies (lower feed:gain ratios). However, it should be noted that feed efficiency in all Chapters was lower at the high T regimen from 112 d of age to slaughter. Apparently, turkeys at this age with lower feed intake will necessarily use a larger part of energy intake for maintenance, and thus less energy remained for processes of protein and lipid accretion. This phenomenon was illustrated by Fuller and Dale (1979), who conducted an experiment with broilers to determine the influence of feed intake on performance in a hot or cool environment. Broilers were fed *ad libitum* in both environments, and a group in the cold environment was limited to the amount of feed consumed by the broilers in the hot environment. Body weight gain was depressed by 25% in the hot environment. However, when pair-fed broilers reared in the cool environment were fed the same amount of feed as consumed by the broilers in the hot environment, performance was reduced by only 16% compared to chickens fed on an *ad libitum* basis. Thus the heat load caused an extra energy requirement. Limiting feed intake alone did not result in an equal reduction in performance as the birds maintained in a hot environment with the same level of feed intake. High environmental temperature imposed limitations on the performance of broilers that were not completely related to feed intake. In the study of Fuller and Dale (1979), 16% of the depression in BW gain was due to the reduced feed intake and 9% was due to heat stress.

Carry-over effects

Carry-over effects may be a factor of importance when interpreting the results of separate age intervals as done in this dissertation. For example, efficiencies of utilization of dietary lysine, observed as performance during a certain age interval might have been influenced by the diets previously fed to the turkeys. Because of their long growing period, it is most feasible to present turkeys diets that satisfy their nutritional requirements as feed phases of three to four weeks in duration. Therefore, the most appropriate way to develop a feeding program of sequential diets is to determine the requirements for optimum growth performance during each age interval. This very expensive and tedious approach, however, would require an excessive number of experimental animals. Re-randomizing the birds at the start of each age interval could be an option, but an increased variance within experimental units would certainly influence the power of the experiment and ability to detect significant treatment effects. In the present study, the emphasis was more on observing responses rather than determining requirements. Therefore, cumulative effects were studied in all experiments. Only in Chapter 4 were requirements for dietary lysine per age interval estimated.

Supplementation of synthetic amino acids

To achieve the turkey's genetic potential for growth and breast meat yield, both an appropriate dietary level and balance of amino acids are necessary. High temperatures adversely affect turkey growth performance, feed intake being most pronounced. In Chapter 2, we hypothesized that turkeys exposed to high ambient temperatures require higher dietary amino acid contents to compensate for the reduced protein intake associated with the reduced feed intake. Therefore, an experiment was designed with two experimental diets. Dietary energy and amino acid contents recommended by the breeder[1] were used to formulate a basal diet to which 10% extra lysine and methionine was supplemented from 22 d of age to slaughter and 10% extra threonine was supplemented from 22 d to 69 d of age. The age intervals for the feed phases used in these studies were different from those used in the NRC (1994) publication. In comparison to the NRC (1994) recommendations, the basal diets used in this study contained about 10, 8, 10, and 20% higher dietary lysine, about 15, 25, 37, and 50% higher methionine+cystine, and about 13, 12, 12, and 14% higher threonine during the feed phases of 22 to 41 d, 42 to 68 d, 69 to 105 d, and 106 to

[1] British United Turkeys Ltd., Hockenhull Hall, Tarvin, Chester CH3 8LE, UK.

134 d of age, respectively. In contrast, dietary energy contents of the diets were similar to NRC (1994) recommendations. The high initial amino acid contents in the basal diet had a great impact on the responses of turkeys that were fed 10% extra dietary lysine, methionine, and threonine.

From 22 to 41 d of age, turkeys reared in low T responded to amino acid supplementation, whereas no response was observed among those reared in high T. This response indicates that dietary amino acid requirements for turkeys reared in low T may be increased, because protein content in the basal diet was not sufficient for optimal BW gain. Those turkeys in the low T environment may have had insufficient dietary protein to sustain processes of protein accretion, whereas the protein content in the basal diets was sufficient for production of turkeys exposed to the high T. It seems to be a matter of sufficient energy to protein ratio at each of the intake levels and weight (age) classes. From 69 to 105 d of age, feed efficiency of turkeys at high T that were fed the amino acid-supplemented diets was lower than that of turkeys fed basal diets, mainly due to a decrease in BW gain. When turkeys in this age interval did not deposit the extra lysine and methionine+cystine into body tissue, these amino acids are catabolized and the excess nitrogen is excreted. In birds, excess nitrogen is combined with glycine to form uric acid formation before it is excreted. Glycine can be converted from serine which in turn can be converted from threonine (Bender, 1985). Thus, when a relatively large excess of nitrogen must be excreted and there is not enough glycine or serine available, non-productive threonine requirement may be increased (Ten Doeschate, 1995). In the present study, the supplemented diet had sufficient threonine only until 68 d of age and not thereafter.

Generally, ME intake of turkeys reared in the high T was lower than those reared in the low T. The lack of benefit for amino acid supplementation of the birds subjected to the high T could maybe explained by the low absolute amount of ME consumed. Those birds had not enough energy to use for production purposes. Moreover, extra heat increment with extra amino acids probably occurred because 1) the control basal diets already had sufficient amino acids to satisfy nutritional demands at high T, or 2) the supplementation of synthetic lysine caused an imbalance with other amino acids, such as arginine (Brake et al., 1994), or 3) the energy content of the diet was not sufficient at high T due to the use of extra energy to dissipate heat. An imbalance of amino acids can contribute to an increased dietary heat increment, which aggravate the extra negative effect of high temperatures.

No significant temperature * diet interaction effects were observed for carcass yields. Brake et al. (1995) and many other authors observed a positive relationship between BW gain and breast meat yields, but this was not confirmed in this experiment. Turkeys exposed to the high T and fed the amino acid-supplemented diets had retarded BW gain (not significant) after 69 d of age without an effect on their carcass yields. Probably, when growth was depressed in the second part of the production curve (after 70 d of age), carcass yields as a % of cold carcass weight are not as much affected as during early growth. Breast meat yields were lower, and drum yields were higher in turkeys at high T than in turkeys at low T. Based on the results of Chapter 2, new experiments were designed to study the effect of arginine to lysine ratios (Chapter 3), the effect of lysine content *per se* (Chapter 4), and energy to lysine ratios (Chapter 5) on performance and carcass yields at high and low T.

Arginine to lysine ratios and electrolyte balance

Arginine not only has a function in structural proteins but it is also involved in a number of crucial metabolic processes. In the uric acid pathway, it enables the disposal of excess amino acid nitrogen (Ferket et al., 1998). Arginine is also a precursor of nitric oxide (NO), which plays an important role in vasodilatation of peripheral blood vessels and helps to dissipate heat (Moncada et al., 1991). Jones (1961), and D'Mello and Lewis (1970) demonstrated an antagonistic interaction between lysine and arginine. A decreased digestibility of some amino acids has been noted in animals exposed to high environmental temperatures. High ambient temperatures might alter relative gut absorption of certain amino acids and induce a plasma imbalance of amino acids that might decrease performance and thermal tolerance in turkeys. Therefore, sufficient dietary arginine is important at high ambient temperatures because its availability from dietary sources may be decreased or its metabolic requirement may be increased.

A proper dietary electrolyte balance is important to maintain physiological functions in poultry during hot weather. Increased respiration rate necessary for evaporative cooling results in carbon dioxide loss, which will cause lower carbon dioxide levels in the blood. As a result, the bicarbonate level in the blood will decrease and the body will lower the sodium content. Arginine to lysine antagonism can be exacerbated by excess anions, such as chloride, and this can be ameliorated by cations, such as sodium and potassium (Ferket et al., 1998).

In Chapter 3, we hypothesized that higher dietary arginine to lysine ratios could alleviate the adverse effects of high T and that dietary electrolyte balance could modulate this effect. However, the results in this Chapter did not show that altering the arginine to lysine ratio or changing the dietary electrolyte balance could partly or completely prevent the impaired performance in turkeys subjected to high T. A high arginine to lysine ratio was beneficial only during the early part of the growing period.

A high dietary arginine to lysine ratio (1.25:1) increased feed intake significantly by about 1.5% from 29 to 56 d of age. This effect was most pronounced (2.8%) among turkeys subjected to low T, as indicated by the significant temperature * arginine to lysine ratio interaction. Body weight gain was significantly increased by about 1.9% until 98 d of age when turkeys were fed a high arginine to lysine ratio, but no effects of arginine to lysine ratios were observed subsequently.

The lack of an effect of higher arginine to lysine ratio after 10 weeks may be explained by two reasons: Firstly, the source of arginine used in this study differed from sources used by others who actually found more pronounced effects of an increased arginine to lysine ratio. A differential rate of absorption between free and protein-bound amino acids may have had a major impact on the utilization of arginine. Brake et al. (1994) reported that arginine uptake capacity was not significantly different from that of lysine under thermal neutral conditions. However, under conditions of heat stress, uptake capacity for lysine may have increased while that of arginine was not. A reduced uptake of arginine could occur in poultry subjected to heat stress conditions when arginine is in competition with lysine. Brake et al. (1994) and Kroon and Balnave (1996) observed an improved feed efficiency of broiler chickens that were heat stressed at 32℃ when the arginine to lysine ratio exceeded 1.2:1. In contrast, Mahmoud et al. (1996) and Mendes et al. (1997) found no effect of the arginine to lysine ratio greater than 1:1 on performance of broilers grown at thermal neutral or heat stress conditions. Brake et al. (1994), and Kroon and Balnave (1996) increased dietary arginine to lysine ratio by modifying dietary ingredient inclusion levels, whereas Ferket et al. (1995), Mahmoud et al. (1996), and Mendes et al. (1997) used synthetic arginine. Secondly, after 70 d of age, dietary lysine contents were probably not insufficient. The conclusion of England et al. (1996) and Waldroup et al. (1998) that increased dietary arginine to lysine ratios only improves performance when lysine content of the diet is low was confirmed in our experiment. Dietary lysine contents in the experimental diets were low as compared to NRC (1994) until 70 d of age and this was also the period when a higher arginine to lysine ratio resulted in a higher BW gain.

Dietary electrolyte balance did not affect performance at all. Under more thermal neutral conditions, Kidd and Kerr (1998) observed a significantly higher feed efficiency when dietary electrolyte balance was increased (148 vs 202 meq/kg). Under heat stress circumstances, however, Brake et al. (1994) reported lower feed efficiencies in turkeys that were fed 250 meq/kg compared to those that were fed 150 meq/kg.

Arginine to lysine ratios did not affect carcass yields, although BW gain during the first part of the growing period (until 70 d of age) was improved by the higher arginine to lysine ratios. Probably, the BW gain response of turkeys to higher arginine to lysine ratios during the early growth period was not carried over to the end of the growing period and expressed as increased carcass yield.

In general, an increased dietary arginine to lysine ratio did not alleviate the adverse effects of a high T on performance of turkeys in this experiment. A beneficial effect of a high dietary arginine to lysine ratio may only be significant when dietary lysine levels are deficient or when dietary electrolyte balance is low (e.g., < 150 meq/kg). In this experiment blood parameters were also evaluated to study the effects of dietary arginine to lysine ratios and electrolyte balances on immunity.

Blood parameters

Dietary arginine is a precursor of nitric oxide (NO), which plays a key role in the immune system (Moncada et al., 1991; Sung et al., 1991). Improvements in immunity, as affected by dietary arginine in animals including humans, include improved thymic weight and function, enhanced lymphocyte mitogenesis, improved immunity against tumors, and enhanced wound healing have been reported (Efron and Barbul, 1998; and Evoy et al., 1998). Qureshi (1998) also reported that higher arginine to lysine ratios at high T may enhance the cell-mediated immunity of turkeys. In our experiment, we have studied the humoral immunity. The HI-NCD titers in the experiment in Chapter 3, however, were not affected by a higher arginine to lysine ratio. Kidd et al. (2001) studied the SRBC-response in broilers when fed different arginine contents. They also did not observe a response and explained this by the fact that the arginine content in the basal diets was high enough. Apparently, dietary arginine levels close to the NRC (1994) recommendation (as in our study) should support a proper humoral immune function in healthy turkeys.

High T resulted in our experiment in significantly lower hematocrit values in turkeys as compared to the low T. Parker and Boone (1971) also found significantly lower hematocrit levels in heat-stressed adult turkeys. Parker and Boone (1971) reported no effect on blood pH when birds were exposed to heat stress for more than 21 d (chronic hyperthermia). Kohne and Jones (1975a) reported that acute hyperthermia produced alkalosis but chronic hyperthermia (Kohne and Jones (1975b) had no effect. In our experiment, turkeys were also subjected to chronic heat stress. The lack of an alkalosis is consistent with the results of Kohne and Jones (1975b). Values for pCO_2 and HCO_3^- in the blood were not affected in our experiment. Apparently, turkeys are able to adapt to a situation of chronic heat stress by changing their metabolic rate.

Dietary lysine

The estimated lysine requirements in Chapter 4 are presented as a percentage of lysine in the diet. Whenever nutrient requirements are presented as a proportion of the diet, feed intake should be taken into account before they are used in practical formulations. Although feed intake is influenced by several factors, the most important are: (1) dietary energy content, (2) form of the diet (mash, crumbs, or pellets) and (3) ambient temperature. Differences in dietary energy are accounted for, if one expresses lysine requirements in terms of g lysine/MJ ME (Nixey, 1991), as is mentioned in Chapter 4. Moreover, Nixey (1991) stated that the influence of ambient temperature is an additional cause of weakness in defining lysine requirements in terms of g lysine/MJ ME. The requirement relative to dietary energy content will change according to ambient temperature. For example, the g lysine intake requirement increases as ambient temperature increases to counteract for the reduced feed intake due to the lowered ME-requirement to maintain body temperature (Nixey, 1991). Thus, the requirement can be calculated if feed intake at different temperatures is known. Ambient temperature during response experiments should always accompany the requirement presented as g lysine/MJ, in addition to feed intake at each weight class.

From the experiments described in Chapter 2 and 3, there was no clear response to a higher dietary amino acid content at high T and there was no beneficial effect of a higher dietary arginine to lysine ratio on performance, respectively. These observations were probably due to already adequate dietary lysine contents in the basal diets. Based on the results of these two experiments, a third experiment (Chapter 4) was designed to test the response of commercial male turkeys to dietary lysine in high and low T regimens.

Results from Chapter 4 showed that feed intake and lysine intake were decreased by high T (Figure 5). If turkeys are kept under high T conditions (relative to low T), high lysine concentrations in the diet do not fully compensate the decrease in feed intake to catch up with levels of dietary lysine intake per day under low T. The energy demand of turkeys at high T is lower than of those at low T and therefore less feed was consumed. As a consequence dietary lysine intake was lower.

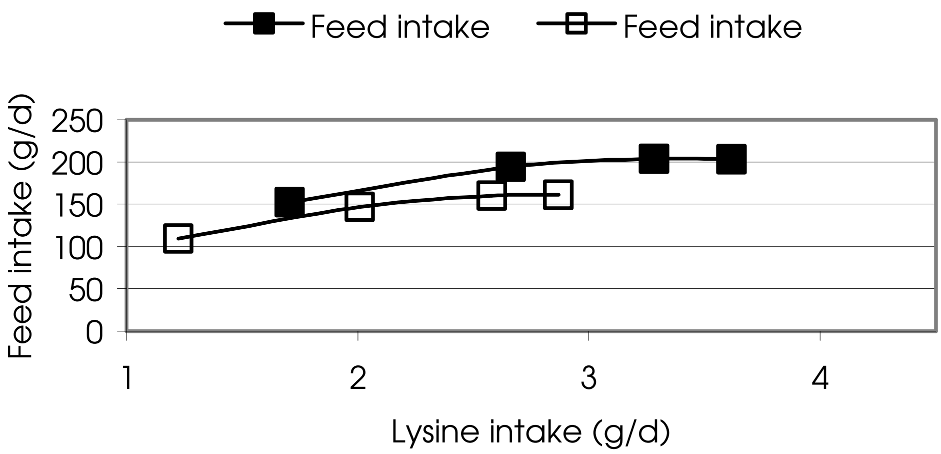


Figure 5. Feed intake response to dietary lysine at high (open signs) and low (closed signs) ambient temperature in the age interval from 29 to 56 d of age.

In Figure 5, the results for the age interval of 29 to 56 d of age were presented, but as turkeys grew older, feed intake of birds was more affected by high T. Turkeys in the age interval of 115 to 140 d of age at high T fed the *highest* lysine concentrations hardly achieved the dietary lysine intake of turkeys that were fed the *lowest* lysine concentrations at low T.

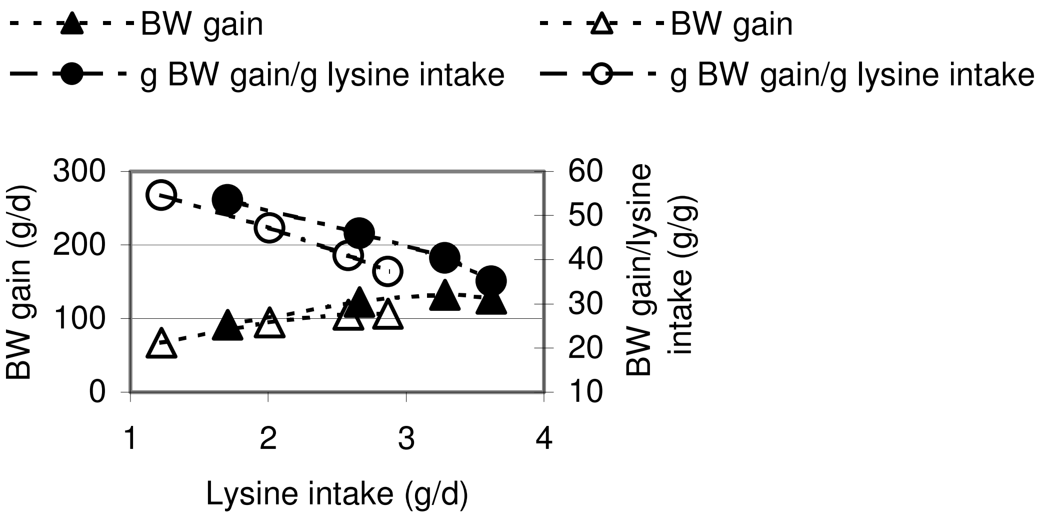


Figure 6. Body weight gain response to dietary lysine intake and BW gain per g lysine intake at high (open signs) and low (closed signs) in the age interval from 29 to 56 d of age.

Data in Figure 5 show that feed intake at high T was reduced and also that at the same total lysine intake, feed intake was also less at high T. This means that the non lysine intake of birds was more influenced at high T than the lysine part. It is obvious that this is energy because of its relation with heat loss and heat stress.

The relationship between lysine intake per day and BW gain per day was similar for high and low T, although BW gains at high T were somewhat lower than at low T (Figure 6). At a certain level of lysine intake per day, lysine efficiency was better in the low T birds compared to the high T birds. Data in Figure 6 show that BW gain at the medium lysine intake in high T is somewhat less than at a similar intake in low T probably caused by an energy deficiency. This is also reflected in a reduced BW gain per lysine intake in high T at the higher lysine intakes.

Turkeys at high T produce on a lower level because they reduce energy intake to avoid extra heat production. When birds are suffering from severe heat stress, they will try to slow down metabolism by producing on a lower level. This seems to be a strategy to balance the thermoregulatory mechanisms in order to survive severe heat stress. Production level of turkeys under high T regimen was decreased and feed intake, BW gain, feed:gain ratio of turkeys responded similarly to changes in dietary lysine concentration as in turkeys on low T. Exponential curves for the different parameters were fitted parallel in Chapter 4. This similar response illustrates that the birds were able to adapt to high T by lowering their feed and dietary lysine intake. From Figure 6 it may be concluded that slow growing turkeys in high T need a lower dietary lysine to energy ratio to reach similar lysine efficiencies. This will lower dietary lysine intakes. Turkeys at high T seemed to have a lack of energy to use the extra dietary lysine for protein accretion.

From Figure 6 it can also be concluded that lysine efficiency decreases as dietary lysine intake increases. This confirms the general statement that birds use nutrients more efficient when low levels were provided.

In this experiment, a positive linear relationship was observed between BW gain and breast meat yields (Figure 7). This confirms the results reported by Brake et al. (1995). An interaction effect has been observed for breast meat yields: breast meat yields gave a higher response to increasing levels of dietary lysine among turkeys reared in the low than in the high T regimen. Turkeys in the high T regimen allocate protein to other protein stores than breast meat.

Figure 7 also suggest that the preference for using nutrients and energy for breast meat is less at a slower growth rate. At the higher growth rate breast meat is deposited with more relative preference than other parts of the body.

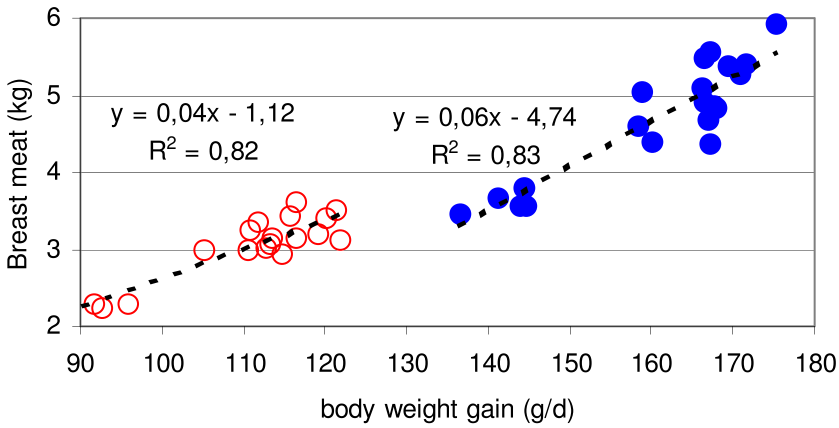


Figure 7. Breast meat yield response to an increase of BW gain at high (open signs) and low (closed signs) ambient temperature.

The absolute amount of dietary energy intake may have influenced the growth responses in Chapter 4. Dietary energy contents may have had a considerable influence on feed intake and herewith also on dietary lysine intake. The energy contents in the diets after 28 d of age were higher than recommended by NRC (1994) to be sure that energy was not the limiting factor for optimal growth performance. High dietary energy contents, however, adversely affected feed (nutrient) intake in high T more than in low T. In the experiment discussed in Chapter 5, turkeys responded differently to changes in lysine to energy ratios when those were reared in high and low T.

Dietary lysine to energy ratios

In Chapter 5, different dietary lysine to energy ratios were investigated in turkeys reared in high and low T. Dietary energy plays an important role in the effectiveness of converting amino acids into body protein (growth). In an experiment conducted by Meyer (1999), increasing dietary energy (about 90% of NRC (1994) recommendations) by 5% resulted in an overall 4.5% better feed efficiency, due to a reduced feed intake at a similar BW gain. Furthermore, a higher BW gain was observed in young turkeys fed the lowest energy level until 63 d of age. However, this experiment was conducted at moderate temperatures.

In the experiment discussed in Chapter 5 it was questioned whether young turkeys need a higher lysine to energy ratio (by lowering the energy level) due to the fact that feed intake capability is limited at early ages. Moreover, young turkeys need high levels of lysine (Chapter 4). Older turkeys may need lower lysine to energy ratios because they need sufficient energy to sustain maximal protein accretion during heat stress. They eat less energy and therefore have a relative larger part of dietary energy for maintenance. This part will need less protein compared to the part used for gain. In addition heat stress may require some additional energy for thermoregulatory efforts to get rid of the heat.

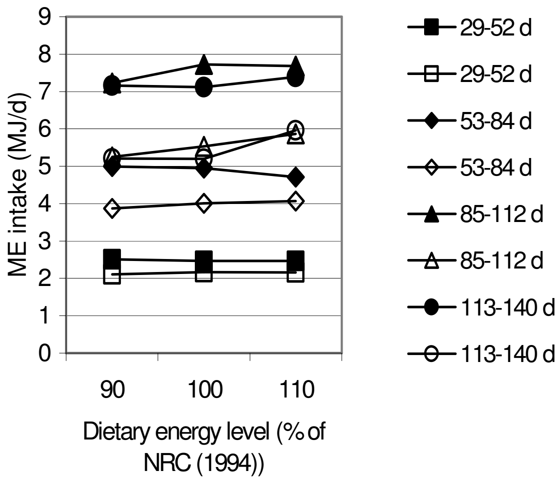


Figure 8. Metabolizable energy intake at different dietary energy levels at high (open signs) and low (closed signs) ambient temperature per age interval.

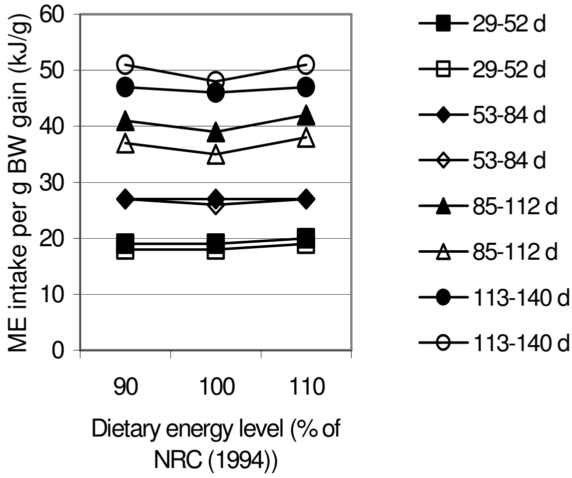


Figure 9. Metabolizable energy intake per g body weight gain at high (open) and low (closed signs) ambient temperature per age interval.

Based on the results reported in Chapter 5, turkeys evidently regulate their feed intake to meet the energy requirements. In general, increasing dietary energy levels resulted in decreased feed intake because energy requirements were met with the lower feed intake of high-energy diets.

The effect of a higher dietary energy level on the decrease of feed intake was more pronounced at low than at high T from 29 to 52 d and 53 to 83 d of age. This was also illustrated by the decrease in ME intake of turkeys exposed to low T and the increase in ME intake of those exposed to high T, as dietary energy level increased from 90 to 110% during these age intervals (Figure 8). Metabolizable energy intake per g BW gain was similar at high and low T during these periods (Figure 9). So, the extra ME intake at high T was used for BW gain primarily.

From 85 to 112 d of age, feed intake also decreased as dietary energy concentration increased, but turkeys decreased their feed intake as dietary energy increased regardless of the ambient temperature (no temperature * energy interaction effects were observed). Metabolizable energy intake at low T increased only when dietary energy was increased from 90 to 100%, whereas ME intake at high T increased when dietary energy was increased from 90 to 110% (Figure 8). From 85 to 112 d of age, the turkeys did not show a response in BW gain when dietary energy increased, so an extra energy intake was used for maintenance purposes. Metabolizable energy intake per g BW gain was lower at high than at low T from 85 to 112 d of age (Figure 9). As observed during the earlier age intervals, turkeys kept at high T used less energy for maintenance than turkeys at low T.

During the age interval from 113 to 140 d, the results were considerably different than observed during earlier age periods. Feed intake was decreased at low T when dietary energy increased from 90 to 100% of NRC (1994) recommendations, whereas no clear feed intake response was observed to increasing dietary energy at high T. Dietary energy hardly affected ME intake of turkeys at low T, whereas an increase of dietary energy from 100 to 110% resulted in a 15% higher ME intake of birds at high T (Figure 8). The turkeys reared in high T probably used extra dietary energy for panting and other heat-dissipation activities during this age period, as illustrated by the higher amount of energy intake per g BW gain (Figure 9). These turkeys produce less heat per kJ extra ME intake. Body weight gain was not affected by dietary energy level.

Feed:gain ratio of turkeys was lower at the high T until 112 d of age. However, in the period from 113 to 140 d of age, feed:gain ratios tended to be higher at high than low T. This illustrates again that turkeys during this age interval had used extra energy for maintenance rather than for production purposes due to panting behavior, if kept under heat stress conditions. Feed:gain ratio was significantly influenced by dietary energy level. An increase of dietary energy level resulted in a remarkable decrease of feed:gain ratio. The decrease in feed:gain ratio was more pronounced among turkeys reared in the low than in high T from 29 to 52 d and 53 to 84 d of age.

Generally, dietary lysine level did not affect performance results in this experiment, so dietary lysine at 105% of NRC (1994) recommendations met the requirements for optimal growth performance.

Breast meat yields were lower at high T due to a decrease in BW gain. An increase in dietary energy decreased breast meat yields more than BW gain, in favour of increased thigh and drum yields. The decrease in breast meat yields may be explained by the decreased BW gain during the age intervals of 29 to 52 d and 53 to 84 d of age when dietary level was increased. Feed intake was reduced when turkeys were fed high-energy diets. Because turkeys did not respond to extra lysine during these periods, amino acids other than lysine were assumed to be limiting or the energy supply. No two or three-way interaction effects on carcass yields were observed.

Practical implications

Based on the results of this dissertation it may be concluded that turkeys reared in high T had adapted to chronical heat stress very effectively. By lowering their feed intake, turkeys had a lower body weight. This is associated with a reduced metabolic rate and contributed to the survival strategy of the birds. Low feed intake means: Low digestion rate, low metabolic rate, and low heat increment. Birds try to avoid the panting because this requires extra energy intake. Turkeys reared in a high T environment have lowered their protein accretion and produce as efficient as turkeys in low T. It is very difficult to influence biological processes by dietary adjustments.

Nutritional information on feeding commercial turkeys is available from many different sources, including primary breeder organizations, research stations, and feed manufacturers. Nutritional recommendations however, vary significantly among the different sources. Independent turkey farmers or integrated turkey companies must consider specific production objectives and economic situations before deciding which specific feed program is most beneficial. This economic consideration is clearly demonstrated by Douglas (1997). General diets for Europe and USA were formulated using North American ingredient costs. The USA feeding program resulted in a lower feed:gain ratio (0.25) over the European feeding program due to higher dietary energy contents. However, high protein (lysine) in the European program resulted in 0.8% more breast meat yield than the American program. By use of an economic calculation program, it was demonstrated that the European program cost $0.30 USD more to produce a male turkey of 14.5 kg. In Europe, however, turkeys are grown to heavier market weights because of the difference in costs of protein and energy and the market of breast meat (Ferket, 2000). In the USA where maize is only half the price of soya, protein ingredients are much more expensive relatively than energy. In contrast, energy is expensive relative to protein in Europe because of the ample regional supply of protein by-products and the low-energy grains. In addition, high-energy corn must be imported from the USA. The formulations and lysine to energy levels reflect these economic factors, as demonstrated in feed compositions for both regions in Tables 2 and 3.

Table 2. Typical dietary composition for commercial male turkeys in Southeast USA (Ferket, 2000).

Feed phase	1	2	3	4	5	6	7
Feeding period (wk)	0-3	4-6	7-9	10-12	13-15	16-18	19-21
				(g/kg)			
MJ ME/kg	12.14	12.77	13.19	13.61	14.24	14.65	14.86
Crude fat	40	60	80	95	100	110	120
Crude protein	280	260	230	210	190	170	150
Arginine	19.5	18.0	16.5	15.0	13.5	11.5	10.0
Lysine	18.0	16.5	15.0	13.5	12.0	10.5	8.0
Methionine	6.5	6.0	5.5	5.0	4.5	4.0	3.5
Methionine+Cystine	12.0	11.0	10.0	9.0	8.0	7.5	6.0
Threonine	11.0	10.0	9.0	8.5	7.5	6.5	5.5

Table 3. Typical dietary composition for commercial male turkeys in Europe (Ferket, 2000).

Feed phase	1	2	3	4	5
Feeding period (wk)	0-4	5-8	9-12	13-16	17-market age
			(g/kg)		
MJ ME/kg	11.93	12.56	13.40	13.82	14.03
Crude fat	60	80	115	110	115
Crude protein	300	270	240	210	190
Arginine	21.0	18.5	16.0	13.5	11.8
Lysine	19.0	17.0	15.0	13.0	11.0
Methionine	7.5	7.0	6.5	6.0	5.0
Methionine+Cystine	12.0	11.0	10.0	9.0	8.0
Threonine	11.5	10.5	9.0	8.0	7.0

In all experiments it is clear that high ambient temperatures had a great impact on performance and carcass yields of male turkeys. The optimum temperature for growing and finishing turkeys is 15°C or lower. Higher contents of dietary lysine, methionine+cystine, and threonine to compensate for the lower feed intake did not have a positive effect on performance and carcass yields, provided that the basal diets contained sufficient contents of these amino acids. When dietary lysine contents were marginal relative to NRC (1994), a significant effect of a higher arginine to lysine ratio was observed. A minimum arginine to lysine ratio of 1.25 should be fixed in diet formulation when dietary lysine is limiting to avoid a deficiency of arginine. If lysine contents in the diets are sufficient (meeting or exceeding NRC (1994) recommendations) then the use of synthetic arginine is not significant. Based on the results presented in Chapter 4, it can be concluded that the NRC (1994) recommendation for dietary lysine until 4 weeks of age is low. A dietary lysine content of 2.0% (1.8 g/MJ ME) seems to be adequate to obtain optimal performance results. Turkeys in the growing and finishing period at high as well as at low ambient temperature respond in exactly the same way when dietary lysine levels were increased. No differences in requirements for dietary lysine were observed for high and low ambient temperature.

Based on the results in this dissertation, dietary energy may be increased from 90 to 110% of NRC (1994) recommendations to improve feed efficiency. The beneficial effect of increasing dietary energy on improving feed:gain ratios is more pronounced at low than at high ambient temperatures. In countries where BW gain and breast meat yield is the most important production goal, dietary energy levels should not be increased. Moreover, high-energy diets affected breast meat yields negatively. This confirms the results reported by Ferket (2000). Thus the American style diets are more suitable to improve feed efficiency, whereas the European style diets are more suitable to maximize breast meat yield. Maybe when amino acids other than lysine are increased in the diets, the negative effect of high-energy diets on breast meat yield will be diminished.

Based on the results in this dissertation a survey of dietary adjustments for different ages and weight classes was made to accommodate the higher growth rates and ambient temperatures than on which NRC (1994) recommendations were based. It should be noted that for most of the nutrients, requirement information is based on fragments of information from several different studies (Table 4).

In general, turkeys subjected to high and low ambient temperature responded to dietary energy and amino acids in the same manner, except during the period from 16 to 20 wk of age. During this period, turkeys use extra energy for maintenance in order to dissipate the surplus of heat by panting. High-energy diets have a very strong effect on reducing feed intake thus amino acid intake, resulting in reduced protein accretion. In general, it is very important that dietary amino acid contents are high enough when high-energy diets are fed to turkeys.

In practice, feed formulations should be recommended for the period from 0 to 4 wk of age with dietary energy contents below NRC (1994) recommendations to enable maximal growth. From 16 to 20 wk of age, it is important to formulate dietary energy contents above NRC (1994), certainly during warm weather conditions and especially for European wheat based diets. The dietary lysine requirement for the starter period (0 to 4 wk of age) was determined to be 2.0%. This is 25% higher than NRC (1994) requirements due to the progress in body weight gain since 1994 (see weight classes in Table 4) and the limited feed intake capacity at this age. The birds will show a large body weight gain response when dietary lysine is formulated above NRC (1994) recommendations. Current standard European diets almost meet the requirement, but American diets are low in dietary lysine to optimize growth in modern turkeys. After 8 wk of age, dietary lysine recommendations of NRC (1994) are sufficient for optimal growth if birds consume enough feed. This is also applicable for other amino acids. So, dietary energy concentrations are very important in this case. Breast meat yields are very susceptible to sub-optimal amino acid contents in high-energy diets. Furthermore, diets should be formulated with arginine to lysine ratios above 1.0. Dietary electrolyte balance in NRC (1994) seemed to be low after 8 wk of age. A safe dietary electrolyte balance may be recommended of about 160 meq/kg feed for all age intervals.

Table 4. Indications of dietary adjustments for optimal performance of male turkeys relative to NRC (1994) recommendations, as obtained in this dissertation.

Age (weeks)	0 to 4	5 to 8	9 to 12	13 to 16	17 to 20
	NRC (1994)				
	(%)				
Weight class (kg)	0.06 to 1.00	1.00 to 4.00	4.00 to 8.20	8.20 to 12.60	12.60 to 16.10
ME (MJ/kg)	11.7	12.1	12.6	13.0	13.4
CP	28.0	26.0	22.0	19.0	16.5
Lysine	1.60	1.50	1.30	1.00	0.80
Meth+Cys	1.05	0.95	0.80	0.65	0.55
Threonine	1.00	0.95	0.80	0.75	0.60
Arginine	1.60	1.40	1.10	0.90	0.75
Electrolyte balance	211	179	141	146	121
Lysine/ME ratio	1.37	1.24	1.03	0.77	0.60
Arginine/lysine ratio	1.00	0.93	0.85	0.90	0.94
	Veldkamp et al. (2002)				
	(%)				
Weight class (kg)	0.06 to 1.30	1.30 to 4.60	4.60 to 9.50	9.50 to 14.50	14.50 to 19.40
ME (MJ/kg)	11.1	12.1	12.6	14.1	14.1-14.6
CP	28.0	26.0	22.0	19.0	16.5
Lysine	2.00	1.60	1.30	1.00	0.80
Meth+Cys	1.18	0.95	0.80	0.65	0.55
Threonine	1.10	0.95	0.80	0.75	0.60
Arginine	2.20	1.75	1.45	1.10	0.90
Electrolyte balance	160	160	160	160	160
Lysine/ME ratio	1.80	1.32	0.95	0.71	0.57-0.55
Arginine/lysine ratio	1.10	1.10	1.10	1.10	1.10

The best but also expensive way of getting higher growth rate and breast meat yields during warm periods seems to be by artificially lowering the ambient temperature when it exceeds the temperature for optimal production. In this dissertation, it is clear that performance is adversely affected when ambient temperatures exceed 25°C. Turkey farmers should be very keen on ventilation rates in their houses. Air movement in the house results in a lower sensible heat. It is possible to cool turkey houses in a way that it is economically feasible. Some turkey farmers now introduce cooling air inlets in the turkey houses by sprinkling equipment in front of the air inlet. Water evaporation will extract heat from the turkey house. In the present study the constant high ambient temperatures led to severe losses of weight gain (up to almost 4 kg). When turkeys in practice gain about one kg live weight less if they were exposed to periodic heat stress, the economical impact is still large. Assuming that a retarded growth of one week will cost € 0.50 due to the extended growing period, it will cost the farmer € 2000 per flock for a commercial turkey house with 4000 male turkeys. With 2.7 flocks a year, it will cost € 5400 for this turkey house per year. With yearly interest costs of about 10%, it is maybe possible to invest € 50000 for cooling techniques in one male turkey house if economics in the turkey industry are favorable. Of course, in moderate climates, only during spring, summer and autumn, temperatures are too high for optimal performance. In this case we should calculate with half the amount of flocks a year (only those where the cooling unit is operative). In that case it would be justifiable to invest € 25000 per house to achieve optimum growth rate in modern turkeys.

Conclusions

The main conclusions to be drawn from this dissertation are:

- Turkeys at high ambient temperature adapted to chronic heat stress very effectively. By lowering their feed intake, turkeys will have stunted growth, which results in a low metabolic rate and will contribute to an improved surviving strategy of the birds. It is very difficult to influence this surviving strategy of the birds by dietary adjustments.
- Adverse effects of high ambient temperature on feed intake and body weight gain increased as turkeys grew older, but overall feed efficiency was improved at high ambient temperature.
- Increasing the arginine to lysine ratio improved performance results when dietary lysine contents were marginal. This may be due to an arginine deficiency.
- Turkey performance reared in high and low ambient temperatures responded in exactly the same way to dietary lysine supplementation.
- Absolute breast meat yields of turkeys responded better to increasing dietary lysine at low than at high ambient temperature.
- A positive linear relationship existed between BW gain and breast meat yields.
- High-energy diets improved feed efficiency, which was more pronounced at low than at high ambient temperature in the first half of the production period.
- Breast meat yields were negatively affected by high-energy diets.
- In turkeys until 16 wk of age, metabolizable energy intake per g body weight gain was slightly lower at high than at low ambient temperature. After 16 wk of age, when the birds start dramatically suffering from the heat, ME intake per g body weight gain was higher at high than at low ambient temperature. Feed manufacturers should be aware that dietary energy contents should be increased at high ambient temperature to at least 110% of NRC (1994) recommendations because turkeys will need more energy to dissipate heat.

Suggestions for further research

- The thermal comfort zone for turkeys from hatching to slaughter should be determined to obtain more accurate values for heat production.
- When turkeys are exposed to heat stress it should be determined how many energy is used to dissipate heat.
- High-energy diets are interesting to improve feed efficiency further. However, more research is needed to determine which factors affects breast meat yields negatively. Intake of amino acids will decrease as feed intake decreases due to high-energy diets. In this dissertation no effect of increasing dietary lysine contents were observed. It should therefore be valuable to study effects of amino acids other than lysine to improve breast meat in high-energy diets.
- Energy and amino acid requirement studies should be conducted frequently to accomplish for the genetic improvement in growth rate in commercial male turkeys.
- Researchers should include ambient temperatures at which their experiments are conducted in their scientific papers. In most publications, ambient temperature is not mentioned, but this dissertation results clearly demonstrate that this is a critical piece of information.

References

Bender, D. A., 1985. Amino acid metabolism –2nd ed.- Wiley-Interscience Publication, London.

Black, J. L., 1995. Modelling energy metabolism in the pig – critical evaluation of a simple reference model. Pages 87-102 in Modelling growth in the pig. EAAP Publication No. 78. Ed. P. J. Moughan, M. W. A. Verstegen, and M. I. Visser-Reyneveld. Wageningen Pers, Wageningen, The Netherlands.

Brake, J., P. R. Ferket, J. Grimes, D. Balnave, I. Gorman, and J. J. Dibner, 1994. Optimum arginine:lysine ratio changes in hot weather. Pages 82-104 in Proceedings 21st Annual Carolina Poultry Nutrition Conference, Charlotte, NC.

Brake, J., G. B. Havenstein, P. R. Ferket, D. V. Rives, and F. G. Giesbrecht, 1995. Relationship of sex, strain, and body weight to carcass yield and offal production in turkeys. Poultry Science 74: 161-168.

Collier, J., and P. Vallence, 1989. Second messenger role for NO widens to nervous and immune systems. Trends Pharmacol. Science 10: 427-431.

D'Mello, J. P. F., and D. Lewis, 1970. Amino acid interactions in chick nutrition. 1. The interrelationship between lysine and arginine. British Poultry Science 11: 299-311.

Douglas, J. H., 1997. Feeding for breast meat yield. Pages 15-25 in Proceedings 24th Carolina Poultry Nutrition Conference, Charlotte, NC, USA.

Efron, D. T., and A. Barbul, 1998. Modulation of inflammation and immunity by arginine supplements. Curr. Opin. Clin. Nutr. Metab. Care 1: 531-538.

Evoy, D., M. D. Lieberman, T. J. Fahey, and J. M. Daly, 1998. Immunonutrition: The role of arginine. Nutrition 14: 611-617.

Emmans, G. C., 1989. The growth of turkeys. Pages 135-166 in Recent Advances in Turkey Science. Poultry Science Symposium 21. Ed. C. Nixey, and T. C. Grey. Butterworths, Wellington, UK.

England, J. A., P. W. Waldroup, M. L. Kidd, and B. J. Kerr, 1996. Increasing arginine:lysine ratios in turkey diets does not improve performance when lysine levels are adequate. Poultry Science 75(supplement 1): 3.

Ferket, P. R., J. L. Grimes, J. Brake, and D. V. Rives, 1995. Effects of dietary virginiamycin, arginine:lysine ratio, and electrolyte balance on the performance and carcass yield of turkey toms. Poultry Science 74(supplement 1): 190.

Ferket, P. R., F. Chen, and L. N. Thomas, 1998. Amino acid profiles in turkeys. Pages 15-20 in Proceedings Turkey Nutrition Workshop. April 3, NCSU, Raleigh, NC, USA.

Ferket, P. R., J. D. Garlich, R. Kuiper, and M. T. Kidd, 1998. Dietary arginine requirement of growing and finishing turkey toms. Pages 6-14 in Proceedings of Turkey Nutrition Workshop, North Carolina State University, Raleigh, NC.

Ferket, P. R., 2000. The nutrition of commercial turkeys. Pages 5-24 in Proceedings Multi-State Poultry Feeding and Nutrition Conference and BASF Corporation Technical Symposium. May 23-25, Indianapolis, IN, USA.

Fuller, H. L., and N. M. Dale, 1979. Effect of diet on heat stress in broilers, Page 17 in Proceedings Nutritional Conference Feed Mfg. University of Nottingham, UK.

Halvorson, J. C., P. E. Waibel, E. M. Oju, S. L. Noll, and M. E. El Halawani, 1991. Effect of diet and population density on male turkeys under various environmental conditions. 2. Body composition and meat yield. Poultry Science 70: 935-940.

Hudson, A. A., 1998. Twenty-first century poultry: Challenge and opportunity in a global economy. Pages 11-20 in Pacesetter Conference Proceedings. International Poultry Exposition, Atlanta, GA, USA.

Hurwtiz, S., and I. Ben-Gal, 1982. Energy use and performance of young turkeys kept under various constant and cycling environmental temperatures. Poultry Science 61: 1082-1085.

Hurwitz, S., D. Sklan, and I. Bartov, 1978. New formal approaches to determination of energy and amino acid requirements of chicks. Poultry Science 57:197-205.

Hurwitz, S., I. Plavnik, I. Bartov, and S. Bornstein, 1980. The amino acid requirements of chicks: experimental validation of models of calculation. I. Application of two models under various conditions. Poultry Science 56: 969.

Hurwtiz, S., M. Weiselberg, U. Eisner, I. Bartov, G. Riesenfeld, M. Sharvit, A. Niv, and S. Bornstein, 1980. The energy requirements and performance of growing chickens and turkeys as affected by environmental temperature. Poultry Science 59: 2290-2299.

Hurwtiz, S., and I. Ben-Gal, 1982. Energy use and performance of young turkeys kept under various constant and cycling environmental temperatures. Poultry Science 61: 1082-1085.

Jones, J. D., 1961. Lysine toxicity in the chick. Journal of Nutrition 73: 107-112.

Kidd, M. T., and B. J. Kerr, 1998. Dietary arginine and lysine ratios in large white toms. 2. Lack of interaction between arginine:lysine ratios and electrolyte balance. Poultry Sci. 77:864-869.

Kidd, M. T., E. D. Peebles, S. K. Whitmarsh, J. B. Yeatman, and R. F. Wideman, Jr., 2001. Growth and immunity of broiler chicks as affected by dietary arginine. Poultry Science 80: 1535-1542.

Kohne, H. J., and J. E. Jones, 1975a. Changes in plasma electrolytes, acid-base balance and other physiological parameters of adult female turkeys under conditions of acute hyperthermia. Poultry Sci. 54:2034-2038.

Kohne, H. J. and J. E. Jones, 1975b. Acid base balance, plasma electrolytes and production performance of adult turkey hens under conditions of increasing ambient temperature. Poultry Sci. 54:2038-2045.

Kroon, J. M. M., and D. Balnave, 1996. Heat stress in broilers. Thesis, Wageningen Agricultural University, The Netherlands and University of Sidney, Australia.

Krueger, K. K., 2000. Are production practices keeping up with genetic improvements? In: 24th Annual North Carolina Turkey Industry Days, Raleigh, NC, USA.

Mahmoud, H. A., R. G. Teeter, and M. N. Makled, 1996. Arginine:lysine ratio effects on performance and carcass variables of broilers reared in thermoneutral and heat stress environments. Poultry Science 75(supplement 1): 88.

Mendes, A. A., S. E. Watkins, J. A. England, E. A. Saleh, A. L. Waldroup, and P. W. Waldroup, 1997. Influence of dietary lysine and arginine:lysine ratio on performance of broilers exposed to heat or cold stress from 3 to 6 weeks of age. Poultry Science 76: 472-481.

Meyer, H., 1999. Einfluss unterschiedlicher Fütterungsintensitäten bei schweren un mittelschweren Putenhähnen auf Mastleistung, Schlachtkörperzusammensetzung und Fleischqualität. Thesis, Institut für Tierzuchtwissenschaft der Rheinischen Friedrich-Wilhelms-Universität, Bonn, Germany.

Moncada, S., R. M. J. Palmer, and E. A. Higgs, 1991. Nitric oxide: physiology, pathophysiology, and pharmacology. Pharmacological Reviews 43: 109-142.

Nixey, C., 1991. The lysine response of the turkey. Thesis. University of Nottingham. October 1991.

Noll, S. L., and P. E. Waibel, 1989. Lysine requirements of growing turkeys in various temperature environments. Poultry Science 68: 781-794.

Noll, S. L., M. E. El Halawani, P. E. Waibel, P. Redig, and K. Janni, 1991. Effect of diet and population density on male turkeys under various environmental conditions. 1. Turkey growth and health performance. Poultry Science 70: 923-934.

National Research Council. 1994. Nutrient Requirements of Poultry. 9th rev. ed. National Academy Press, Washington, DC.

Oju, E. M., P. E. Waibel, and S. L. Noll, 1987. Protein, methionine, and lysine requirements of growing hen turkeys under various environmental temperatures. Poultry Sci. 66:1675-1683.

Parker, J. T., and M. A. Boone, 1971. Thermal stress effects on certain blood characteristics of adult male turkeys. Poultry Sci. 50:1287-1295.

Plavnik, I. and S. Hurwitz, 1993. Amino acids and protein requirement in turkeys. Pages 300-308 in Proceedings European Symposium on Poultry Nutrition. Jelenia Gòra, Poland.

Qureshi, M. A., P. R. Ferket, and G. B. Havenstein, 1998. Turkey immune system as affected by dietary and environmental factors. Proceedings of Turkeys 21st Technical Turkey Conference, Cheshire, UK.

Rose, S. P., and W. Michie, 1987. Environmental temperature and dietary protein concentrations for growing turkeys. British Poultry Science 28: 213-218.

Siegel, H. S., L. N. Drury, and W. C. Patterson, 1974. Blood parameters of broilers grown in plastic coops and on litter at two temperatures. Poultry Sci. 53:1016-1024.

Sung, Y. J. H. Hotchkiss, R. E. Austic, and R. R. Dietert, 1991. L-Arginine-dependent production of a reactive nitrogen intermediate by macrophages of a uricotelic species. J. Leukocyte Biol. 50: 49-56.

Ten Doeschate, A. H. M., 1995. Towards a physiological feeding strategy for protein in broilers. Thesis. Landbouw Universiteit Wageningen, Wageningen, The Netherlands.

Veldkamp, T., 1990. Effect of relative humidity and ambient temperature on performance and carcass quality in commercial male turkeys (in Dutch). Onderzoekverslag 3:1-24.

Viandes, M. H. R. 1998. Subject: Turkey consumption per country – 1997. http://www.mhr-viandes.com/en/docu/docu/d0000461.htm. Accessed June, 2002.

Waibel, P. E., M. E. El Halawani, and B. R. Behrends, 1975. Ambient temperature and protein requirements of turkeys. Minn. Agric. Exp. Stn. Misc. Rep. 134:77-84.

Waibel, P. E., M. E. El Halawani, and B. R. Behrends, 1976. Growth and efficiency of large white turkeys in relation to dietary protein and environmental temperatures. Pages 119-127 in Proceedings of the 37th Minn. Nutr. Conf., St. Paul, MN.

Waldroup, P. W., M. H. Adams, and A. L. Waldroup, 1997a. Evaluation of national research council amino acid recommendations for large white turkeys. Poultry Science 76: 711-720.

Waldroup, P. W., J. A. England, A. L. Waldroup, and N. B. Anthony, 1997b. Response of two strains of large white male turkeys to amino acid levels when diets are changed at three- or four-week intervals. Poultry Science 76: 1543-1555.

Waldroup, P. W., J. A. England, M. T. Kidd, and B. J. Kerr, 1998. Dietary Arginine and Lysine in large white toms. 1. Increasing arginine:lysine ratios does not improve performance when lysine levels are adequate. Poultry Science 77: 1364-1370.

Yahav, S., 2000. Relative humidity at moderate ambient temperatures: its effect on male broiler chickens and turkeys. British Poultry Science 41: 94-100.

SUMMARY

SUMMARY

The wild turkey (*Meleagris gallopavo*) is a North American native that was transported to Europe by Spanish explorers in the early 16th century. The introduction of artificial insemination and incubation and specific selection programs increased the process of domestication in the second quarter of the twentieth century.

Turkey production and consumption of turkey meat is increasing all over the world. Over 50% of total turkey production takes place in the United States, followed by the European Union with a share of about 35%. In both market sectors, further processing is developing at a rapid pace. Breast meat is economically the most important part because of the high consumer demand for white low fat meat. However, environmental conditions vary within both continents and this variability affects performance and carcass meat yields. Raising turkeys in warm weather particularly has adverse effects on growth and breast meat.

Experiments described in this dissertation were designed to address how commercial male turkeys subjected to chronic heat stress utilize feed nutrients, especially energy and amino acids. Growth and carcass results were used in most experiments as the major response measurements of treatments.

The objective of this study was to investigate how male turkeys reared in high and low ambient temperatures responded to dietary supplementation of synthetic amino acids, different arginine to lysine ratios, dietary lysine *per se*, and different lysine to energy ratios in order to reduce the adverse effects of heat stress on performance and carcass results.

Turkeys are homeotherms, which means that they have mechanisms that enable them to maintain constant body temperature under varying environmental temperatures. Heat is produced by all metabolic processes within the bird. The turkey will try to maintain its body temperature and dissipate excess metabolic body heat, the amount depending on the ambient temperature. From the experiments reported in this dissertation, it was clearly evident that turkeys become more susceptible to high ambient temperatures as they grow larger and daily body weight gain is near maximum. Metabolism associated with digestion, body maintenance, and growth, yields a considerable amount of heat. Due to the large amount of feed consumed by growing market turkeys, considerable amount of heat of digestion must be dissipated. Turkeys subjected to high ambient temperatures make behavioral and physiological adjustments in order to dissipate this extra heat: decreased

feed intake, spread and dropped wings, raised feathers on the back, reduced physical activity, assumed positions in cool places, wetted head and neck, increased water consumption, and increased panting. Unbalanced diets will result in less efficient protein accretion as surplus amino acids must be deaminated and the excess nitrogen excreted. This process generates a large amount of heat at the expense of productive energy, which will adversely affect performance further.

All the experiments in this dissertation were conducted at constant high and low ambient temperature. Ambient temperature had a large impact on feed intake and body weight gain. Feed intake was decreased by 1.1, 1.7, 2.3, and 2.3% for each degree Celsius increase, respectively in the temperature range from 15 to 25 °C, 15 to 30 °C, 15 to 30 °C, en 18 to 28 °C in the successive experiments, respectively. The lower feed intake in these experiments resulted in a decrease in body weight gain of 0.8, 1.5, 2.1, and 2.0% respectively, for each degree Celsius increase in temperature. The negative effect of high ambient temperature on feed intake and body weight gain increased with increasing age. Overall, the decrease in body weight gain per degree Celsius increase was less than the decrease in feed intake, which implies that turkeys reared in high ambient temperatures had lower feed:gain ratios than those in low temperatures. However, it should be noted that feed:gain ratios in each experiment were higher at high ambient temperature from 17 to 20 weeks of age. Apparently, turkeys at this age used a significant portion of energy intake for maintenance, leaving less energy for protein and lipid accretion.

In the first experiment (Chapter 2) performance and carcass results were studied to determine if dietary amino acid was balanced according to the ideal protein concept using dietary supplementation of extra lysine, methionine, and threonine when male turkeys were subjected to high ambient temperatures. In the experimental diets, 10% extra lysine and methionine+cystine was added from 22 to 134 d of age and 10% extra threonine was added from 22 to 69 d of age. It was assumed that dietary threonine contents after 69 d of age were sufficient for optimal production. The basal diet was formulated according to the recommendations of the breeder and contained relatively high amino acid concentrations. From 22 to 41 d of age, feed:gain ratio of turkeys fed the amino acid-supplemented diet was lower than turkeys fed the basal diet at low ambient temperature (1.56 vs. 1.62). The supplemented amino acids were apparently used for protein accretion at low temperature, whereas the supplemented amino acids at high temperature could not be used when dietary energy intake was insufficient. From 69 to 105 d of age, feed:gain ratio of turkeys fed the amino acid-supplemented diets was higher than those fed basal diets at high ambient temperatures (2.89 vs. 2.59) due to retarded body weight gain. When turkeys in this age interval did not deposit the extra lysine and methionine+cystine into body tissue, the surplus of amino acids must be catabolized and the excess nitrogen excreted. Threonine is involved in the excretion of excess nitrogen from amino acid catabolism. Just in the period after 69 d of age, dietary threonine may have been insufficient for this process because no extra threonine was supplemented in this period.

In general, extra dietary amino acid supplementation did not improve performance and carcass results. The lack of an effect may be due to various reasons: 1) the basal diets already had sufficient amino acids to satisfy nutritional demands at high ambient temperature; 2) the supplementation of synthetic lysine caused an imbalance with other amino acids; 3) the energy intake was insufficient for protein synthesis at high ambient temperature or 4) electrolyte balances may have been sub-optimal.

In the second experiment (Chapter 3) we hypothesized that increased dietary arginine to lysine ratios could alleviate the adverse effects of high ambient temperatures, and this response could be modulated by electrolyte balance. Arginine plays a role in thermoregulation. In the uric acid cycle, arginine helps to excrete the surplus of nitrogen. It is also a precursor of nitric oxide, which plays an important role in vasodilatation of peripheral blood vessels and helps to dissipate heat. Moreover, it is known that an antagonism exists between lysine and arginine. In addition, a proper dietary electrolyte balance is important to maintain physiological functions in poultry during hot weather. Increased respiration rate necessary for evaporative cooling lowers carbon dioxide levels in the blood. As a result bicarbonate level in the blood will decrease and the body will lower sodium content. An increase of dietary sodium bicarbonate may therefore be beneficial at high ambient temperature.

The results in this experiment demonstrated that altering the arginine to lysine ratio from 1.00 to 1.25 and/or increasing the electrolyte balance from 164 to 254 meq/kg did not improve performance at high ambient temperature. The high dietary arginine to lysine ratio increased feed intake significantly (200.6 vs. 197.6 g/d) from 29 to 56 d of age, which was more pronounced at low ambient temperature than at high temperature. Body weight gain was significantly increased until 98 d of age when turkeys were fed a high arginine to lysine ratio (10.03 vs. 9.84 kg). Until 70 d of age, dietary lysine contents in the diets were low as compared to the NRC (1994) recommendations. Waldroup and coworkers reported an effect of higher arginine to lysine ratios only when dietary lysine levels were marginal. This response may be more associated with a deficiency of arginine *per se* than an effect of the higher arginine to lysine ratio. This conclusion may also explain why there was no beneficial effect of higher arginine to lysine ratios after 70 d of age in our experiment. Moreover, the source of arginine used to increase the arginine to lysine ratios may further explain the responses observed in this experiment. In studies with broilers, a positive effect of higher arginine to lysine ratios was reported when the ratio was increased by modifying dietary ingredient inclusion levels, whereas no effect has been reported when synthetic arginine was used. By using synthetic arginine, the rate of uptake is very high and therefore high amounts of arginine arise in the blood right after consumption. As a consequence these high concentrations will be interpreted by the body as an amino acid imbalance, leading to increased amino acid catabolism and nitrogen excretion. In the study an effect of a higher electrolyte balance was also not observed. Therefore, an electrolyte balance of 164 meq/kg was sufficient for optimal performance both at high and at low ambient temperatures. Arginine to lysine ratios as well as electrolyte balances did not affect carcass yields.

In this experiment, blood parameters were also determined to study the effects of arginine to lysine ratios and electrolyte balances on immunity and metabolic parameters in turkeys reared in high and low ambient temperature. The HI-NCD-titers were not affected by arginine to lysine ratio. Apparently, dietary arginine level in the basal diets was sufficient to support proper immune functions in healthy turkeys. High ambient temperature resulted in significantly lower hematocrit values than the low ambient temperature (28.1 vs. 29.7%). Carbon dioxide and bicarbonate values in the blood were not affected by ambient temperature. Kohne and Jones reported that acute hyperthermia resulted in alkalosis and that chronic hyperthermia had no effect. In our experiment turkeys were subjected to chronic heat stress and they had likely adapted to high ambient temperature.

From the experiments, described in Chapter 2 and 3, we did not observe a clear response to increased amino acid levels fed to turkeys, regardless of the ambient temperature. The absence of a response in both experiments was probably due to an already sufficient dietary lysine content in the basal diets. Based on the results of the first two experiments, a third experiment was designed to test the response of dietary lysine level in commercial male turkeys reared in chronically high and low ambient temperatures. Four diets with different dietary lysine concentrations (75, 90, 105, and 120% of NRC (1994) recommendations were compared at high and low ambient temperature. The turkeys in this experiment responded to dietary lysine supplementation similarly in both the high and low ambient temperature treatment groups. Turkeys in high ambient temperature had a lower lysine intake than those in the low ambient temperature, resulting in a lower body weight gain. Although, body weight gain was lower at the high ambient temperature, efficiency of dietary lysine utilization was equal to the utilization at the low ambient temperature. Breast meat yields response to high dietary lysine contents was higher at low than at high ambient temperature. Dietary energy contents were higher than NRC (1994) recommendations to be sure that energy content was not the limiting factor for optimal performance. High dietary energy contents may have affected nutrient intake at high temperature more than at low temperature.

In order to address this question, a fourth experiment was designed to evaluate how turkeys respond to different dietary lysine to energy ratios at high and low ambient temperature. Dietary energy plays an important role in the effectiveness of converting amino acids into body protein. In Chapter 5 it was clearly found that energy played an important role in feed intake regulation. Increasing the density of the diets decreased feed intake due to the fact that energy requirements were met with lower feed intake. The negative effect of high-density diets on feed intake was more pronounced at low than at high ambient temperature from 29 to 52 and from 53 to 84 d of age. Therefore, turkeys subjected to low temperature reached their energy intake requirements earlier than those subjected to high temperature when dietary energy concentrations were increased. It should be noted that absolute energy intake at low temperature was higher than at high temperature. Dietary energy intake per g body weight gain was lower at high than at low ambient temperature. This means that turkeys at high ambient temperature used less energy for both maintenance and production than at low ambient temperature in these age intervals. From 85 to 112 d of age no temperature * dietary energy interaction effect was observed. Turkeys decreased their feed intake in the same way as dietary energy content was increased at both temperatures.

During 113 to 140 d of age, results are really different from earlier age intervals. Feed intake was decreased at low ambient temperature when dietary energy increased from 90 to 100% of NRC (1994) recommendations, whereas no clear feed intake response to increasing dietary energy was observed. Dietary energy had no clear effect on dietary energy intake of turkeys reared in low ambient temperature, whereas an increase of dietary energy from 100 to 110% resulted in a 15% higher energy intake of birds at high ambient temperature. Turkeys subjected to the high ambient temperature may have used extra dietary energy for panting during this age interval. Turkeys needed more energy per g of body weight gain when reared in high than in low ambient temperature from 113 to 140 d of age, regardless of their dietary energy level. Overall, an increase of dietary energy level resulted in a remarkably higher feed efficiency (feed:gain ratio with different energy contents were respectively at 90%: 2.76; at 100%: 2.57; and at 110%: 2.44). The higher feed efficiency was more pronounced at low than at high ambient temperature from 29 to 52 and from 53 to 84 d of age. The efficiency of protein utilization in the high-energy diets was higher at low temperature than at high temperature.

Dietary lysine content did not affect performance and carcass results. Increasing dietary energy levels adversely affected carcass results. The higher energy diets decreased breast meat yields (breast meat yield with different energy contents were respectively at 90%: 31.2%; at 100%: 30.4%; and at 110%: 29.4%). Amino acids other than lysine may have been limiting due to the lower feed intake with high-density diets.

Finally, some scientific and practical implications are discussed in the General Discussion as well as differences between traditional diets for the USA and Europe.

In summary, the results presented and discussed in this dissertation demonstrated several clear points as follows:

- Turkeys at high ambient temperature adapted to chronical heat stress very effectively. By lowering their feed intake, turkeys exhibit stunted growth, which results in a reduced metabolic rate that contributed to their ability to survive. It is very difficult to influence this survival strategy by dietary adjustments.
- Adverse effects of high ambient temperature on feed intake and body weight gain increased as turkeys grew older, but overall feed efficiency was improved at high ambient temperature.
- Increasing the arginine to lysine ratio improved performance results when dietary lysine contents were marginal. This maybe due to an arginine deficiency.
- Turkey performance at high and low ambient temperature responded in exactly the same way to dietary lysine supplementation.
- Turkeys had a higher response for absolute breast meat yields to increasing dietary lysine at low than at high ambient temperature.

- High density diets improved feed efficiency which was more pronounced at low than at high ambient temperature during the first half of the production period.
- Breast meat yields were negatively affected by high-energy diets.
- In turkeys until 16 wk of age, metabolizable energy intake per g body weight gain was slightly lower among turkeys subjected to high than to low ambient temperature. After 16 wk of age, when the birds started to exhibit heat-stress symptoms, ME intake per g body weight gain was higher at high than at low ambient temperature. Feed manufacturers should be aware that dietary energy contents should be increased at high ambient temperature to at least 110% of NRC (1994) recommendations because turkeys will need more energy to dissipate heat.

Based on the results in this dissertation, a survey of dietary adjustments for different ages and weight classes was made to accommodate the higher growth rates and ambient temperatures than on which the NRC (1994) recommendations were based. It should be noted that for most of the nutrients, requirement information is based on fragments of information from several different studies (Table 1).

Table 1. Indications of dietary adjustments for optimal performance of male turkeys relative to NRC (1994) recommendations, as obtained in this dissertation.

Age (weeks)	0 to 4	5 to 8	9 to 12	13 to 16	17 to 20
	NRC (1994)				
	(%)				
Weight class (kg)	0.06 to 1.00	1.00 to 4.00	4.00 to 8.20	8.20 to 12.60	12.60 to 16.10
ME (MJ/kg)	11.7	12.1	12.6	13.0	13.4
CP	28.0	26.0	22.0	19.0	16.5
Lysine	1.60	1.50	1.30	1.00	0.80
Meth+Cys	1.05	0.95	0.80	0.65	0.55
Threonine	1.00	0.95	0.80	0.75	0.60
Arginine	1.60	1.40	1.10	0.90	0.75
Electrolyte balance	211	179	141	146	121
Lysine/ME ratio	1.37	1.24	1.03	0.77	0.60
Arginine/lysine ratio	1.00	0.93	0.85	0.90	0.94
	Veldkamp et al. (2002)				
	(%)				
Weight class (kg)	0.06 to 1.30	1.30 to 4.60	4.60 to 9.50	9.50 to 14.50	14.50 to 19.40
ME (MJ/kg)	11.1	12.1	12.6	14.1	14.1-14.6
CP	28.0	26.0	22.0	19.0	16.5
Lysine	2.00	1.60	1.30	1.00	0.80
Meth+Cys	1.18	0.95	0.80	0.65	0.55
Threonine	1.10	0.95	0.80	0.75	0.60
Arginine	2.20	1.75	1.45	1.10	0.90
Electrolyte balance	160	160	160	160	160
Lysine/ME ratio	1.80	1.32	0.95	0.71	0.57-0.55
Arginine/lysine ratio	1.10	1.10	1.10	1.10	1.10

In general, turkeys subjected to high and low ambient temperature respond to dietary energy and amino acids in the same manner, except during the period from 16 to 20 wk of age. During this period, turkeys use extra energy for maintenance in order to dissipate the surplus of heat by panting.
High-density diets have a very strong effect on reducing feed intake and thus amino acid intake, resulting in reduced protein accretion. In general, it is very important that dietary amino acid contents are high enough when high-density diets are fed to turkeys.

In practice, feed formulations should be recommended for the period from 0 to 4 wk of age with dietary energy contents below NRC (1994) recommendations to enable maximal growth. From 16 to 20 wk of age, it is important to formulate dietary energy contents above NRC (1994), certainly during warm weather conditions and especially for European wheat-based diets. The dietary lysine requirement for the starter period (0 to 4 wk of age) was determined to be 2.0%. This is 25% higher than NRC (1994) requirements due to the progress in body weight gain since 1994 (see weight classes in Table 1) and the limited feed intake capacity at this age. The birds will show a large body weight gain response when dietary lysine is formulated above NRC (1994) recommendations. Current standard European diets almost meet the requirement, but American diets are low in dietary lysine to optimize growth in modern turkeys. After 8 wk of age, dietary lysine recommendations of NRC (1994) are sufficient for optimal growth if birds consume enough feed. This is also applicable for other amino acids. So, dietary energy concentrations are very important in this case. Breast meat yields are very susceptible to sub-optimal amino acid contents in high-density diets. Furthermore diets should be formulated with arginine to lysine ratios above 1.0. Dietary electrolyte balance in NRC (1994) seemed to be low after 8 wk of age. A safe dietary electrolyte balance may be recommended of about 160 meq/kg feed for all age intervals.

It is a challenge for the feed industry to keep up with the fast increasing growth rates in commercial turkeys and therefore energy and amino acid requirements should be conducted frequently. Data from this dissertation can be used to make more accurate models for determining these requirements.

SAMENVATTING

SAMENVATTING

De wilde kalkoen (*Meleagris gallopavo*) komt van origine uit Noord Amerika en werd door Spaanse ontdekkingsreizigers in Europa ingevoerd in de 16^{e} eeuw. Na de introductie van kunstmatige inseminatie, broedmachines en fokprogramma's werd de kalkoen in de tweede helft van de 20^{e} eeuw snel verder gedomesticeerd.

De productie van kalkoen en de consumptie van kalkoenvlees neemt toe over de hele wereld. Ongeveer de helft van de totale kalkoenproductie vindt plaats in Amerika en ongeveer 35% vindt plaats in Europa, waarbij de delenproductie steeds meer opgang vindt. Borstvlees is economisch het meest aantrekkelijke deel van de kalkoen. Binnen beide continenten komen grote spreidingen voor in klimatologische omstandigheden en deze variatie werkt ook door in reactie van de dieren op deze omstandigheden. Als gevolg zullen de dieren anders gaan groeien. De klimatologische omstandigheden zullen dus de groei- en slachtresultaten aanzienlijk beïnvloeden. Warme perioden veroorzaken een achterblijvende groei met als gevolg minder borstvlees.

De in dit proefschrift beschreven experimenten hebben zich geconcentreerd rond de vraag: hoe de voerbenutting van kalkoenhanen wordt beïnvloed door hittestress en daarbij is met name gekeken naar de rol die energie en aminozuren hierbij spelen. In de experimenten zijn groei- en slachtresultaten gebruikt om de respons te meten.

Het doel van deze studie was te onderzoeken hoe kalkoenhanen reageren op toevoegingen van synthetische aminozuren, verschillende arginine:lysine verhoudingen, verschillende lysineniveaus en verschillende verhoudingen van lysine en energie bij een hoge en lage omgevingstemperatuur met het uiteindelijke doel de negatieve effecten van hoge omgevingstemperaturen op groei- en slachtresultaten te verminderen.

Kalkoenen zijn homeotherm, wat betekent dat deze diersoort probeert te allen tijde de lichaamstemperatuur constant te houden onder alle externe omstandigheden. Bij alle metabolische processen komt in meer of mindere mate warmte vrij en afhankelijk van de omgevingstemperatuur zal de kalkoen deze warmte proberen vast te houden of juist proberen kwijt te raken. Uit de experimenten blijkt dat de kalkoenen gevoeliger worden voor een hoge omgevingstemperatuur naarmate ze ouder worden. De dieren hebben dan een groot lichaam en ze hebben bovendien een snelle groei. Het onderhoudsmetabolisme en groei samen levert veel warmte op. De dieren hebben moeite om de hoeveelheid warmte die vrijkomt bij de vertering van de steeds groter wordende hoeveelheid voer kwijt te raken.

Als dieren hun overtollige warmte niet voldoende kwijt kunnen raken dan worden een aantal gedrags- en fysiologische aanpassingen gedaan zoals: vermindering van de voeropname, vleugels uitzetten en laten hangen langs het lichaam, opzetten van veren op de rug, verminderen van activiteit, op zoek gaan naar een koele omgeving, natmaken van kop en hals, toename van het waterverbruik en een versnelde ademhaling (panting). Een onbalans tussen verschillende nutriënten veroorzaakt een inefficiënte aanzet van eiwit waarbij bijvoorbeeld aminozuren die over zijn, moeten worden afgebroken en afgevoerd. Bij dit proces komt veel warmte vrij (kost veel energie) wat juist in een warme omgeving de resultaten negatief zal beïnvloeden.

Alle voedingsexperimenten in dit proefschrift zijn steeds uitgevoerd bij een constante hoge en lage omgevingstemperatuur. Temperatuur had een sterke invloed op de voeropname en de groei. De voeropname verminderde in de opeenvolgende experimenten met 1,1, 1,7, 2,3, en 2,3% per graad Celsius temperatuurstijging in respectievelijk de volgende temperatuurstrajecten: 15 tot 25 °C, 15 tot 30 °C, 15 tot 30 °C, en 18 tot 28 °C. De groei verminderde in de opeenvolgende experimenten respectievelijk met 0,8, 1,5, 2,1, en 2,0% per graad Celsius temperatuurstijging. Het negatieve effect van een hoge omgevingstemperatuur nam toe naarmate de dieren ouder werden. Gerekend over de gehele productieperiode was de voerconversie bij hoge temperatuur beter dan bij lage temperatuur. Hierbij dient opgemerkt te worden dat in het leeftijdsinterval van 17 tot 20 weken de voerconversie steeds slechter was bij hoge temperatuur. Blijkbaar gebruiken kalkoenen op deze leeftijd een groter deel van de lagere energieopname voor onderhoud en daardoor blijft minder energie over voor eiwitsynthese en vetaanzet.

In het eerste experiment (hoofdstuk 2) is onderzocht of productieresultaten positief worden beïnvloed door het voereiwit beter te maken en meer te laten aansluiten bij het ideale aminozuurpatroon. Dit werd onderzocht door extra lysine, methionine, en threonine in synthetische vorm aan het voer toe te voegen. Het werd speciaal gedaan wanneer kalkoenhanen worden blootgesteld aan hoge omgevingstemperaturen. De gedachte hierachter was om de verminderde opname aan aminozuren bij een hoge omgevingstemperatuur, als gevolg van de verminderde voeropname, te compenseren door 10% extra lysine en methionine+cystine in de periode van 22 tot 134 dagen leeftijd toe te voegen en 10% extra threonine van 22 tot 69 dagen leeftijd. Verondersteld werd dat threoninegehalten na 69 dagen leeftijd hoog genoeg zouden zijn voor optimale productie. Het basale voer in dit experiment was volgens de normen van de fokkerijorganisatie en bevatte relatief vrij hoge aminozuurgehalten. In de periode van 22 tot 41 dagen was de voerconversie van kalkoenen die extra aminozuren in het voer kregen beter bij de lage temperatuur (voerconversie: 1.56 vs. 1.62). Bij de hoge temperatuur werd geen positief effect waargenomen. Aminozuurgehalten zoals die toegepast werden, werden bij lage temperatuur aangewend voor extra eiwitsynthese terwijl bij hoge temperatuur de energieopname waarschijnlijk ontoereikend was om de extra aminozuren voor eiwitsynthese aan te wenden. In de periode van 69 tot 105 dagen was de voerconversie bij de dieren bij hoge temperatuur die extra aminozuren kregen zelfs slechter dan bij het basale voer (voerconversie: 2.89 vs. 2.59) omdat de groei van deze dieren sterk achterbleef. Ook hier was waarschijnlijk onvoldoende energie beschikbaar om de extra aminozuren te kunnen gebruiken voor eiwitsynthese. Als overtollige aminozuren in het lichaam niet worden aangezet als eiwit dan moeten deze worden uitgescheiden. Threonine heeft een gunstige werking bij de uitscheiding van overtollige aminozuren en juist in de periode na 69 dagen was het threoninegehalte wellicht onvoldoende om hier een bijdrage in te kunnen leveren.

Algemeen kan gesteld worden dat de extra aminozuren niet hebben geleid tot betere groei- en slachtresultaten. De volgende vier zaken kunnen hierbij een rol hebben gespeeld: de aminozuurgehalten in het basale voer waren al toereikend bij hoge temperatuur; de toevoeging van lysine veroorzaakte een onbalans met andere aminozuren zoals arginine; de energieopname was bij hoge temperatuur lager dan bij lage temperatuur waardoor er misschien een energietekort was voor eiwitsynthese; en de elektrolytenbalans was misschien niet optimaal.

In het tweede experiment (hoofdstuk 3) is onderzocht of ruimere arginine:lysine verhoudingen en een hogere elektrolyten balans de negatieve effecten van een hoge temperatuur kunnen beperken. Van arginine is bekend dat dit een rol kan spelen in de temperatuurregulatie. In de urinezuurcyclus vervult arginine een belangrijke rol bij de uitscheiding van overtollig stikstof en daarnaast heeft arginine een functie bij de productie van stikstofoxide, dat zorgt voor verwijding van de bloedvaten en zo helpt bij de warmteafvoer. Daarnaast bestaat een antagonistische werking tussen lysine en arginine. Verder is een goede elektrolytenbalans belangrijk om fysiologisch functies bij hoge temperaturen in stand te houden. Een voorbeeld hiervan is de versnelde ademhaling bij hoge temperaturen. De uitscheiding van kooldioxide neemt toe waardoor de kooldioxidespanning in het bloed daalt. Als resultaat daalt ook het bicarbonaatgehalte in het bloed waardoor vervolgens ook het natriumgehalte daalt. Verhoging van het bicarbonaatgehalte of natriumgehalte in het voer zou daarom gunstig kunnen werken bij hoge temperaturen.

In het experiment heeft een ruimere arginine:lysine verhouding (1.00 vs. 1.25) en of een hogere elektrolytenbalans (164 vs. 254 meq/kg voer) niet geleid tot een verbetering van de groei- en slachtresultaten bij hoge temperatuur. Een ruimere arginine:lysine verhouding leidde in de periode van 29 tot 56 dagen tot een significant hogere voeropname bij de lage temperatuur (200.6 vs. 197.6 g/d). De groei van kalkoenen, die voer kregen met een ruimere arginine:lysine verhouding, was bij de lage temperatuur significant hoger tot 98 dagen leeftijd (10.03 vs. 9.84 kg). De gehanteerde lysinegehalten in het voer waren tot 70 dagen leeftijd vrij laag vergeleken met de NRC (1994) aanbevelingen. In andere experimenten is ook gevonden dat ruimere arginine:lysine verhoudingen alleen effect hebben als het lysinegehalte in het voer marginaal is, waarbij opgemerkt dient te worden dat dit waarschijnlijk een gevolg is van een arginine-tekort. Dit verklaart ook waarom na 70 dagen geen effect is gevonden. Een andere mogelijkheid waardoor geen effect is gevonden is de bron van arginine. In enkele studies met vleeskuikens bleek dat een effect van ruimere arginine:lysine verhouding werd gevonden wanneer de verhouding hoger gemaakt werd door gebruik te maken van natuurlijke grondstoffen terwijl een effect bij gebruik van synthetische arginine niet werd aangetoond. Bij gebruik van synthetische arginine wordt dit snel opgenomen en daardoor komen in het bloed hoge pieken voor waardoor arginine mogelijk weer wordt uitgescheiden. Ook een positief effect van een hogere elektrolytenbalans is niet aangetoond waardoor geconcludeerd kan worden dat een elektrolytenbalans van 164 meq/kg voldoende hoog is voor optimale groeiresultaten bij zowel hoge als lage temperatuur zoals wij die toepasten. De slachtresultaten werden niet beïnvloed door de behandelingen.

In dit experiment werden ook enkele bloed parameters gemeten die een indicatie kunnen geven of het metabolisme van kalkoenen bij hoge temperatuur anders is dan bij lage temperatuur en of een ruimere arginine:lysine verhouding en een hogere elektrolytenbalans leiden tot een verhoogde immuniteit. De NCD-titers werden niet beïnvloed door de arginine:lysine verhouding. Blijkbaar was het argininegehalte in het basale voer hoog genoeg voor een optimale immuniteit in gezonde kalkoenen. Hematocriet waarden waren bij hoge temperatuur significant lager dan bij lage temperatuur (28.1 vs. 29.7%). Dit is ongetwijfeld een gevolg van een lager metabolisme. Kooldioxide- en bicarbonaatwaarden in het bloed werden niet beïnvloed door de temperatuur. In andere experimenten is gevonden dat acute hittestress leidt tot alkalosis en chronische hittestress niet. In ons experiment werden de dieren blootgesteld aan chronische hittestress. Dit betekent dat de dieren in ons onderzoek aangepast waren.

In de hoofdstukken 2 en 3 werden geen duidelijke effecten van de behandelingen bij hoge en lage temperatuur gevonden omdat het lysinegehalte in het basale voer misschien al voldoende was voor een optimale productie. In hoofdstuk 4 is daarom onderzocht of de lysinebehoefte voor kalkoenen bij hoge en lage temperatuur verschillend is. Vier voeders met verschillende lysinegehalten (75, 90, 105, en 120% ten opzichte van de NRC (1994) aanbevelingen werden vergeleken bij hoge en lage temperatuur. Uit de resultaten bleek dat de kalkoenen bij hoge en bij lage temperatuur op dezelfde manier reageren op hogere lysinegehalten. De lysineopname was bij hoge temperatuur veel lager dan bij lage temperatuur resulterend in een lagere groeisnelheid. Maar hoewel de dieren langzamer groeiden bij hoge temperatuur was de lysinebenutting ongeveer gelijk aan de benutting bij lage temperatuur. De kalkoenen vertoonden bij lage temperatuur een hogere borstvlees respons op hogere lysinegehalten dan bij hoge temperatuur. De energiegehalten in de voeders waren in dit experiment hoger dan de NRC (1994) aanbevelingen om er zeker van te zijn dat energie niet de beperkende factor zou zijn. De hoge energieniveaus hebben misschien bij hoge temperatuur meer effect gehad op de nutriëntenopname dan bij lage temperatuur.

Een volgend experiment werd opgezet om te onderzoeken of kalkoenen verschillend reageren op verschillende lysine:energie verhoudingen bij hoge en bij lage temperatuur. Energie vervult een belangrijke rol bij de omzetting van aminozuren in lichaamseiwit (groei). In hoofdstuk 5 is duidelijk aangetoond dat energie van invloed is op de regulatie van de voeropname. Hogere energiedichtheden verminderden de voeropname omdat de energiebehoefte wordt gedekt met een lagere voeropname bij verstrekking van hoog-energetische voeders. In de periode van 29 tot 52 en van 53 tot 84 dagen leeftijd werd de voeropname bij lage temperatuur sterker verminderd dan bij hoge temperatuur als het energiegehalte in het voer toenam. Dit impliceert dat de energiebehoefte van kalkoenen bij lage temperatuur eerder wordt gedekt met een toename van het energiegehalte dan bij hoge temperatuur. Hierbij dient opgemerkt te worden dat de absolute energieopname bij lage temperatuur hoger was dan bij hoge temperatuur. De energieopname per gram groei was bij de hoge temperatuur lager dan bij de lage temperatuur. Dit betekent dat kalkoenen bij hoge temperatuur minder energie gebruikten voor onderhoud en groei samen dan bij lage temperatuur in deze perioden. In de periode van 85 tot 112 dagen leeftijd is geen interactie tussen temperatuur en energiegehalte aangetoond. Zowel bij hoge als bij lage temperatuur nam de voeropname af als het energiegehalte toenam.

De resultaten werden echt anders in de periode van 113 tot 140 dagen. De voeropname nam bij lage temperatuur af wanneer het energiegehalte werd verhoogd van 90 naar 100% van NRC (1994) aanbevelingen terwijl bij hoge temperatuur geen duidelijke voeropname respons is waargenomen bij verschillende energiegehalten. Hierdoor bleef de energieopname bij lage temperatuur ongeveer gelijk als het energiegehalte in het voer toenam terwijl bij hoge temperatuur 15% meer energie werd opgenomen als het energiegehalte werd verhoogd van 100 tot 110%. Waarschijnlijk hebben kalkoenen bij hoge temperatuur in deze periode meer energie nodig voor het proces van versnelde ademhaling (panting). De kalkoenen verbruikten nu bij hoge temperatuur meer energie per gram groei dan bij lage temperatuur. Over het gehele experiment leidde een verhoging van het energiegehalte tot een betere voerefficiëntie (voerconversie bij energiegehalte van 90%: 2.76; bij 100%: 2.57; en bij 110%: 2.44). Het gunstige effect van hogere energiegehalten op de voerefficiëntie was bij lage temperatuur groter dan bij hoge temperatuur in de perioden van 29 tot 52 en van 53 tot 84 dagen. Bij hogere energiedichtheden was de benutting van eiwit dus beter bij lage temperatuur dan bij hoge temperatuur.

Het lysinegehalte had in dit experiment geen effect op de groei- en slachtresultaten. Verhoging van het energiegehalte had een negatief effect op de slachtresultaten. Het borstvleesrendement verminderde bij een toename van het energiegehalte (borstvleesrendement bij energiegehalte van 90%: 31.2%; bij 100%: 30.4%; en bij 110%: 29.4%). Waarschijnlijk hebben de kalkoenen als gevolg van de verminderde voeropname bij hogere energiegehalten een tekort aan een bepaald aminozuur die na lysine beperkend wordt.

In de afsluitende discussie worden de bevindingen uitgebreid bediscussieerd en worden enkele verschillen in voersamenstellingen tussen Amerika en Europa beschreven.

Samenvattend hebben de resultaten, zoals beschreven in dit proefschrift, het volgende duidelijk aangetoond:

- Kalkoenen passen zich zeer efficiënt aan chronische hittestress aan. Ze verminderen de voeropname waardoor ze kleiner blijven hetgeen resulteert in een lager metabolisme en dit draagt bij aan de overlevingsstrategie. Het blijkt zeer moeilijk om deze overlevingsstrategie middels wijzigingen in de voersamenstelling te beïnvloeden.
- Negatieve effecten van hoge omgevingstemperaturen namen toe naarmate de kalkoenen ouder werden maar de voerconversie, gerekend over de gehele productieperiode, was bij hoge temperatuur beter dan bij lage temperatuur.
- Ruimere arginine:lysine verhoudingen verbeterden de groeiresultaten wanneer het lysinegehalte in het voer marginaal was, waarschijnlijk als gevolg van een arginine-tekort.
- De respons van kalkoenen op hogere lysinegehalten was exact hetzelfde bij hoge en bij lage omgevingstemperaturen. De dieren bij hoge temperaturen produceerden alleen op een lager niveau.
- Kalkoenen vertoonden bij lage temperatuur een hogere borstvlees respons op hogere lysinegehalten dan bij hoge temperatuur.
- Hoog-energetische voeders verbeteren de voerefficiëntie. Dit gunstige effect was bij lage temperatuur groter dan bij hoge temperatuur in de eerste helft van de productieperiode.
- Het borstvleesrendement werd negatief beïnvloed door hoog energetische voeders.
- De energieopname per gram groei was bij hoge temperatuur lager dan bij lage temperatuur tot 16 weken leeftijd. Hierna was de energieopname per gram groei bij hoge temperatuur hoger dan bij lage temperatuur wat er op duidt dat kalkoenen na 16 weken ernstig hinder ondervinden van de hoge temperatuur. Het energiegehalte dient daarom voor deze periode verhoogd te worden naar ten minste 110% van de NRC (1994) omdat extra energie wordt gebruikt voor de warmteafvoer via de versnelde ademhaling (panting).

De resultaten uit dit proefschrift zijn nog eens samengevat in een overzicht met aanpassingen in de voersamenstelling voor verschillende leeftijden en gewichtsklassen en waarbij rekening is gehouden met de genetische vooruitgang in groei en waar van toepassing ook voor hoge omgevingstemperaturen. Hierbij dient opgemerkt te worden dat voor de meeste voedingsstoffen geen studies zijn gedaan om de exacte behoefte vast te stellen. De gegevens in Tabel 1 zijn gebaseerd op indicaties die verkregen zijn in de verschillende experimenten in dit proefschrift.

Tabel 1. Indicaties voor aanpassingen in de voersamenstelling voor optimale groeiresultaten van kalkoenhanen in verhouding tot NRC (1994) aanbevelingen.

Leeftijd (weken)	0 tot 4	5 tot 8	9 tot 12	13 tot 16	17 tot 20
	NRC (1994)				
	(%)				
Gewichtsklasse (kg)	0.06 tot 1.00	1.00 tot 4.00	4.00 tot 8.20	8.20 tot 12.60	12.60 tot 16.10
ME (MJ/kg)	11.7	12.1	12.6	13.0	13.4
Ruw eiwit	28.0	26.0	22.0	19.0	16.5
Lysine	1.60	1.50	1.30	1.00	0.80
Meth+Cys	1.05	0.95	0.80	0.65	0.55
Threonine	1.00	0.95	0.80	0.75	0.60
Arginine	1.60	1.40	1.10	0.90	0.75
Elektrolytenbalans	211	179	141	146	121
Lysine/ME verhouding	1.37	1.24	1.03	0.77	0.60
Arginine/lysine verhouding	1.00	0.93	0.85	0.90	0.94
	Veldkamp et al. (2002)				
	(%)				
Gewichtsklasse (kg)	0.06 tot 1.30	1.30 tot 4.60	4.60 tot 9.50	9.50 tot 14.50	14.50 tot 19.40
ME (MJ/kg)	11.1	12.1	12.6	14.1	14.1-14.6
Ruw eiwit	28.0	26.0	22.0	19.0	16.5
Lysine	2.00	1.60	1.30	1.00	0.80
Meth+Cys	1.18	0.95	0.80	0.65	0.55
Threonine	1.10	0.95	0.80	0.75	0.60
Arginine	2.20	1.75	1.45	1.10	0.90
Elektrolytenbalans	160	160	160	160	160
Lysine/ME verhouding	1.80	1.32	0.95	0.71	0.57-0.55
Arginine/lysine verhouding	1.10	1.10	1.10	1.10	1.10

Algemeen kan gesteld worden dat kalkoenen op exact dezelfde manier reageren op energie- en aminozurengehalten in kalkoenenvoer bij hoge en lage temperatuur, met uitzondering van de periode van 16 tot 20 weken leeftijd. In deze periode gebruiken kalkoenen extra energie voor onderhoud vanwege versnelde ademhaling (panting gedrag). Hoog energetische voeders verminderen de voeropname en hiermee ook de opname aan aminozuren significant in jonge kalkoenen waardoor de eiwitaanzet zal verslechteren. Het is belangrijk om de aminozuurgehalten hoog genoeg te stellen als wordt overgegaan op hoog energetische voeders.

Voor de praktijk betekent dit dat geadviseerd kan worden om de energiegehalten in de opfokperiode (0 tot 4 weken) omlaag te brengen tot onder de aanbevelingen van NRC (1994) om de kalkoenen in staat te stellen maximaal te groeien. In de periode van 16 tot 20 weken leeftijd is het belangrijk om de energiegehalten in de voeders te verhogen tot boven de NRC (1994) aanbevelingen, en in het bijzonder tijdens warm weer en speciaal in de standaard Europese voeders die gebaseerd zijn op tarwe. De lysinebehoefte voor de opfokperiode is geschat op 2.0%. Dit gehalte is 25% hoger dan de aanbevelingen van NRC (1994) en wordt veroorzaakt door de genetische vooruitgang in groei sinds 1994 en de beperkte voeropnamecapaciteit van jonge dieren. De standaard Europese voeders benaderen deze behoefte maar de Amerikaanse voeders bevatten te weinig lysine voor optimale groei van de kalkoenen. Na 8 weken leeftijd zijn de lysine aanbevelingen van NRC (1994) toereikend voor een optimale groei, mits de kalkoenen voldoende voer opnemen. Dit is ook van toepassing voor de andere aminozuren. Hierbij is dus opnieuw het energiegehalte in het voer erg belangrijk. Met name de vorming van borstvlees is gevoelig voor suboptimale aminozuurgehalten. Verder kan worden aanbevolen om de arginine:lysine verhoudingen te verhogen tot boven 1.00. Een elektrolytenbalans van minimaal 160 meq/kg is voldoende voor een optimale productie.

Studies naar behoefte van energie en aminozuren zullen frequent uitgevoerd moeten worden als de groeisnelheid van kalkoenen blijft toenemen.

CURRICULUM VITAE

Teun Veldkamp werd op 16 juli 1965 geboren in Olst en is opgegroeid op een boerderij (koeien, later varkens en weer later snijheesters) in het dorp Welsum. Na de basisschool werden vier jaren MAVO en twee jaren HAVO doorlopen. In 1981 behaalde hij zijn MAVO diploma en in 1983 zijn HAVO diploma aan de Christelijke Scholengemeenschap ‘De Heertganck’ te Heerde. In datzelfde jaar begon hij met de studie Nederlandse Landbouw aan de toenmalige Hogere Landbouwschool te Deventer. De studie werd in 1987 afgesloten in de afstudeerrichting ‘Veehouderij’ met als hoofdvak ‘Varkenshouderij’ en als bijvak ‘Melkveehouderij’. Aansluitend werd de Hogere Kadercursus ‘Pluimvee- en Varkenshouderij’ gevolgd op het toenmalige Opleidingscentrum voor Dierveredeling te Almelo en daarna was hij van januari tot december 1988 werkzaam als instructeur bij eerdergenoemd Opleidingscentrum. In 1989 heeft hij een functie als technisch medewerker aanvaard bij de Stichting Pluimveeteeltproefbedrijven te Beekbergen. Op 1 januari 1990 werd hij Technisch Medewerker kalkoenenhouderij bij de Stichting Praktijkonderzoek voor de Pluimveehouderij en werd de kennis van de kalkoenenhouderij verder uitgebouwd. Na enkele naamswijzigingen van de functie is hij in mei 2001 aangesteld als Wetenschappelijk Onderzoeker bij Praktijkonderzoek Veehouderij B.V. en nog steeds verantwoordelijk voor het onderzoek in de kalkoenenhouderij.

The research published in this dissertation has been conducted at the Research Institute for Animal Husbandry, P.O. Box 2176, 8203 AD Lelystad, The Netherlands.

PRAKTIJKONDERZOEK
VEEHOUDERIJ

Cover 'turkey aquarelle' by Regien Veldkamp-Jacobs.

Printed by Grafisch Service Centrum Van Gils B.V., Wageningen.