Meat Quality of Slow- and Fast-Growing Chicken Genotypes Fed Low-Nutrient or Standard Diets and Raised Indoors or with Outdoor Access

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ABSTRACT Consumer interest in free-range and organic poultry is growing. Two concurrent experiments were conducted to assess 1) the impact of alternative genotype and production system and 2) the impact of genotype and diet on meat quality of chickens for specialty markets. Specifically, a slow-growing genotype (slow) and a fast-growing genotype (fast) were raised for 91 and 63 d (females), respectively, or 84 and 56 d in the case of the second trial (males). In each trial, the slow birds were placed before the fast birds to achieve a similar final BW at processing. Each genotype was assigned to 4 pens of 20 birds each and raised in indoor floor pens in a conventional poultry research facility; each genotype was also assigned to 4 floor pens in a small facility with outdoor access. A low-nutrient diet was used, formulated for a slower rate of production. Birds were commercially processed and deboned at 4 h postmortem. In the second trial, the diets compared were a conventional diet that met NRC requirements or the low-nutrient diet, and all birds were raised indoors. There was an interaction between genotype and production system for the color (b*; $P < 0.05$). The meat and skin of the slow birds became more yellow when the birds had outdoor access; however, this did not occur when the fast birds had outdoor access. The breast meat of the slow birds had more protein and α-tocopherol ($P < 0.05$) than the fast birds and half the amount of fat ($P < 0.05$). In addition, the meat of the outdoor birds had more protein than the indoor birds ($P < 0.05$). The slow birds had poorer water-holding capacity but were more tender than the fast birds ($P < 0.05$). The type of diet had little impact on meat quality. These data indicate that meat quality differences exist between genotypes with different growth rates and raised in alternative production systems.

Key words: chicken, genotype, meat, alternative production system

2007 Poultry Science 86:2245–2255

INTRODUCTION

A growing awareness of human health and nutritional concerns has led to specialty markets for poultry produced in alternative systems such as free-range or organic. This trend, like the shift to further processing, can add value to poultry products.

Modern birds grow very fast due to genetic selection, efficient production systems, improved nutrition, and regular veterinary attention. Meat chickens reach a market weight as early as 6 wk and have high breast meat yields due to the high demand for breast meat in the United States. However, selection for fast growth and high yield may have negatively impacted the sensory and functional qualities of the meat (Dransfield and Sosnicki, 1999; Le Bihan-Duval, 2003), pushing muscle fibers to their maximum functional size constraints (Macrae et al., 2006). Parts and further processing represents 91% of US poultry markets (National Chicken Council, 2006). The amount of further processing in the US poultry industry underscores the need for good meat quality.

Although US consumers are accustomed to paying low prices for poultry meat, they are increasingly interested in products that they perceive as naturally produced or environmentally friendly, provide a high level of nutrition with no contaminants, good flavor, provide good welfare for the birds, and provide more information about the products they eat. The organic market in many countries has strong growth due to environmental concerns, personal health concerns, highly publicized food scares, and debates over genetically modified food (Chang and Zepeda, 2005). Interest is growing in quality aspects rather than quantity of meat and provide opportunities for market segmentation in the United States.

Whereas some countries have very specific definitions for free-range and or other specialty production, the USDA does not. The term free-range is permitted on labels after a review process in which producers simply submit written descriptions of their production system to ensure it provides outdoor access (USDA, 2006). As a result, production systems vary widely from large stationary houses with yards to small portable houses that are moved frequently to new pasture. In contrast, EU

Received January 8, 2007.
Accepted June 9, 2007.
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legislation for free-range poultry meat specifies maximum stocking densities for indoor and outdoor areas, age at slaughter, as well as a diet that is at least 70% cereals at finishing, ensuring a low-protein diet for slow growth (European Union, 1991). For organic production, the USDA's National Organic Program (USDA, 2005) requires outdoor access, organic feeds produced without synthetic chemicals, and prohibits the use of antibiotics, but again it does not specify stocking densities or slow-growing genotypes as the EU organic program does (EEC, 1991). Another well-known program, the French Label Rouge program, requires slow-growing genotypes, a low-nutrient diet at finishing, and an 81-d growing period (Ministere de L'Agriculture, 1996), and the products sell for a premium.

In the US slow-growing genotypes are not required in any specialty programs and, in fact, are not widely available. The conventional Cornish × White Plymouth Rock cross is typically used in specialty and conventional production. However, these fast-growing birds were developed for production in indoor, climate-controlled conditions. These birds grow quickly with high yield but they may not be appropriate for alternative systems where conditions are not well controlled. Meat quality is a complex trait that is influenced by genetic and environmental factors, and the variation in meat quality within and between animals can be large (Rehfeldt et al., 2004).

Conventional diets typically meet NRC requirements for commercial broilers; however, these requirements were developed for fast-growing broilers in indoor production. In specialty programs in Europe, a low-protein diet is used to support a slower rate of growth and improve meat quality (Komprda et al., 2000; Dreisigacker, 2005; Sundrum, 2006). Moreover, diets typically do not include routine medications or animal by-products.

Because US producers have the option to use any genotype in specialty production and various production practices, it is important to provide information to help them make decisions. The objectives of this study were to assess the impact of genotype, production system, and diet on meat quality. Specifically, slow- and fast-growing genotypes were compared, as well as a conventional indoor production system and alternative system with outdoor access. In addition, low-nutrient and conventional diets were compared. Alternative poultry production systems and genotypes need to be evaluated in a US setting where few studies of this type have been conducted. In addition, a domestic slow-growing genotype was used.

MATERIALS AND METHODS

Two experiments were conducted at the University of Arkansas Poultry Research Farm from August to November 2004; all procedures were approved by the University of Arkansas Institutional Animal Care and Use Committee. In both experiments a slow-growing genotype (slow; S & G Poultry, Clanton, AL) and a fast-growing genotype (fast; Cobb-Vantress Inc., Siloam Spring, AR) were compared. Because of the difference in growth rate, chick placement dates in both experiments were staggered in an attempt to reach a similar final BW at the time of processing (Fanatico et al., 2005b). For each treatment, 4 replicated pens per treatment were used, containing 20 birds per pen in both experiments. Feed and water were freely available in both trials.

Experiment 1: Production System

The objective of experiment 1 was to evaluate the impact of production system (indoor vs. outdoor access) on the meat quality of female slow- and fast-growing genotypes, which were raised for 91 or 63 d, respectively. Birds were randomly assigned to pens in a conventional indoor facility or a portable facility with outdoor access. The 4 treatments consisted of slow-growing birds given outdoor access (slow-out), slow-growing birds that were confined indoors (slow-in), fast-growing birds given outdoor access (fast-out), and fast-growing birds that were confined indoors (fast-in).

The indoor treatments were raised in floor pens in a conventional poultry research facility that contained a concrete floor, side curtains, and fans for ventilation and cooling. A thermostatically controlled heater and gas brooders along the length of the house were used to provide additional heat during brooding. Indoor pens measured 1.8 m × 1.8 m (6.2 birds/m^2) and contained 1 bell waterer and hanging tube feeder. Pens contained new wood shavings, and a constant photoperiod of 24 h was provided.

The treatments with outdoor access were grown in a small portable facility (that was not moved during the course of this trial) measuring 3.7 m × 5.5 m. The facility was insulated and naturally ventilated but had no access to power. Propane space heaters were used to keep nighttime temperatures above 15.5°C inside the house. No artificial lighting was used; photoperiod was limited to natural daylight. The house was subdivided into 8 indoor pens that opened to 8 separate yards, which was surrounded by electric net fencing. The indoor areas of each pen measured 1.2 m × 1.5 m (11.1 birds/m^2), and all pens allowed outdoor access through bird exits (0.6 m × 0.5 m). Birds were allowed access to grassy yards during daytime hours unless the outdoor temperature was less than 4.4°C. The outdoor yards were at 9.3 m^2 in dimension and completely covered with vegetation (a combination of cool-season fescue and warm-season Bermudagrass). The indoor portion of each pen contained 1 fount-style waterer and hanging tube feeder, and the floor was covered with fresh wood shavings. The outdoor portion of each pen contained 1 waterer and a range-type tube feeder with a rain shield. Temperature and photoperiod/intensity in this facility obviously differed from the conventional facility and was considered to be part of the alternative production system.

All birds were provided with multiphase diets that were formulated to be low in protein and energy as used by the French Label Rouge program for slow-growing birds (Table 1). Although the study was not conducted

Table 1. Composition of experimental diets[1]

Ingredient	Conventional				Low nutrient			
	Starter	Grower I	Grower II	Finisher	Starter	Grower I	Grower II	Finisher
	%							
Corn	55.06	66.12	72.17	77.48	61.45	64.75	69.85	72.05
Soybean meal	37.18	27.94	22.61	18.08	29.00	21.00	15.00	10.50
Wheat middlings	—	—	—	—	6.00	11.00	12.00	14.30
Corn oil	3.96	2.31	2.05	1.29	—	—	—	—
Dicalcium phosphate	1.20	1.30	1.10	1.10	1.40	1.20	1.00	1.00
Limestone	1.60	1.40	1.30	1.30	1.30	1.30	1.40	1.40
NaCl	0.40	0.40	0.30	0.30	0.40	0.30	0.30	0.30
Vitamin mix[2]	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Mineral mix[2]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Choline·Cl (60%)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
DL-Met	0.1563	0.0815	0.0174	—	—	—	—	—
Sacox salinomycin[3]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Calculated composition								
ME, kcal/kg	3,100	3,100	3,150	3,150	2,886	2,902	2,946	2,956
CP, %	22.9	19.4	17.4	15.7	20.5	17.7	15.5	13.9
Digestible Lys, %	1.10	0.89	0.76	0.65	0.94	0.76	0.62	0.52
Digestible Met, %	0.41	0.33	0.28	0.26	0.31	0.27	0.25	0.23
Digestible Cys, %	0.41	0.34	0.29	0.26	0.31	0.28	0.25	0.24
Digestible Thr, %	0.75	0.63	0.53	0.50	0.65	0.55	0.47	0.41
Ca, %	1.00	0.90	0.80	0.80	0.90	0.85	0.80	0.80
Nonphytate P, %	0.45	0.35	0.30	0.30	0.45	0.35	0.30	0.30
Protein:energy ratio[4]	7.39	6.26	5.52	4.98	7.10	6.10	5.26	4.70

[1]Conventional diets were fed in experiment 2, whereas low-nutrient diets were fed in experiments 1 and 2.

[2]Provided (per kilogram of diet): vitamin A, 7,715 IU (retinyl acetate); cholecalciferol, 2,204 IU; vitamin E, 16.5 IU (DL-α-tocopheryl acetate); thiamin, 1.54 mg; niacin, 38.6 mg; riboflavin, 6.6 mg; D-calcium pantothenate, 9.9 mg; vitamin B_{12}, 0.013 mg; vitamin B_6, 2.8 mg; D-biotin, 0.07 mg; folic acid, 0.88 mg; menadione dimethylpyrimidinol bisulfite, 3.30 mg; choline, 400 mg; ethoxyquin, 125 mg; Se, 0.1 mg; $MnSO_4 \cdot H_2O$, 308 mg; $FeSO_4 \cdot 7H_2O$, 250 mg; $ZnSO_4 \cdot 7H_2O$, 440 mg; $CuSO_4 \cdot 5H_20$, 39.3 mg; MgO, 43.9 mg; and $Ca(IO3)2 \cdot H_2O$, 3.2 mg.

[3]Sacox 60, Hoechst-Roussel Agri-Vet. Co., Somerville, NJ. Provided 66 mg of salinomycin activity/kg.

[4]Calculated as protein (%) divided by energy (kcal/kg) multiplied by 1,000.

under specific organic guidelines, the diets were devoid of animal by-products and synthetic methionine. Anticoccidial medication was included. All chicks were brooded in the indoor facility; chicks in the treatments with outdoor access were moved to the portable facility at 3 wk of age.

Experiment 2: Dietary Nutrient Level

The objective of experiment 2 was to evaluate the impact of dietary nutrient level (conventional vs. low-nutrient) on the meat quality of male slow- and fast-growing genotypes, which were raised for 84 or 56 d, respectively. Birds in this trial were raised for a shorter period of time than birds in experiment 1 (conducted concurrently) because processing capacity dictated that the 2 experiments be terminated on different days. Moreover, because of gender and diet differences, males in experiment 2 were expected to grow at a faster rate than the females in experiment 1. All birds were housed in the conventional indoor facility described above. The experimental diets consisted of a low-nutrient diet (as used in experiment 1) or a conventional diet that was formulated according to NRC (1994) recommendations (Table 1). Diets were provided in multiple phases, and the 4 treatments consisted of slow-growing birds fed the low-nutrient diets (slow-low), slow-growing birds fed the conventional diets (slow-conventional), fast-growing birds fed the low-nutrient diets (fast-low), and fast-growing birds fed the conventional diets (fast-conventional).

Experiments 1 and 2: Processing and Sample Analysis

At trial termination all birds were commercially processed at the University of Arkansas Pilot Processing Plant. Feed was withheld for 10 h before slaughter, and broilers were weighed individually at the plant. Automated equipment was used for stunning, scalding, picking, vent opening, and evisceration. Birds were electrically stunned (11 V, 11 mA, 10 s) and soft-scalded at 53°C for 120 s. Carcasses were prechilled at 12°C for 15 min and chilled (immersion) at 1°C for 1 h. After chilling, the carcasses were aged on ice for an additional 2.5 h before hand deboning at 4 h postmortem. Pectoralis major samples were then collected for evaluation of meat quality. Due to logistical reasons, birds in experiment 2 were aged on ice for 3.75 h and then deboned at 5.25 h postmortem.

At 24 h postmortem, the breasts were weighed to determine drip loss, which was expressed as a percentage of the initial muscle weight. Inadvertently, drip loss was not determined for experiment 2. Color was measured by the CIELAB method using a Minolta colorimeter (Minolta CR-300, Minolta Corp., Ramsey, NJ). In this method, higher L* values are light, higher a* values are red, and higher b* values are yellow. Three color measurements

were taken on the medial surface of each right breast and then averaged. The color of the skin (thigh) was also measured.

Breast fillets were cooked on racks in aluminum-lined, covered pans in a preheated convection oven to an internal temperature of 76°C. After cooking, the breasts were weighed to determine cook loss. Cook loss was determined by calculating the weight loss during cooking as a percentage of the weight before cooking. Total moisture loss was calculated from the cooked weight as a percentage of the raw weight at the time of deboning.

Tenderness was assessed on the breast fillets with the Meullenet-Owens razor shear (**MORS**) method (Cavitt et al., 2004). Razor blade shear energy (N·mm) was determined on intact fillets. Energy was determined using a Texture Analyzer (model TA-XT2i; Texture Technologies, Scarsdale, NY) with a 5-kg load cell using a razor blade with a height of 24 mm and a width of 8.9 mm set to a penetration depth of 20 mm. Crosshead speed was set at 5 mm/s and was triggered by a 10 g of contact force. Data points were collected with an acquisition rate of 200 points per second. Breasts were punctured across muscle fibers, and shear energy was calculated as the area under the force deformation curve from the beginning to the end of the test. The fillets from the fast-growing treatments averaged 34 mm in height, and those from the slow-growing treatments averaged only 20 mm. Data from fillets less than 20 mm in height were calculated to base shear energy on the smaller height.

Muscle pH of Pectoralis major was determined using the iodoacetate method as described by Sams and Janky (1986) and Jeacocke (1977). Five samples were taken from each replication of each treatment (n = 20 samples per treatment) at 24 h and frozen at –80°C for 3 mo.

Proximate analysis was performed on the raw breast (fat was trimmed) at the University of Arkansas Central Analytical Laboratory. In experiment 1, DM content, ash, protein, fat, vitamin A, α-tocopherol, and δ-tocopherol were determined by AOAC approved methods (AOAC, 1990). Fat was reported as a percent of DM. Five samples were taken from each replication in each treatment (n = 20 samples from each treatment). However, for vitamin analysis, only 2 samples from each replication of each treatment (n = 8 from each treatment) were analyzed. The nutrient analysis was more limited in experiment 2; there was no analysis of treatments with the fast-growing genotype (only slow-growing birds raised indoors and slow-growing birds raised with outdoor access), and then only DM, ash, protein, and fat content were analyzed (no vitamin analysis).

Statistical Analysis

The data were subjected to ANOVA using the GLM procedure (SAS, 2004) appropriate for a completely randomized design; a factorial arrangement of treatments was used. Treatment means were separated using the LSD multiple comparison procedure.

RESULTS AND DISCUSSION

There are many aspects to overall meat quality of poultry products, which may be affected by genotype, age, gender, type of production system, stocking density, temperature, diet, and other factors. The number of factors evaluated in these experiments was necessarily limited and focused on factors (genotype, age as a function of genotype, production system, and diet) likely to cause an impact or variation in meat quality. Outdoor poultry production, in particular, is inherently variable due to changes in temperature, photoperiod, level of activity, etc.

Growth data is reported separately (Fanatico et al., 2005b), but a brief summary is given here to provide an indication of the differences in weight gain and body composition. In experiment 1, the weight gain of the fast-growing birds exceeded that of the slow-growing birds even though the slow birds were started earlier in an attempt to reach a similar weight. In experiment 2, the low-nutrient diet reduced the weight gain of the slow, but not the fast; whereas on the conventional diet, weight gains were similar between the genotypes. The carcass weights reflected the differences in weight gain. The fast genotype exhibited superior breast yield in both experiments. Breast yield were reduced by the low-nutrient diet in the case of the fast birds. Although birds differed in both age and body composition, it is important to evaluate meat quality under conditions that are representative of alternative production systems.

Nutrient Composition

In experiment 1, which evaluated genotype and production system, there were no significant differences among treatments for dry matter or ash in breast meat ($P > 0.05$), indicating little difference in mineral contents (Table 2). This agrees with previous work (Latter-Dubois, 2000; Fanatico et al., 2005a), although Baeza et al. (2002) found that fast-growing ducks had increased protein and mineral contents and decreased moisture in breast muscle compared with slow-growing ducks, explained by a difference in the stage of muscle development.

There was a genotype effect for the protein content of the breast meat. The slow birds had higher protein than fast ($P < 0.05$; Table 2), which may be related to age. Typically, as an animal ages, the composition of body and muscle changes; protein and fat increase and moisture decreases (Aberle et al., 2001), although lower moisture was not evident in breast meat in experiment 1. In the present trial, the slow birds were 4 wk older than the fast at harvesting. Production system also affected protein content. The outdoor birds had higher protein than indoor ($P < 0.05$; Table 2), possibly related to exercise in an outdoor system contributing to muscle development and higher protein.

In experiment 2, which evaluated genotype and diet, the conventional diet led to a higher dry matter, lower ash content, and higher protein than the low diet ($P < 0.05$; Table 3), which may be related to the fact that the

Table 2. Impact of genotype and production system on nutrients in breast meat (experiment 1)

Item	DM,[1] %	Ash,[1] %	Protein,[1] %	Fat,[1,2] %	Vitamin A,[3] μg/g of fat	α-Tocopherol,[3] μg/g of fat
Slow-outdoor access	26.37	4.00	13.90[a]	4.47[b]	14.61	274.07[a]
Slow-indoor	25.99	4.10	13.56[b]	5.25[b]	9.90	224.93[ab]
Fast-outdoor access	25.56	4.10	13.45[b]	7.90[a]	7.11	152.43[b]
Fast-indoor	26.5	4.00	13.00[c]	8.86[a]	11.34	212.40[ab]
Pooled SEM	0.26	0.05	0.09	0.33	4.20	65.76
ANOVA	*P*-value					
Genotype	0.2280	0.9132	0.0001	0.0001	0.1933	0.0758
Production system	0.6818	0.5980	0.0010	0.0214	0.9152	0.8771
Genotype × production system	0.0799	0.1470	0.5465	0.7812	0.0654	0.1392

[a–c]Means within a column lacking a common superscript differ ($P < 0.05$).

[1]n = 20.

[2]Based on a percentage of DM.

[3]n = 8.

conventional diet resulted in higher fat in breast meat. As the amount of fat increases in the body, the moisture decreases (Aberle et al., 2001).

There were also genotype and production system effects in terms of intramuscular fat content (**IMF**; experiment 1). The breast meat of the slow birds had half the amount of fat than fast ($P < 0.05$; Table 2). Poultry meat is known for being low in fat because unlike other meat animals, fat is mainly deposited subcutaneously or in the abdomen rather than in the meat (IMF). Domestic poultry selected for rapid growth show excessive body fat deposition (Leclercq, 1988), although a certain amount of intramuscular fat is associated with sensory and meat quality traits (Gerbens, 2004). Like the present study, Wattanachant et al. (2004) also reported higher protein and lower fat in the slow-growing genotype compared with fast-, and Havenstein et al. (2003) reported that 2001 broilers had more whole carcass fat than 1957 broilers at 4 different ages.

The outdoor birds had lower fat than the Indoor birds ($P < 0.05$; Table 2; experiment 1). This is consistent with other studies that have shown that the additional space provided in free-range and organic production increases leanness in poultry, most likely due to activity (Robertson et al., 1966; Lei and van Beek, 1997; Castellini et al., 2002a). Low density and outdoor access favor myogenesis instead of lipogenesis (Castellini et al., 2002b).

In experiment 2, the conventional diet led to a higher fat content than the low diet, which is not surprising because the conventional diet is higher in energy. Havenstein et al. (2003) found that modern diets resulted in better growth rates but also produced considerably higher fat levels than 1957 diets. Peter et al. (1997) studied the impact of protein level and energy level on carcass and meat quality of slow-growing meat chickens grown to 12 wk and found that breast meat quality (chemical composition, grill loss, shear force) was only slightly influenced by feeding. Peter et al. (1997) found that increasing protein level lowered IMF in breast meat, whereas increasing dietary energy increased IMF. Crude protein content of the carcass increases with increasing dietary protein, whereas increasing dietary energy leads to decreased protein contents in the carcass (Peter et al., 1998).

There were no significant differences in terms of vitamin A ($P > 0.05$), but a genotype effect existed for α-tocopherol (Table 2; experiment 1). Vitamin E is a fat soluble vitamin, and although the fast birds had higher α-tocopherol content than slow, when expressed on a unit of fat basis, the content of α-tocopherol was higher in slow birds than the fast ($P < 0.05$). Surprisingly, there was no impact on vitamins from outdoor access. It was expected that there would be more vitamins in the meat of outdoor birds because forage plants are high in vitamins. Karsten et al. (2003) found eggs from chickens raised on legume pasture have more vitamin A and E and more omega-3 fatty acids than eggs from chickens raised indoors. Robertson et al. (1966) found the meat of free-range birds to contain more thiamine than the indoor birds. It may be necessary to move housing frequently, especially in seasons when there is little regrowth of plants, to see a greater impact from production system.

Table 3. Impact of diet on nutrients in breast meat (experiment 2)

Item	DM,[1] %	Ash,[1] %	Protein,[1] %	Fat,[1] %
Conventional diet	26.41[a]	3.97[b]	13.29[b]	7.23[a]
Low-nutrient diet	25.84[b]	4.11[a]	13.51[a]	5.08[b]
Pooled SEM	0.12	0.03	0.06	0.43
	P-value			
ANOVA	0.0120	0.0136	0.0303	0.0123

[a,b]Means within a column lacking a common superscript differ ($P < 0.05$).

[1]n = 20.

Color

Color is one of the first characteristics noticed by consumers when buying meat products. In natural and organic markets, where carcasses are often marketed whole, the color of the skin plays a particularly important role. Skin color is dependent on the genetic ability of the bird to produce melanin pigments in the dermis and epidermis, as well as to absorb and deposit carotenoid pigments in the epidermis (Fletcher, 1999). Scalding can also impact

Table 4. Impact of genotype and production system on breast meat[1] and thigh[1] skin color (experiment 1)

	Skin			Meat		
Item	L*	a*	b*	L*	a*	b*
Slow-outdoor access	72.19[b]	0.44[c]	14.58[a]	51.04[a]	2.55[b]	7.55[a]
Slow-indoors	73.68[a]	–0.17[d]	13.17[b]	51.91[b]	2.54[b]	6.32[b]
Fast-outdoor access	69.86[c]	4.01[a]	9.98[c]	51.77[ab]	4.12[a]	4.84[c]
Fast-indoors	70.05[c]	3.32[b]	10.27[c]	52.16[b]	3.83[a]	5.29[c]
Pooled SEM	0.49	0.27	0.39	0.25	0.18	0.20
ANOVA	*P*-value					
Genotype	0.0001	0.0001	0.0001	0.0750	0.0001	0.0001
Production system	0.0049	0.0004	0.1768	0.0289	0.4244	0.0765
Genotype × production system	0.0211	0.7523	0.0489	0.3552	0.4618	0.0013

[a–d]Means within a column lacking a common superscript differ ($P < 0.05$).

[1]n = 80; measured at 24 h postmortem.

skin color. The use of a soft scald allows retention of the cuticle and associated pigments, whereas a hard scald, which is common during processing in the United States, will remove portions of the cuticle and the epidermis and pigments as well.

In experiment 1, there was an interaction between genotype and production system for the yellowness of the skin ($P < 0.05$). The slow birds had significantly higher b* values than fast both indoors and outdoors, indicating more yellow skin, and when the slow had access to the outdoors, their skin became even more yellow than when indoors ($P < 0.05$; Table 4). Production system had no effect on skin color of the fast birds ($P > 0.05$). This interaction was attributed to the fact that the slow birds spent more time outdoors and were more active than the fast and foraged more. Use of the outdoor area and foraging behavior are reported separately (C. Falcone and J. Mench, University of California, Davis, CA, unpublished data). Apparently, the fast birds did not forage sufficiently to ingest pigments from the plants. This interaction is in agreement with previous findings (Fanatico et al., 2005a).

In selling cut-up parts, uniformity of meat color in packages is important. Myoglobin content is a major factor contributing to meat color and is dependent on species, muscle, and age of bird. Other intrinsic factors, such as muscle and pH, can also influence meat color (Fletcher, 2002). Color is also an indicator of meat quality (Owens et al., 2000; Woelfel et al., 2002). The L* value indicates the degree of paleness and is associated with poor meat quality; pale, soft, and exudative meat is an increasing problem in the poultry industry (Baeza et al., 2002). In the present trials, there was no genotype effect on L* value. In contrast, Berri et al. (2001) found that the breast meat of breeds selected for fast-growth was more pale and less red than that of nonselected birds, which was explained by a lower level of heme. Because heme pigments normally increase with age (Baeza et al., 2002), slow-growing birds normally have a redder meat than fast- because the slow-growing are typically older (Gordon and Charles, 2002). However, in the present study, the slow birds were less red (lower a*) than the fast ($P < 0.05$). Nielsen et al. (2003) also found the breast meat of slow-growing birds to be less red than fast-growing. The meat of the slow birds was more yellow than that of the fast birds ($P < 0.05$), which agrees with other findings (Quentin et al., 2003; Fanatico et al., 2005a; Santos et al., 2005a).

A production system effect was evident in the meat as in the skin. The meat of the indoor birds had higher L* values (paler meat) than outdoor birds ($P < 0.05$; Table 4), but all the values were within normal ranges as characterized by Woelfel et al. (2002). In contrast, Castellini et al. (2002a) found that organic production system with outdoor access resulted in higher paleness values compared with indoor system. These differences in trends of meat paleness may be related to the differences in environmental conditions in each study. Outdoor access and associated exercise could impact muscle fibers and color. In fact, Brackenbury and Williamson (1989) found that the oxidative capacity of the chicken iliotibialis lateralis caudalis muscle increased from 40 to 60% after 15 wk of treadmill training. Outdoor access resulted in the same impact on the yellowness (b* value) of slow as was discussed above for skin.

In experiment 2, the genotype effect on color was similar to results of experiment 1 (Table 5). On the conventional diet, the meat of the slow birds was more pale than the fast birds, but in the case of the low diet, there was no difference between genotypes ($P > 0.05$). Lyon et al. (2004) has found that breast meat is lighter in color when birds are fed a wheat-based diet compared with corn. In the present study, although the low diet included wheat middlings and less corn than the conventional, the low diet did not result in lighter meat.

pH

Postmortem pH decline is one of the most important events in the conversion of muscle to meat due to its impact on meat texture, color, and water-holding capacity (**WHC**; Aberle et al., 2001). The rate of pH decline is dependent on the activity of glycolytic enzymes just after death; the ultimate pH is determined by the initial glycogen reserves of the muscle (Bendall, 1973). A low pH is associated with poor water-holding capacity and poor functionality (Owens et al., 2000; Woelfel et al., 2002), and

Table 5. Impact of genotype and diet on breast meat[1] and thigh skin color[1] (experiment 2)

	Skin			Meat		
Diet	L*	a*	b*	L*	A*	b*
Slow-low nutrient	73.28[a]	0.69[d]	10.94[a]	52.19[a]	2.83[b]	3.92[a]
Slow-conventional	72.31[b]	1.04[c]	10.49[a]	52.89[b]	2.93[b]	4.38[a]
Fast-low nutrient	70.60[c]	2.98[b]	7.81[b]	52.43[ab]	4.51[a]	2.48[b]
Fast-conventional	68.24[d]	3.51[a]	6.83[b]	51.66[a]	4.79[a]	2.85[b]
Pooled SEM	0.27	0.12	0.35	0.30	0.13	0.21
ANOVA	*P*-value					
Genotype	0.0001	0.0001	0.0001	0.1221	0.0001	0.0001
Diet	0.0001	0.0025	0.0610	0.8989	0.1522	0.0661
Genotype × diet	0.0213	0.4710	0.4639	0.0289	0.5132	0.8475

[a–d]Means within a column lacking a common superscript differ ($P < 0.05$).

[1]n = 80; measured at 24 h postmortem.

a high pH is associated with poor shelf life because it is a more favorable environment for bacteria (Aberle et al., 2001). Although all pH values in this study were in normal ranges and do not indicate problems, in experiment 1, the slow birds had a lower ultimate pH compared with the fast ($P < 0.05$; Table 6). Others have also found lower pH in slow-growing genotypes compared with fast-growing (Wattanachant et al., 2004; Berri et al., 2005; Santos et al., 2005b). Selection for fast growth and high yield has reduced the rate and extent of pH decline (Berri et al., 2001, 2005), possibly due to a decrease in the glycolytic potential, which is essentially a measure of glycogen content (Monin and Sellier, 1985; Baeza et al., 2002). Fernandez et al. (2001) found fast-growing turkeys had lower glycogen content than slow-growing in the pectoralis superficialis muscle, which normally leads to less decline in pH.

Slow-growing birds may be more stress susceptible than fast-growing birds. According to Debut et al. (2005), active birds such as slow-growing birds are more prone to shackling stress, which leads to rapid breast muscle acidification. The fast-growing birds do not struggle as much, and their pH decline is slower. Breast muscle is more sensitive to wing flapping on the shackling line than thigh muscle.

Exercise is likely to affect muscle metabolism (Farmer et al., 1997). In the present study, outdoor access resulted in lower pH in slow, and there was no impact in fast. The impact of exercise is likely to differ due to the amount of foraging and the environment. Like the present study, Castellini et al. (2002a) and Culioli et al. (1990) also found outdoor access resulted in lower pH, but in contrast, Alvarado et al. (2005) found that outdoor access resulted in higher pH.

Table 6. Impact of genotype and production system on pH and instrumental tenderness of breast meat (experiment 1)

Item	pH[1]	TE,[2] N·mm
Slow-outdoor access	5.53[c]	111.16[b]
Slow-indoors	5.60[b]	102.57[b]
Fast-outdoor access	5.72[a]	140.11[a]
Fast-indoors	5.69[a]	149.88[a]
Pooled SEM	0.02	5.10
ANOVA	*P*-value	
Genotype	0.0001	0.0001
Production system	0.2947	0.9096
Genotype × production system	0.0187	0.0941

[a–c]Means within a column lacking a common superscript differ ($P < 0.05$).

[1]n = 20.

[2]Meullenet Owens razor shear, TE = total energy; n = 40.

Water-Holding Capacity

Water-holding capacity is important in whole meat and further processed meat products and can be measured by drip or cook loss. Poor WHC affects functionality, as well as sensory characteristics. The slow birds had higher drip loss than the fast ($P < 0.05$; Table 7), which agrees with earlier findings (Fanatico et al., 2005a). Because the fillets from the slow birds are smaller and thinner in dimension, they had relatively more surface area in relation to muscle mass exposed to the air, which may have resulted in more drip loss. As breast weight increased, the drip loss was less (r = –0.73 in experiment 1). Baeza et al. (2002) found a decrease in drip loss with increasing age at slaughter, partly explained by the decrease in muscle water content of duck breast (Baeza et al., 2002). In the present study, the fast birds had more thaw loss than the slow ($P < 0.05$), possibly related to the freezing rate. Because fillets from fast birds were heavier ($P < 0.05$) and had large dimensions (i.e., thicker), the freezing rate was likely slower, possibly resulting in larger ice crystal formation, leading to more membrane damage. The fast birds also lost more water than the slow during cooking ($P < 0.05$), which may be related to higher fat in fast. Chartrin et al. (2006) found that cooking loss was greater in breast muscle containing high lipid levels. This also may be due to larger fillet dimensions, which leads to more cooking time and more moisture loss. As breast weight increased, so did thaw and cook loss (r = 0.85 and 0.90, respectively, in experiment 1). Previous findings showed a higher cook loss in slow-growing broilers compared with fast-growing broilers (Lonergan et al., 2003; Fanatico et al., 2005a), which may be related to the higher fat content of the fast.

When total moisture loss is considered, the slow birds had more moisture loss than the fast. This agrees with

Table 7. Impact of genotype and production system on water-holding capacity of breast meat (experiment 1)

Item	Breast weight,[1] g	Drip loss,[1] %	Thaw loss,[1] %	Cook loss,[1] %	Total loss,[1,2] %
Slow-outdoor access	311.8[b]	1.26[a]	0.63[b]	13.37[d]	32.19[bc]
Slow-indoors	296.2[b]	1.54[a]	0.81[b]	14.58[c]	37.52[a]
Fast-outdoor access	792.4[a]	0.88[b]	1.24[a]	18.11[b]	28.83[c]
Fast-indoors	799.8[a]	0.95[b]	1.52[a]	22.1[a]	33.12[abc]
Pooled SEM	0.03	0.11	0.11	0.38	1.55
ANOVA	*P*-value				
Genotype	0.0001	0.0007	0.0001	0.0001	0.0274
Production system	0.8776	0.1204	0.0538	0.0001	0.0090
Genotype × production system	0.6654	0.3603	0.6741	0.0030	0.7412

[a–d]Means within a column lacking a common superscript differ ($P < 0.05$).

[1]n = 80.

[2]Calculated as [(fillet weight at deboning – cooked weight) / fillet weight at deboning] × 100.

Santos et al. (2005b) who found that the breast meat of a slow-growing genotype had poorer WHC than fast-growing ones. Castellini et al. (2002b) attributed poor WHC in slow-growing birds to their tissue being less mature metabolically at harvest than the fast-growing birds. Interestingly, Berri et al. (2005) found when slow-growing and fast-growing, heavy birds were slaughtered under conditions which minimized struggle, the slow-growing had better WHC, as measured by drip loss, than birds from a heavy line. The authors concluded that breast meat from heavy broilers was predisposed to poor processing ability.

Production system impacted WHC. The indoor birds had more total loss than the outdoor ($P < 0.05$) (Table 7; experiment 1). This agrees with Latif et al. (1998) who found under intensive management (indoor), a slow-growing genotype had better WHC (leg quarters) than fast-growing, and Castellini et al. (2002a) found that organic production with outdoor access system resulted in poorer WHC.

There was an interaction between genotype and diet for the thaw loss (experiment 2). The low diet led to more thaw loss in the case of the fast birds ($P < 0.05$) but not the slow (Table 8). For cook loss, there were both genotype and diet main effects. The slow birds had a higher cook loss than the fast, and the birds on the low diet had a higher cook loss than the conventional ($P < 0.05$). Jensen et al. (1984) also found birds on a low energy diet had lower cook loss. However, Quentin et al. (2003) found diet concentration had little impact on pH and drip loss in fast-, medium-, and slow-growing meat chickens that were fed with 3 different levels of protein and energy.

Table 8. Impact of genotype and diet on water-holding capacity of breast meat (experiment 2)

Item	Breast weight,[1] g	Thaw,[1] %	Cook,[1] %
Slow-low nutrient	352[c]	2.17[b]	25.07[a]
Slow-conventional	408[b]	2.18[b]	23.92[ab]
Fast-low nutrient	544[a]	3.40[a]	22.13[b]
Fast-conventional	590[a]	1.47[c]	18.35[c]
Pooled SEM	13	0.19	0.68
ANOVA	*P*-value		
Genotype	0.0001	0.2015	0.0001
Diet	0.0024	0.0003	0.0033
Genotype × diet	0.6988	0.0003	0.0763

[a–c]Means within a column lacking a common superscript differ ($P < 0.05$).

[1]n = 80.

Tenderness

Texture, particularly tenderness, is a crucial consumer attribute. In the present study, the slow birds were more tender than the fast birds in both experiments ($P < 0.05$) as measured by the MORS method (lower total energy; Table 6). The values for slow treatments were in the category of extremely tender, and the fast treatments were categorized as moderately to slightly tender as categorized by Cavitt et al. (2004). It was expected that the slow birds would be less tender than the fast because the slow were older. According to Fletcher (2002), older birds are more mature at the time of harvest and have more cross-linking of collagen. In addition, the fast birds had more IMF in breast meat, which is usually associated with higher tenderness (Le Bihan-Duval, 2003). Other studies have found the meat of slow-growing or older genotypes to be less tender compared with fast-growing (Castellini et al., 2002b; Wattanachant et al., 2004; Fanatico et al., 2005a). However, like the present study, Farmer et al. (1997) found that breast meat from slow-growing birds was more tender than meat from fast-growing birds.

Although all treatments were deboned at 4 h postmortem, it is possible that fast and slow genotypes have different rates of rigor due to their different BW. Berri et al. (2005) found that a heavy line of fast-growing broilers had higher pH at 15 min postmortem than slow- and fast-growing birds, although the ultimate pH of the fast-growing (not heavy line) was higher than others.

The differences in tenderness may be related to endogenous proteolytic activity during aging. Birds with large muscle mass accrete protein through reduced protein catabolism (Dransfield and Sosnicki, 1999). Because they have reduced proteolytic potential, there is less postmortem proteolysis and, therefore, reduced tenderization in the meat. Schreurs et al. (1995) compared birds with different grow rates and found that fast-growing birds show little proteolytic activity, whereas slow-growing birds like White Leghorns show high rates. There was a 12-fold

difference in the amount of μ-calpain. Slow-growing birds had higher μ-calpain and m-calpain and lower calpastatin than fast-growing birds (Schreurs et al., 1995).

Outdoor access has been shown to result in meat that is more firm than indoor production (Castellini et al., 2002a; Santos et al., 2005a). In this trial, there was no impact of production system on tenderness. In previous research, outdoor access actually resulted in more tender meat in the case of the fast birds (Fanatico et al., 2005a). According to Dingboom and Weijs (2004), the impact of exercise on meat quality is minor and ambiguous.

Adequate nutrition is needed for normal muscle development and weight gains, but low-nutrient diets are used in Europe with extensive poultry production to slow growth and improve meat quality. Feed restriction in quantity or quality leads to decreased muscle fiber diameter (Rehfeldt et al., 2004). However, in the present trial, the low nutrient diet did not have a significant impact on tenderness (data not shown). Chartrin et al. (2006) found that feeding levels had no effect on tenderness, but tenderness was negatively correlated with breast muscle weight. Ristic (1988) compared a high-protein/high-energy diet and a high energy diet compared with a standard diet and found no significant differences in sensory data, cooking losses, instrumental tenderness, or chemical composition. Grashorn (2006) found that nutrient level did not impact the texture of the breast. Moritz et al. (2005) found few differences in cook loss and texture of breast meat among broilers raised in conventional and alternative production systems and without or without synthetic methionine and feed restriction, although feed restriction led to a firmer breast texture.

Conclusions

The study focused on factors important to alternative poultry producers: genotype, production system, and diet. A better understanding of meat quality of widely divergent genotypes raised in different production systems and provided different diets will help producers make informed decisions about their production systems.

There was little effect from a meat quality perspective of raising birds with outdoor access, other than reduced fat and increased yellow color, but some consumers prefer this natural system (Neufield, 2002). There were advantages from the use of an alternative genotype, including more vitamins; however, WHC was worse. Slow-growing birds are less efficient than fast-growing birds due to their slower rate of growth; however, slow-growing genotypes may bring premium prices. Although some producers use a low energy diet to raise birds more slowly to improve the meat quality (Dreisigacker, 2005), there were no meat quality advantages from using a low nutrient feed in this study. These data indicate that meat quality differences exist among genotypes with different growth rates and reared in alternative production systems and may be ways to add value to poultry carcasses.

ACKNOWLEDGMENTS

We would like to thank the USDA Southern Region Sustainable Agriculture Research and Education program and the US Poultry and Egg Association for funding for this research.

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