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Factors affecting breast meat yield in turkeys

L.A. CASE[1]*, S.P. MILLER[1] and B.J. WOOD[1,2]

[1]Department of Animal and Poultry Science, University of Guelph, Guelph, ON, Canada; [2]Hybrid Turkeys, Suite C, 650 Riverbend Drive, Kitchener, ON, Canada
***Corresponding author: lcase@uoguelph.ca**

There is a global demand for turkey products and a high value attributed to breast meat from these birds. Breast meat can be considered the most important component of the carcass and consequently it is important to investigate factors that influence breast meat yield (BMY). The BMY trait is influenced by both genetics and the environment at all stages from pre-hatch until the end of the commercial growing period. Additive genetic effects appear to be the primary contributor to BMY, as there is minimal evidence for heterosis or maternal inheritance. The genetic potential for BMY is affected by sex, strain, and selection pressure within a pure line and this affects both muscle morphology and yield. For a turkey to fulfil its full genetic potential for BMY, optimal husbandry and management is required. Nutrition is an important component of production efficiency, although turkeys may be able to tolerate a reduction in dietary protein levels without a negative response in BMY, provided that the levels of all other nutrients are sufficient to meet metabolic needs. Housing conditions, such as barn temperature and lighting, also influence production efficiency. Cooler temperatures increase both weight gain and BMY, relative to a warmer rearing environment. Further, a light cycling programme with a daily set light and dark schedule is associated with higher BMY values compared to frequently alternating light and dark periods throughout the day in an intermittent lighting regime. Due to the influence of both genetics and the environment on BMY, maximisation of yield requires optimum management by all segments of the turkey production industry from the primary breeder through to the commercial grower.

Keywords: yield; turkeys; allometric growth; genetics; hatchery; nutrition; management

Introduction

Turkey production is both an important and profitable agricultural industry and the investigation of factors that affect profitability is warranted, especially for a consumer-valued product such as turkey breast meat. Increasing the proportion of breast meat

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contributes to higher yields from the carcass and increases overall profitability as breast meat has the highest economic value relative to other carcass components and makes a large contribution to the gross margin. Consequently, breeding and management practices that optimise this trait should be identified and implemented. Sex, strain, and selection pressure affect final carcass yields. This inherited genetic potential interacts with environmental factors including nutrition, light, and temperature to determine the proportion of breast meat on the carcass. Breast meat accretion is influenced at all stages of production, including breeder, hatchery, and grow-out operations. This necessitates careful planning of management practices throughout all segments of the industry in order for a turkey to fulfil its full genetic potential. As a result, all segments of the turkey industry must be conscious of the impact their management decisions can have on the final breast meat yield.

Defining breast meat yield

Breast meat yield is most commonly defined as the proportion of breast meat relative to the weight of the processed carcass or as the weight of the breast relative to slaughter weight. The *M. pectoralis superficialis* (fillet) and the *M. pectoralis profundus* (tender) are the contributing muscles to breast meat and are considered in these definitions. However, the method of carcass dissection and muscle isolation is variable between processing plants and BMY analysis is often only relevant when comparing measurements taken at the same location. As a result, it would be beneficial to have a standard procedure for breast meat separation. This would enable a straight-forward comparison between carcass yield studies based on the evaluation of equivalent cuts. To this end, a review was published to illustrate methods of turkey carcass dissection (Hahn and Spindler, 2002). A regulated dissection procedure would ensure that the weight of the two breast muscles and carcass weight, which are required to calculate BMY, are comparable across studies.

Allometric growth

The relative body composition of a turkey changes throughout the growing phase because the body components do not increase in size at a uniform rate (Peng *et al.,* 1985; Brenoe and Kolstad, 2000). This allometric growth results in a disproportionate increase in the size of the breast at later stages of the growth trajectory. The observed increase in the proportion of breast meat is primarily due to an accelerated increase in the depth of the breast, as the relative length and width remain fairly constant with increasing body size (Swatland, 1979, 1989b). *M. pectoralis superficialis* growth is primarily responsible for the relationship between breast and body size, as this muscle has a stronger and more consistent relationship with both body weight and age across strains and sexes (Barbour and Lilburn, 1995; Brake *et al.,* 1995). A positive linear correlation between BMY and body weight reflects these phenotypic observations (Summers *et al.,* 1989; Brake *et al.,* 1995).

Similar to allometric growth between other body compartments, the various muscles within the breast grow at different rates. The proportion of the *M. pectoralis superficialis* is increased in growth selected lines (Wilson *et al.,* 1990; Lilburn and Nestor, 1991). This suggests that selection to increase body size has a stronger impact on the growth rate of the *M. pectoralis superficialis* relative to the *M. pectoralis profundus*. The allometric growth of the turkey, therefore, results in unequal expansion of the breast relative to other

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body components and growth rates are also variable between the breast muscles. Consequently, the overall growth characteristics result in a linear increase in BMY as body size increases.

Muscle development

As a turkey's muscles develop, their increase in size can be attributed to an increase in both the number (hyperplasia) and the size (hypertrophy) of the muscle fibres. The relative influence of these two factors changes between the growing phases with hyperplasic and hypertrophic growth predominating pre- and post-hatch, respectively. The significance of post-hatch hypertrophy is indicated by the increase in protein and DNA content of the muscle during the growing phase (Kang *et al.,* 1985; Swatland, 1989b; Mozdziak *et al.,* 1994; Velleman, 2007). Muscle development is consequently not a static process and the factors controlling breast growth shift throughout development from early hyperplasia to later hypertrophy.

The early stage of post-hatch hypertrophy is characterized by high satellite cell mitotic activity and a high rate of protein deposition, and this initial phase is followed by an increase in the cytoplasm to nucleus ratio of the fibres (Kang *et al.,* 1985; Mozdziak *et al.,* 1994; Moore *et al.,* 2005). This pattern indicates that hypertrophy occurs initially by contributing new genetic material to the muscle fibres, and these new nuclei enable the expansion of muscle fibre size. The initial supply of new DNA is critical, and restricting satellite cell proliferation can decrease a muscle's capacity for growth, which can reduce the size of the mature muscles (Mozdziak *et al.,* 1997, 2000). The outcome of the hypertrophic growth is an increase in fibre width and in the size of the extracellular space, while decreasing the fibre density as the bird ages (Velleman *et al.,* 2003b). It is evident that hypertrophic growth is a dynamic process and new genetic material must first be generated to provide the DNA required for the fibres to expand in size.

The muscle growth processes interact differently with the growth trajectories of each sex (Shaklee *et al.,* 1952; Chapuis *et al.,* 1996). The linear relationship between BMY and body weight varies, and this is demonstrated by the different intercept and regression coefficient terms for toms and hens (Brake *et al.,* 1995). These developmental differences are apparent physiologically where toms show an increased fibre diameter, increased number of muscle fibres, and increased rate of satellite cell differentiation compared to hens (Swatland, 1989a; Velleman *et al.,* 2000). Cumulatively, these studies indicate that male and female birds have different growth physiology related to both hypertrophy and hyperplasia.

Inheritance

Additive genetic factors affect BMY as a trait independent of the relationship between absolute breast weight and body size (Velleman *et al.,* 2003b; Velleman and Nestor, 2004). There are limited heritability estimates in the literature, but the few there are display moderate to high heritabilities (BMY $h^2 = 0.32$, breast width $h^2 = 0.30$ (Nestor *et al.,* 1988; Le Bihan-Duval *et al.,* 2003)). This would indicate that selection based on BMY would result in relatively rapid genetic progress given a breeding objective developed with yield as an important component.

The patterns of inheritance and impact of selection on BMY have been studied by comparing lines that have been developed with different selection emphases on BMY. This has been done by contrasting experimental strains, developed by selecting for body

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weight alone, to commercial lines which are characteristically selected for both growth rate and BMY (Velleman *et al.,* 2003b; Velleman and Nestor, 2004). Differences in BMY between lines can consequently be used to determine the impact of selection emphases on characteristics of the breast muscles, and to provide an indication of the level of genetic gain that can be achieved by including BMY in a breeding objective.

Phenotypic variation in BMY is related to changes in muscle morphology. These physiological differences can be attributed directly to increasing BMY and increases in growth rate. Increased body size in both growth-selected and commercial lines has been associated with a decrease in the width of the perimysial and endomysial spaces relative to random bred control lines (Velleman *et al.,* 2003b; Velleman and Nestor, 2004). The proliferative capacity of satellite cells increases with selection for growth and the higher amount of genetic material is associated with larger numbers and size of the muscle fibres. Larger muscles are favoured by focusing selection pressure on BMY in commercial breeding objectives, as seen by an increase in fibre width and a decrease in fibre density (Swatland, 1989a; Wilson *et al.,* 1990; Cherel *et al.,* 1994; Merly *et al.,* 1998; Velleman *et al.,* 2000). These divergent patterns in morphology are established early in development as differences in the extracellular space and fibre width are apparent in growth selected and commercial lines, respectively, in the embryo at 25 days of incubation (Velleman *et al.,* 2002a). As a result of a selection emphasis on growth, the characteristics of the extracellular space are altered and increased selection pressure on BMY is associated with a change in the morphology of the muscle fibre.

In contrast to additive genetic variation, heterosis and maternal effects do not appear to have a significant effect on BMY. Line crosses do not consistently show heterotic effects, reportedly only being detected for one specific cross within one study (Velleman and Nestor, 2004). Similarly, in a maternal study, objective measurements were not significant when contrasts were made between F_2 crosses and did not support differences detected in visual scores of muscle morphology (Velleman *et al.,* 2003a; Velleman and Nestor, 2004). These studies would indicate that additive genetic factors are the primary genetic contributor to variance in breast morphology, while maternal and heterotic effects have a lower impact on phenotypic differences.

Effect of strain

Muscle morphology and breast yields differ between genetic strains, indicating a divergence in additive genetic factors between genetic groups. There are primarily two genetic pools maintained in the turkey industry; Aviagen Turkeys and Hybrid Turkeys, with a number of small niche breeders supplying the balance of the world parent stock market (Wood *et al.*, 2006). Pure lines derived from nucleus breeding populations are crossed to create commercial strains and these genetic groups, as well as selection pressure within the crossed lines, results in varying BMY potential between strains (MacNeil and Buss, 1968; Blair *et al.*, 1989; Lilburn and Nestor, 1991; Brake *et al.,* 1995). As a result, the coefficients describing the linear relationship between BMY and body weight are specific to each strain (Brake *et al.,* 1995).

Variation in breast growth between strains supports the distinct genetic parameters and relationships with body weight. Before 12 weeks of age, strain effects are most significant on the proportion of *M. pectoralis superficialis* (Barbour and Lilburn, 1996). The effect of strain shifts throughout the growing period to significantly affect *M. pectoralis profundus* yield at later ages (Lilburn *et al.,* 1992; Lilburn and Emmerson, 1993; Barbour and Lilburn, 1995; Roberson *et al.,* 2003). It is apparent that the independent development of genetic resource pools has created turkey strains with

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differences in both the genetic potential for BMY as well as pattern of muscle development.

Hatchery effects

Management of the hatchery environment is important as hyperplasia occurs primarily in the embryo and an increase in the number of muscle fibres is associated with larger mature muscle size. Growth and commercially selected lines show significant variation in the number and size of muscle fibres pre-hatch by 20 days of incubation (Velleman *et al.,* 2002b). The effect of incubation environment was tested by increasing incubation temperature for short periods between 0 and 12 days of incubation (Maltby *et al.,* 2004). The result was an increase in the number of muscle fibres as well as density of nuclei, and this early increase in hyperplasia and hypertrophic mechanisms could contribute to a larger final muscle size in the birds at slaughter. The positive effect of increased temperature, however, was not apparent when temperature was increased after 24 days of incubation (Christensen *et al.,* 2007). While incubation temperature manipulation can impact BMY, varying oxygen levels has not been shown to have an effect on breast muscle development (Christensen *et al.,* 2007). This would indicate that temperature control throughout the early incubation period may contribute to higher BMY by stimulating both muscle hyperplasia and hypertrophy while varying oxygen levels would have no effect.

Nutrition is a key environmental factor post-hatch and the early feeding regime must be carefully managed for a poult to fulfil its genetic potential. Short and long term increases in the proportion of breast meat can be achieved by feeding poults immediately post-hatch (Noy and Sklan, 1998; 1999). In contrast, post-hatch starvation reduces the proportion of the *M. pectoralis superficialis* and overall BMY when birds are compared to those given nutrients (Mozdziak *et al.,* 2002; Moore, 2005). A decrease in satellite cell mitotic activity in the first 4 days post-hatch as well as a smaller fibre diameter and nuclear density were also observed in the starved birds. The association of smaller muscle fibres, lower DNA content, and reduced early satellite cell proliferation with decreased final muscle size indicates that post-hatch starvation could negatively impact final BMY. An alternative to feeding poults post-hatch is in-*ovo* delivery of nutrients to the embryo (Moore, 2005; Foye *et al.,* 2006; de Oliveira, 2007). Results were not supportive of a beneficial relationship with BMY as, regardless of the composition or delivery method, injection of nutrients into the egg did not have any impact on the rate of satellite cell proliferation or BMY. Providing nutrients to poults immediately post-hatch should, consequently, be considered as an effective way to reduce the negative effect that post-hatch starvation may have on BMY.

Nutrition

Nutrition throughout the growing phase has an effect on BMY and a feeding programme that produces the most profitable carcass while minimizing feed costs is required. To identify ways to increase production efficiency, a large number of studies have investigated the effect of diet on BMY. Research has primarily focused on the impact of total feed levels, dietary protein and energy content, and amino acid levels. Study results are summarised in *Table 1*.

Feed costs could be reduced by limiting the total quantity or nutrient content of feed. The effect of dietary restriction, however, relative to more expensive feeding regimes on

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carcass yields must be considered. As would be expected, severe feed restriction negatively impacts BMY (Crouch *et al.,* 2002). On the contrary, dietary protein can be restricted by up to 10%, relative to NRC recommendations, without negatively impacting BMY (Blair *et al.,* 1989; Clarke *et al.,* 1993; Barbour and Lilburn, 1996; Kidd *et al.,* 1997; Waibel *et al.,* 2000). The negative impact of protein restrictions in excess of 10% on final yield values is reduced when the diet limitation occurs before 6 weeks of age (Oju *et al.,* 1988; Ferket and Sell, 1989). This suggests that the time and length of the restriction period must also be considered. Feeding a diet supplemented to contain a 20% increase in protein, above NRC recommendations, after a protein restriction of greater than 10% can also help reduce the negative effect (Hester *et al.,* 1990). Potential for compensatory growth may therefore be higher in younger turkeys and may also be favoured by diets that contain excess protein after the restriction period. These studies indicate that there is potential for the protein content of turkey feed to be reduced to 90%, if all other nutrients are formulated to meet or exceed NRC recommendations, without negatively impacting BMY.

Reducing the total amino acid content, or a combination of essential amino acids (Lys, Met+Cys, Thr, Trp, Arg, His, Leu, Ile, Phe, and Val), has a negative impact on BMY (Waldroup *et al.,* 1993; 1998; Lemme *et al.,* 2006). The effect of amino acid reduction becomes stronger later in the growing phase and with longer restriction periods (Lemme *et al.,* 2006). This supports the increase in sensitivity to dietary restriction with age.

The effect of variation in dietary concentration of specific essential amino acids depends on the amino acid considered. Increasing threonine levels in a diet that meets basic protein requirements can improve the trait, however supplemented threonine does not have a positive effect on BMY when birds are fed a protein deficient diet (Kidd *et al.,* 1997; Lehmann *et al.,* 1997; Waibel *et al.,* 2000). Varying methionine levels can be ineffective, however there is a positive dietary effect when betaine is added with the methionine (Noll, 2002). This is a result of the interaction between betaine and both methionine and the lipid metabolic pathway. Alternatively, increasing lysine levels in turkey feed had a positive impact on BMY and this occurs independently of the relative proportion of dietary arginine (Lilburn and Emmerson, 1993; Lehmann *et al.,* 1996; Kidd and Kerr, 1998; Veldkamp *et al.,* 2003). Cumulatively, these studies show that limitation of certain amino acids, including methionine and threonine, is possible without affecting BMY, however there is are positive correlations between BMY and total amino acid and lysine levels.

The addition of fat as an energy source has been used to improve growth performance, however increasing the dietary fat concentration has not significantly affected BMY (Salmon, 1974; Sell *et al.,* 1985; Halvorson *et al.,* 1991; Sell, 1993; Sell *et al.,* 1994). If the level of protein to energy (fat) in the feed is not maintained, BMY can be reduced (Salmon, 1983). Increasing dietary fat levels, consequently, is not a viable option to reduce feed costs, as the relative level of protein must also be increased to maintain performance levels.

Antibiotics and feed additives have been considered as a means to improve growth performance. Results have shown a positive benefit of virginiamycin and ractopamine on both feed efficiency and body weight (Cervantes, 2009; Elanco Animal Health, 2008; Ferket *et al.*, 2002; Waibel *et al.*, 1991). While the increase in body weight caused by virginiamycin is not associated with an increase in BMY, cellular studies have indicated that ractopamine can increase the number, protein, and DNA content of muscle cells in the turkey (Parks *et al.*, 2005; Shappell *et al.*, 2000). These cellular responses may have a positive effect on breast growth, however there is limited research on the effect of ractopamine on BMY and conclusions cannot be made. As a result, a reduction in dietary protein provides the most potential for reducing feed costs without impacting

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BMY. Caution should be taken to ensure the dietary amino acid and lysine levels are formulated to meet requirements if the concentration of other nutrients is altered.

Growing environment

Natural climatic fluctuations and controlled growing environments have been used to investigate the impact of rearing environment on BMY. Breast meat yield is negatively impacted by heat and increased environmental temperatures decrease BMY (Rose and Michie, 1987; Noll *et al.,* 2001; Noll, 2002; Veldkamp *et al.,* 2005). Rearing environments with higher temperatures during light periods and lower temperatures during darkness produce intermediate BMY relative to consistently hot or cool environments (Halvorson *et al.,* 1991). Altering the dietary electrolyte balance and nutrient levels has been attempted to reduce the negative impact of heat, however these manipulations were not effective (Veldkamp *et al.,* 2000a; 2000b).

Light cycling programmes involve alternating fixed-length light and dark periods each day. Alternatively, intermittent lighting involves exposing the birds to more frequent alternating light and dark periods during a 24 hour day. Light cycling has been shown to increase BMY and the effect has been significant if the light periods are substantially longer than the periods of dark (18L:6D) (Halvorson *et al.,* 1991; Clarke *et al.,* 1993). When light cycling is practiced, gradually decreasing the light exposure results in higher BMY when compared to gradually increasing light hours (Peng *et al.,* 1985; Lilburn *et al.,* 1992). The effect seems to be most strongly correlated to the development of the *M. pectoralis superficialis* (Lilburn *et al.,* 1992). It is apparent that maintaining lower rearing temperatures as well as light cycling should be utilized to optimize BMY. These positive correlations are most likely due to the reduced biological stress and stimulation of bird activity that can be created by these management practices.

Conclusions

The processes regulating muscle growth are dynamic, and hyperplasia and hypertrophy both contribute to breast development. The physiological characteristics of the breast muscle, as well as total yields from the carcass, are under the influence of additive genetic factors and genetic potential can vary by sex and strain. This genetic component makes trait improvement possible by applying selection pressure to breast meat yield in a breeding programme. Management of the rearing environment, including nutrition, lighting, and temperature, all must be carefully considered for turkeys to fulfil their genetic potential. As a result of the combined impact of both genetics and environment on breast meat yield, all industry levels from the primary breeder to the commercial grower must consider the influence that they can have on final proportion of breast meat.

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Table 1 Effect of dietary treatment on turkey breast meat yield

Source	Significant Treatment[1,2]	Effect on BMY[3]
Feed restriction		
(Crouch *et al.*, 2002)	Feed restriction sufficient to reduce BW by 45%, 3-16 weeks	Proportion *p. superficialis* reduced
Protein restriction		
(Barbour and Lilburn, 1996)	13% protein restriction + 20% lysine restriction, 0-8wk	BMY reduced
(Blair *et al.*, 1989)	12% protein restriction, 8-24wk	BMY reduced
(Clarke *et al.*, 1993)	>20% protein restriction, 2-8wk	BMY reduced
(Ferket and Sell, 1989)	40% protein restriction, 1-6wk	BMY reduced
(Hester *et al.*, 1990)	26% protein and amino acid restriction, 6-12wk 20% increase in protein and amino acid levels, 12-20wk	BMY reduced, supplementation after 12wk restored BMY
(Kidd *et al.*, 1997)	>84% protein restriction, 0-18wk	BMY reduced
(Lemme *et al.*, 2004)	20% protein restriction, 3-22wk	BMY reduced
(Oju *et al.*, 1988)	25% reduction in protein + 34% reduction in methionine and lysine, 0-6wk	BMY consistently reduced in toms until 16 wk and in hens until 6wk
(Waibel *et al.*, 2000)	>15% reduction in protein	BMY reduced
Amino acid levels		
(Kidd *et al.*, 1997)	0.2% threonine addition to low protein diet, 0-18wk	No effect
(Kidd and Kerr, 1998)	20% increase in Arg:Lys	No effect
(Lehmann *et al.*, 1996)	0.35% lysine addition to diet, 16-20wk	BMY increased
(Lehmann *et al.*, 1997)	0.15% threonine addition to diet	No effect
(Lemme *et al.*, 2004)	10% protein, Arg, Val, Ile, and Leu restriction, 3-22wk	BMY reduced
(Lemme *et al.*, 2006)	20% increase in essential aa, 1-13 wk	BMY increased when aa levels increased early in growing phase
	10% decrease in essential aa, 14-22wk	BMY reduced when aa levels reduced late in growing phase
(Lilburn and Emmerson, 1993)	Increase in lysine and sulphur aa, 0-12 wk	BMY increased 12wk, proportion *p. superficialis* improved 20wk, proportion *p. profundus* improved
(Noll, 2002)	30% increase in methionine 0.1% betaine addition	No effect of methionine BMY increased by betaine
(Veldkamp *et al.*, 2003)	25% reduction in lysine	BMY reduced
(Waibel *et al.*, 2000)	Threonine supplementation to low protein diet	No effect
(Waldroup *et al.*, 1993)	25% reduction in amino acids	BMY reduced[3,4]

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Table 1 Continued

Source	Significant Treatment[1,2]	Effect on BMY[3]
(Waldroup *et al.,* 1998)	25% reduction in amino acids	BMY reduced[4]
Energy level		
(Halvorson *et al.,* 1991)	1-8% increase energy with age	No effect[5]
(Salmon, 1974)	12.9% increase in energy	No effect
(Salmon, 1983)	18% increase in fat, relative to protein	BMY reduced
(Sell *et al.,* 1985)	8% increase in energy	No effect
(Sell, 1993)	2% or 8% increase during different feeding stages	No effect
(Sell *et al.,* 1994)	2% or 8% increase during different feeding stages	No effect

[1] Evaluated at 5% significance level
[2] If time period unspecified, treatment was administered from 0wk to slaughter
[3] Effect on BMY at slaughter, unless otherwise specified
[4] Negative effect on BMY stronger for 0-6wk and 6-12wk restriction, relative to 0-3wk restriction
[5] Genotype by environment interaction: additional energy increased BMY in birds raised at low temperature (7°C)

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