# Effects of stocking density on large white, commercial tom turkeys reared to 20 weeks of age: 1. growth and performance

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**ABSTRACT** Industry standards for turkey stocking densities are variable and may not represent the more rapidly growing strains currently available. Therefore, a study was completed to evaluate 4 stocking densities: a nominal density (0.3525 $m^2$/bird), 10% tighter density (0.3169 $m^2$/bird), 10% looser density (0.3882 $m^2$/bird), and 20% looser density (0.4238 $m^2$/bird) on the effects on large white, commercial male turkeys with regard to performance from 5 to 20 wk of age. Brooding stocking density was fixed for all pens of birds with 60 birds per replicate pen at 0.46 $m^2$/bird to 5 wk of age. Density treatments were applied from 5 to 20 wk by altering pen size with pen population held constant at 60 per pen. There were 4 pens of birds per density treatment. Birds were weighed individually at 0, 5, and 20 wk of age and performance parameters were calculated. There were no differences in bird performance at 5 wk, which was expected because stocking density was fixed. From 5 to 20 wk and at 20 wk, birds that were reared at the nominal standard (0.3525 $m^2$/bird) and 10% tighter density (0.3169 $m^2$/bird) had significantly lower body weight compared with the 10% looser density (0.3882 $m^2$/bird) and 20% looser density (0.4238 $m^2$/bird) ($P = 0.03$ and 0.01, respectfully). The feed conversion ratio (**FCR**) tended ($P = 0.08$) to be improved for birds reared at looser density. In addition, based on linear regression, as stocking density decreased (i.e., $m^2$/bird increased), BW ($P < 0.05$) increased, and FCR ($P = 0.10$) tended to decrease (improve) at 20 wk. It was concluded that birds reared at looser density had improved performance.

**Key words:** Turkey, stocking density, growth, performance

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## INTRODUCTION

Stocking density is described as the amount of space allotted per animal or per unit weight of animal and can influence several production traits. As reviewed by Erasmus (2017), some stocking density guidelines for poultry species are dated and may no longer reflect the continuous genetic selection for increased growth rate and improved efficiency of currently available birds. Space allotments for food animals are under scrutiny with potential legislative action (Erasmus, 2017) to include poultry species. In addition, the recommendations for stocking density for turkeys provided by associations or agencies in the United States and Europe are variable (Erasmus, 2017). Because turkeys are consistently selected for increase rate of growth and body weight for age (Emmerson, 1997; Havenstein et al. 2007; Kremer et al. 2018), it may be advisable that the growth and behavior of the current commercial turkey reared for the current market be taken into consideration for developing newer stocking density guidelines as best management practices. Environmental- and management-related practices influence bird well-being and can be challenging for the poultry industry. It is not uncommon for food animal production companies to pledge to adapt animal rearing and welfare practices to meet consumer expectations. Despite the growing relevance of turkey production, the scientific literature regarding turkey well-being under intensive rearing systems is limited when compared with other poultry species (Marchewka et al., 2013). For instance, several researchers have reported that turkeys reached greater BW when they were provided with more space per bird (Noll et al., 1991; Martrenchar et al., 1999; Beaulac and Schwean-Lardner, 2018), whereas others have observed no differences in production parameters with lower stocking densities (Moran, 1985; Hafez et al., 2016). In a review, Erasmus (2017) organized the current recommendations within the poultry industry, displaying the wide variation of standards for turkey stocking densities and variations within certification programs,



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including those set forth by the National Turkey Federation, Federal Animal Science Societies Guide, Canadian Codes of Practice, Global Animal Partnership, and American Humane Certified.

To accommodate different stocking densities, populations of birds would have to be altered rather than the size of the enclosure (Estevez and Christman, 2006) to determine the proper stocking density necessary to effectively grow birds while having the welfare of the bird considered. Currently, the effects of stocking density on space use and how space use changes with increasing age have been limited (Erasmus, 2017) with 1 study performed by Beaulac and Schwean-Lardner (2018) in large turkeys. Therefore, the objective of this study was to determine the effect of stocking density on performance of large white commercial tom turkeys grown to 20 wk of age.

## MATERIALS AND METHODS

### Animal Use Protocol

All bird handling procedures used in this study were approved by the Institution Animal Care and Use Committee of North Carolina State University. All bird well-being monitoring, husbandry, and euthanasia procedures were performed with full consideration of animal welfare.

A curtain-sided poultry building with concrete floors and movable metal pen panels were used to conduct this study (Talley Turkey Education Unit, North Carolina State University, Raleigh, NC). Commercial large white male turkeys (Nicholas Select, Aviagen Turkeys, Lewisburg, WV) were hatched in January, weighed, and placed in 1 of 16 pens (8.23 m x 3.38, 27.82 $m^2$ per pen) with a total of 60 poults per pen (total = 960 poults). Poults were brooded until 5 wk of age using standard industry methods in floor pens bedded with new pine shavings. Within each pen, groups of 20 poults were brooded for the first wk inside 3 cardboard rings. Within each pen, there were 3 tube turkey feeders (Kuhl Corporation, Flemington, NJ) and 3 bell drinkers (Plasson Ltd., Israel); 1 each inside each brooder ring. In addition, inside each brooder ring, there were 2 additional supplemental drinkers and 2 feeder flats. The brooder rings and supplemental drinkers and feeder flats were removed at 1 wk of age. At 5 wk, the small bell drinkers were replaced with adult turkey bell drinkers (Plasson Ltd., Israel). The tube feeders were used without the accompanying grill insert and had a trough circumference of 167.64 cm. With 3 feeders per each pen of 60 birds, this provided 8.38 cm of feeder trough space per bird. Each adult turkey drinker had a trough circumference of 137.16 cm. With 3 drinkers per each pen of 60 birds, this provided 6.86 cm of water trough space per bird. However, because birds were neither feed nor water restricted, there was no observed instances of large groups of birds attempting to eat or drink at the same time. Target house temperature was per breeder recommendation and adjusted for poult comfort. Hallway space heaters were used to provide background house temperature. From 5 to 20 wk, the number of feeders and waterers per pen were the same regardless of pen size. Poults removed from the study because of mortality or culling were replaced until 5 wk with extra poults sourced from the same hatch and reared in a separate temporary pen in the same facility. Poults were weighed individually at 5 wk, and feed consumption, by pen, was determined.

At 5 wk, 1 of 4 rearing density treatments (4 pens per density treatment) were assigned to each pen of birds: a nominal US industry standard density based on authors' communications (0.3525 $m^2$/bird), 10% tighter density (0.3169 $m^2$/bird), 10% looser density (0.3882 $m^2$/bird), and 20% looser density (0.4238 $m^2$/bird). These densities are reflective of the variations in recommended densities reported by Erasmus (2017) and breeder commercial performance standards for 18 to 20 wk old male turkeys (Aviagen Turkeys Inc., Lewisburg, WV). The end panels of each pen were moved to create the desired pen size for each target stocking density within each pen. Resulting pen dimensions per treatment were T1 = 5.425 × 3.505 m, T2 = 6.035 × 3.505 m, T3 = 6.645 × 3.505 m, and T4 = 7.254 × 3.505 m. The resulting pen sizes were T1 = 19.01, T2 = 21.15, T3 = 23.29, and T4 = 25.436 $m^2$/pen, respectively. Therefore, the density per bird was T1 = 0.3169, T2 = 0.3525, T3 = 0.3882, and T4 = 0.4238 $m^2$/bird.

Birds were fed a phased ration program consisting of typical commercial turkey soybean meal, corn, and wheat-based diets milled by the North Carolina State University Education Feed Mill (Table 1). The first phase (Starter 1) was fed to 5 wk of age. The other 5 phases were fed from 5 to 20 wk and were allocated on a kg/bird basis. Allocations were adjusted for mortalities and culled birds as they occurred (Table 1). Birds (individually) and feeders were weighed at 0, 5, and 20 wk of age to determine BW, BW gain (**BWG**), feed intake (**FI**), and feed conversion ratio (**FCR**). The FCR was calculated for both mortality adjusted and mortality unadjusted ratios. The pen was considered the experiment unit. Treatment effects of density were determined over each period ranging from 0 to 5 wk and 5 to 20 wk of age.

### Statistical Analysis

The effects of the 4 density treatments on performance were compared in a completely randomized design. Live performance data were analyzed using the ANOVA procedure within JMP (SAS Institute, Cary, NC). Means were separated using the LSmeans procedure and significant differences realized at $P \leq 0.05$ indicated by Tukeys HSD. In addition, linear regression of stocking density on BW, BWG, and FCR was used to determine the effect of density on turkey performance.

## RESULTS

The performance results for turkey toms reared to 20 wk of age are presented in Tables 2 and 3. After randomization of treatment assignments to the pens of

**Table 1.** Feed rations fed to tom turkeys reared to 20 wk of age.

| Ingredient (%) | Starter 1 | Starter 2 | Grower 1 | Grower 2 | Finisher 1 | Finisher 2 |
|---|---|---|---|---|---|---|
| Corn | 18.60 | 22.00 | 26.20 | 34.30 | 40.70 | 44.50 |
| Wheat | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 |
| Soybean Meal | 38.00 | 35.00 | 30.00 | 22.50 | 17.00 | 13.40 |
| Poultry Meal | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 |
| Fat | 7.03 | 7.03 | 8.09 | 8.08 | 8.05 | 8.08 |
| Limestone | 1.80 | 1.65 | 1.58 | 1.45 | 1.10 | 1.08 |
| Monocalcium Phosphate | 2.55 | 2.35 | 2.25 | 2.00 | 1.50 | 1.35 |
| Salt | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Mineral Mix[1] | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Vitamin Mix[2] | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Se Mix | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Choline Chloride | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Lysine | 0.45 | 0.44 | 0.41 | 0.325 | 0.325 | 0.30 |
| Methionine | 0.45 | 0.43 | 0.38 | 0.30 | 0.275 | 0.25 |
| Sodium Bicarbonate | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 |
| Threonine | 0.15 | 0.125 | 0.125 | 0.075 | 0.075 | 0.075 |
| Calculated Nutrient Content | | | | | | |
| CP (%) | 30.7 | 29.5 | 27.2 | 23.9 | 21.6 | 20.0 |
| ME (kcal/kg) | 3,086 | 3,126 | 3,232 | 3,318 | 3,400 | 3,439 |
| Crude Fat (%) | 9.80 | 9.80 | 10.9 | 11.0 | 11.1 | 11.2 |
| Lysine (%) | 1.89 | 1.80 | 1.65 | 1.39 | 1.25 | 1.14 |
| Methionine (%) | 0.84 | 0.81 | 0.73 | 0.62 | 0.58 | 0.55 |
| M + C (%) | 1.23 | 1.18 | 1.08 | 0.93 | 0.87 | 0.80 |
| Trypt (%) | 0.33 | 0.31 | 0.28 | 0.24 | 0.21 | 0.19 |
| Thre (%) | 1.19 | 1.12 | 1.04 | 0.87 | 0.79 | 0.73 |
| Arg (%) | 1.89 | 1.80 | 1.64 | 1.42 | 1.25 | 1.15 |
| Val (%) | 1.31 | 1.25 | 1.15 | 1.01 | 0.91 | 0.84 |
| Calcium (%) | 1.50 | 1.41 | 1.35 | 1.25 | 1.03 | 0.99 |
| Av P (%) | 0.75 | 0.71 | 0.68 | 0.63 | 0.52 | 0.49 |
| Sodium (%) | 0.19 | 0.19 | 0.18 | 0.18 | 0.18 | 0.18 |
| Chloride (%) | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.19 |
| Form | Crumble | Small pellet | Pellet | Pellet | Pellet | Pellet |
| kg/bird[3] | | 5.44 | 8.16 | 11.34 | 13.61 | 15.88 |

[1]Mineral Premix provided the following per kg of diet: manganese, 120 mg; zinc, 120 mg; iron, 80 mg; copper, 10 mg; iodine, 2.5 mg; cobalt, 1 mg.
[2]Vitamin premix provided the following per kg of diet: vitamin A, 19,841 IU; vitamin D3, 5952 IU; vitamin E, 99 IU; vitamin B12, 0.06 mg; biotin, 0.38 mg; menadione, 6 mg; thiamine, 6 mg; riboflavin, 20 mg; pantothenic acid, 33 mg; vitamin B6, 12 mg; niacin, 165 mg; folic acid, 3 mg.
[3]All birds were fed to 5 wk by age and from 5 to 20 wk birds were allotted feed as kg/bird.

birds at 5 wk, there was no "coincidental" treatment effect for FI, BW, or FCR. The overall 5 wk BW mean was 1.84 ± 0.04 kg with a mean FCR of 1.498 ± 0.028. From 5 to 20 wk and at 20 wk, there was a significant decrease in BW ($P < 0.05$) for birds reared the 2 tighter stocking densities (T1 and T2) compared with birds reared at the 2 looser densities (T3 and T4). The effect of density on FCR at 5 to 20 wk and 0 to 20 wk approached significance ($P = 0.11$, $P = 0.08$, respectively). In addition, based on linear regression [BWG = 14.73 + (6.07* ($m^2$/bird); FCR = 2.226–0.3206* $m^2$/bird)] as stocking density decreased (i.e., $m^2$/bird increased), BWG ($P = 0.03$) increased, and FCR ($P = 0.11$) decreased (improved) from 5 to 20 wk.

## DISCUSSION

A 20 wk turkey tom study involving 4 stocking densities based on a nominal stocking density and a range

**Table 2.** Effect of stocking density on turkey body weight (kg) and final CV from 0 to 20 wk of age.

| Density ($m^2$/bird) | Hatch (g) | 5 wk (kg) | 20 wk (kg) | 5 to 20 wk (kg) | 20 wk CV(%) |
|---|---|---|---|---|---|
| 0.3175 | 64.6 | 1.86 | 18.76[b] | 16.70[b] | 5.95 |
| 0.3530 | 65.1 | 1.85 | 18.93[b] | 16.81[b] | 6.28 |
| 0.3887 | 64.9 | 1.85 | 19.21[a] | 17.16[a] | 6.78 |
| 0.4243 | 64.8 | 1.82 | 19.38[a] | 17.32[a] | 6.57 |
| SEM | 0.30 | 0.04 | 0.17 | 0.22 | 0.58 |
| Source of variation | | | *P*-value | | |
| Density | 0.80 | 0.80 | 0.01 | 0.03 | 0.3 |
| Regression* | | | | | |
| Linear effect | 0.7 | 0.4 | 0.01 | 0.03 | 0.3 |

[a,b]Means in a column with different superscripts are considered significantly different ($P < 0.05$).
*BW(kg) at 20 wk = 16.80 + 6.08*($m^2$/BD); $R^2 = 0.37$.
*GN(kg) 5 to 20 wk = 14.73 + 6.07*($m^2$/BD); $R^2 = 0.28$.

**Table 3.** Effect of stocking density on turkey feed intake (FI, kg/bd) and feed conversion ratio (FCR) from 0 to 20 wk of age.

| Density ($m^2$/bird) | 5 wk FI | 5 wk FCR | 5–20 wk FI | 5–20 wk FCR | 20 wk FI[1] | 20 wk FCR[2] | 20 wk FCR[3] |
|---|---|---|---|---|---|---|---|
| 0.3175 | 2.80 | 1.50 | 42.96 | 2.14 | 45.76 | 2.29 | 2.44 |
| 0.3530 | 2.74 | 1.48 | 43.80 | 2.12 | 46.55 | 2.27 | 2.45 |
| 0.3887 | 2.77 | 1.45 | 44.71 | 2.16 | 46.79 | 2.26 | 2.41 |
| 0.4243 | 2.74 | 1.50 | 43.09 | 2.11 | 45.82 | 2.25 | 2.38 |
| MEAN | 2.76 | 1.49 | 43.35 | 2.12 | 46.39 | 2.27 | 2.42 |
| SEM | 0.02 | 0.02 | 0.49 | 0.03 | 0.50 | 0.03 | 0.04 |
| Source of variation | | | | *P*-value | | | |
| Density | 0.30 | 0.90 | 0.61 | 0.11 | 0.53 | 0.08 | 0.40 |
| Regression | | | | | | | |
| Linear effect | 0.20 | 0.80 | 0.5 | 0.20 | 0.70 | 0.10 | 0.10 |

[1]Cumulative feed intake from 0 to 20 wk.
[2]Cumulative FCR from 0 to 20 wk adjusted for mortality.
[3]Cumulative FCR from 0 to 20 wk unadjusted for mortality.

of published recommendations was evaluated. Stocking density within the poultry industry is highly variable depending on guidelines set forth by auditing systems and intensive management practices. Maintenance of high bird densities per unit of space is a common practice in intensive turkey production systems (Marchewka et al., 2013) and has been reviewed by Erasmus (2017) regarding the differences in stocking densities used within the turkey industry. Increasing stocking density may result in health challenges because of increased stress, alterations in environment, or alterations in group size (Beaulac and Schwean-Lardner, 2018). In addition, other environmental factors such as barn type, lighting, ventilation, and increased ammonia levels can interact with or be affected by the density of birds reared in a confined area (Zuidhof et al. 1993; Marchewka et al., 2013; Duggan et al., 2014; Sheikh et al. 2018).

In the current study, as stocking density increased, BW and BWG decreased, and FCR tended to increase (i.e., worsened) after a common 5 wk brooding period. This same effect has also been reported by Beaulac et al. (2019), suggesting that stocking density in younger birds does not have negative impacts because birds are still able to freely move through pens. Whereas, when the birds get older, as floor space becomes more restrictive, stocking density may become a significant factor for bird welfare. When stocking density is high, birds experience increased social stress (Noll et al., 1991). If under chronic stress, energy is directed toward maintaining the stress response rather than directing nutrients and energy to growth, resulting in increased energy expenditure and decrease feed efficiency (Beaulac and Schwean-Lardner, 2018). These parameters have also been evaluated by Moran (1985) in which turkey toms were reared to 131 D with final rearing densities of 44.4 $dm^2$/bird vs. 88.9 $dm^2$/bird. Note that these densities are larger than even the 20% looser density evaluated in the current study. In Moran's case, final body weights were approximately 11 kg vs. today's market size of 20 kg and were not different because of density. However, neither the high density used nor the final body weights of that study is representative of current practices or market bird weights. Noll et al. (1991) compared rearing tom turkeys at 0.21 and 0.46 $m^2$/bird. The higher density resulted in a reduction of BW of 5.5%. The FCR was improved by the lower density (5%) during the last 4 wk from 16 to 20 wk. Mortality was not significantly affected by rearing density. However, the final BW of the birds (12.8 to 13.5 kg; 28 to 30 lb) is also not representative of today's birds at 20 wk (20 to 21 kg; 44 to 46 lb). Although, those results match the results herein grown at 10 and 20% looser stocking densities. Furthermore, Beaulac et al. (2019) results agree with similar findings of turkey toms reared at higher stocking densities having lower BW grown to 16 wk of age.

House environmental conditions are important to maintain conditions that will guarantee good live performance, avoid negative welfare implications, and prevent carcass quality issues observed when stocking density is increased. Negative effects of increased stocking density may include alterations in mortality levels, BW, BWG, and FCR. In the current study, the potential stress associated with an increased stocking density may have resulted in decreased energy put into growth, thereby affecting performance parameters. Although more birds can be reared per unit of area with higher stocking density, the resulting decrease in BW and higher FCR are potentially indicative of welfare issues. Previous studies focused on the effects of density have shown that high densities led to gait deterioration and decreased activity, injuries due to lack of space such as broken wings, increased aggression levels, and increased feather pecking (Marchewka et al., 2013). Dawkins et al. (2004) examined the effect of different stocking densities on bird welfare in commercial broiler facilities from 10 different companies with stocking densities of 30, 34, 38, 42, and 46 kg/$m^2$ compared. In addition to recording environmental conditions in the broiler houses (temperature, relative humidity, ammonia, light intensity, and litter moisture), broiler welfare was monitored through mortality, corticosteroid levels, behavior, and health with an emphasis on leg strength and walking ability. At higher stocking densities broilers grew slower and had reduced walking ability. While stocking density significantly affected 3 of the measured variables, environmental management affected 17 of the 19 variables measured, and it was concluded that while stocking density does affect broiler welfare, the management of the environment in the broiler houses were also important.

In this study, large white, commercial turkey toms were reared from 5 to 20 wk with increased stocking densities which were based on common usage and published recommendations. Turkeys reared at increased stocking density experienced decreased BW, BWG, with a tendency to have higher FCR. Based on these results, lower stocking densities (increased space per bird) improved bird performance after 5 wk.

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## REFERENCES

Beaulac, K., H. L. Classen, S. Gomis, K. S. Sakamoto, T. G. Crowe, and K. Schwean-Lardner. 2019. The effects of stocking density on Turkey tom performance and environment to 16 weeks of age. Poult. Sci. 98:2846–2857.

Beaulac, K., and K. Schwean-Lardner. 2018. Assessing the effects of stocking density on Turkey tom health and welfare to 16 weeks of age. Front. Vet. Sci. 5:213.

Dawkins, M. S., C. A. Donnelly, and T. A. Jones. 2004. Chicken welfare is influenced more by housing conditions than by stocking density. Nature 427:342–344.

Duggan, G., T. Widowski, M. Quinton, and S. Torrey. 2014. The development of injurious pecking in a commercial Turkey facility. J. Appl. Poult. Res. 23:280–290.

Emmerson, D. A. 1997. Commercial Approaches to genetic selection for growth and feed conversion in Domestic poultry. Poult. Sci. 76:1121–1125.

Erasmus, M. A. 2017. A review of the effects of stocking density on Turkey behavior, welfare, and productivity. Poult. Sci. 96:2540–2545.

Estevez, I., and M. C. Christman. 2006. Analysis of the movement and use of space of animals in confinement: the effect of sampling effort. Appl. Anim. Behav. Sci. 97:221–240.

Hafez, H. M., N. Hagen, and T. S. Allam. 2016. Influence of stocking density on health condition in meat Turkey flocks under field conditions. Pak. Vet. J. 36:134–139.

Havenstein, G. B., P. R. Ferket, J. L. Grimes, M. A. Qureshi, and K. E. Nestor. 2007. Comparison of the performance of 1966- versus 2003-type turkeys when fed representative 1966 and 2003 Turkey diets: growth rate, Livability, and feed conversion. Poult. Sci. 86:232–240.

Kremer, J. A., C. I. Robison, and D. M. Karcher. 2018. Growth dependent changes in Pressure Sensing Walkway data for turkeys. Front. Vet. Sci. 5:241.

Marchewka, J., T. T. N. Watanabe, V. Ferrante, and I. Estevez. 2013. Review of the social and environmental factors affecting the behavior and welfare of turkeys (Meleagris gallopavo). Poult. Sci. 92:1467–1473.

Martrenchar, A., D. Huonnic, J. P. Cotte, E. Boilletot, and J. P. Morisse. 1999. Influence of stocking density on behavioural, health and productivity traits of turkeys in large flocks. Br. Poult. Sci. 40:323–331.

Moran, Jr, E.T. 1985. Effect of toe clipping and pen population density on performance and carcass quality of large turkeys reared sexes separately. Poult. Sci. 64:226–231.

Noll, S. L., M. E. E. L. 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. Poult. Sci. 70:923–934.

Sheikh, I. U., S. S. Nissa, B. Zaffer, K. H. Bulbul, A. H. Akand, H. A. Ahmed, D. Hasin, I. Hussain, and S. A. Hussain. 2018. Ammonia production in the poultry houses and its harmful effects. Int. J. Vet. Sci. Anim. Husbandry 3:30–33.

Zuidhof, M. J., J. J. R. Feddes, F. E. Robinson, and C. Riddell. 1993. Effect of ventilation rate and stocking density on Turkey health and performance. J. Appl. Poult. Res. 2:123–129.