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Determining the Contribution of Ventilation and Insulation of Broiler Breeding Houses in Production Performance Using Analytic Hierarchy Process (AHP)

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ABSTRACT

This study was conducted using Analytic Hierarchy Process (AHP) in order to rank broiler breeding farms in Zanjan province, Iran, regarding buildings, installations, and equipment to determine their effects on production factors. Data on 108 farms were collected using designed forms. This data was analyzed based on the effectiveness of each parameter in the production and management category according to experts' opinion. The results indicated that ventilation systems (fans, inlets, and damper) as well as wall and roof insulation in poultry houses, constituted 66% of the technology coefficient. The stocking density increased through improvement of the mechanization coefficient. Most of these farms used longitudinal or tunnel ventilation and a combination of small and large fans. Roof insulation was mostly done using glass wool, and corrugated plastic while installing the heaters outside the poultry house. In these farms, the use of nipple drinkers and plate feeders was more prevalent. Moreover, the results showed that feed conversion and production indices have a significant correlation with mechanization coefficient so that farms with better mechanization coefficients had lower conversion ratio (p=0.04) and higher production indices (p=0.015). In general, the results indicated that ventilation and air inlet systems, as well as wall and roof building technologies have the greatest influence on the mechanization coefficient, while better mechanization coefficients translated into improvements in production efficiency and economic performance of poultry farms.

INTRODUCTION

Providing a suitable place to breed birds is an important issue in poultry production. Poultry do not manifest their true genetic potential in unfavorable living conditions, resulting in economic loss (MacDonald, 2008). Poultry are among homoeothermic species that can maintain their body temperature constant; however, this mechanism is effective within the normal range of environment temperature. Thus, poultry are not able to regulate their body temperature above or below their endurance limit (Daghir, 2008). Paying attention to proper design and using suitable equipment and materials such as good insulation, ventilation systems (minimum, tunnel and transitional), inlets, evaporative pad cooling, foggers, etc. in accordance with different regional environments are among the important considerations for creating suitable environmental conditions (Lacy & Czarick, 1992). Various environmental variables such as temperature, humidity, air flow speed, ventilation rate and concentration of airborne particles, gases and microorganisms determine the environmental quality in poultry houses (Mitchell *et al.*, 2002).

Using the proper construction principles with walls and roof insulation as well as suitable ventilation systems, decrease humidity and reduces the bed moisture, which in turn leads to epidemics of parasitic diseases such as Coccidiosis (Dawkins *et al.*, 2004). Many developing countries are located in tropical regions that require the minimum amount of heating; therefore, suitable buildings and installations are of great importance. Establishing the buildings with complete control over temperature is very expensive (Glatz & Bolla, 2004).

The appropriate design of a poultry house with the temperature control systems can increase feed conversion ratio (FCR) and reduce mortality rate. In the United States, during 1990s, broiler breeding industry experienced 6% growth, however, this rate has fallen to 3% after 2000. Nevertheless, meat production has increased. Although most of this development is due to the genetic enhancements, improvements in buildings, installations and equipment as well as better management were important factors in improving FCR, reduction of mortality and maximizing productivity (MacDonald, 2008).

Poultry producers face the challenge to find available buildings, installations and equipment and recognize their important role in production and productivity. Analytic Hierarchy Process (AHP) is a process in decision that deals with choosing an option from various available options while prioritizing possible solutions. It is one of the most effective methods in multi criteria decision-making. AHP can be used in situations where decision makers face multiple competing options and decision criteria. These criteria could be quantitative or qualitative. This method is based on the paired comparisons enabling the managers to evaluate different scenarios (Saaty, 1994). Buildings and installations play an important role in controlling environmental conditions and optimizing the performance of poultry houses. Therefore, the present study uses AHP technique in order to evaluate the buildings and installations of poultry houses and study their effects on performance parameters.

MATERIALS AND METHODS

Data Collection

In order to achieve the study-oriented goals, necessary data (general information of producer and technical information) regarding the breeding of poultry including management status, number and size of poultry houses, the technology used in the walls and roof (resistance to heat exchange), ventilation and fan systems (based on the needs of the house), feeder and drinker systems (types of feeders and drinkers), heating system (type and requirements of the house), temperature, humidity and gas sensors, poultry house control system (automatic or manual) and lighting system, was collected from 108 active poultry houses in Zanjan province using specifically designed questionnaires.

Analytic Hierarchy Process (AHP) Method

AHP is one of the most recognized techniques in multi criteria decision-making, originally introduced by Thomas L. Saaty in 1970s. AHP can be used wherever decision making faces multiple options with multiple criteria. These criteria could be quantitative or qualitative. This decision making method is based on three principles: 1- depicting the hierarchy tree, 2- determining and specifying the priorities, 3- logical consistency of the judgments (Saaty, 1994). In Fig.1, the hierarchy tree with criteria under investigation regarding the mechanization level of poultry houses is presented.

AHP method is based on the pairwise comparisons. In this method, in order to determine the influence of the parameters and relative weights, a paired comparison questionnaire was designed by Delphi

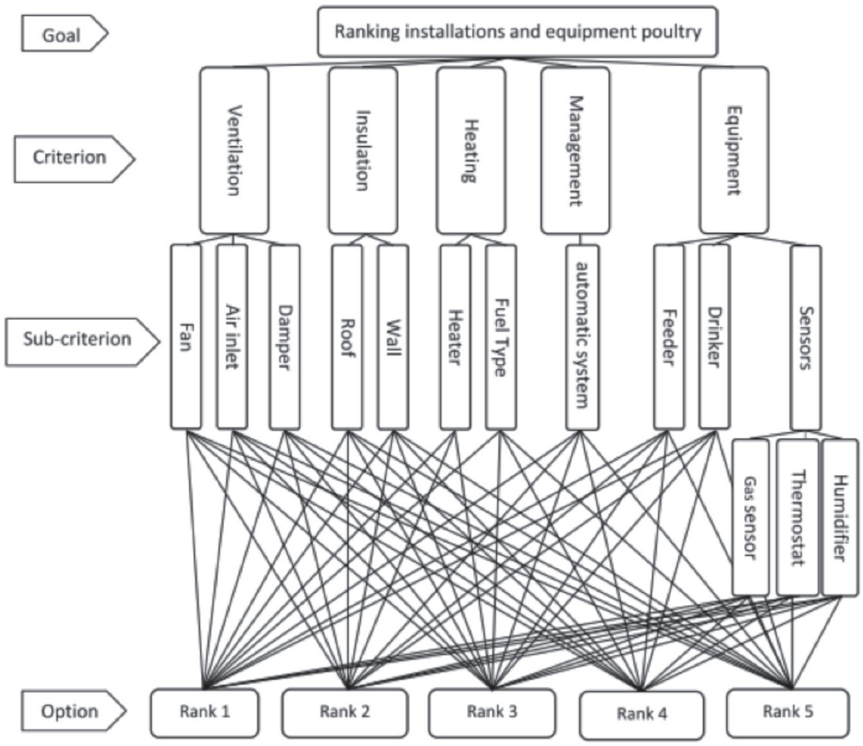

Figure 1 – Hierarchy decided to rank the installations and equipment poultry house.

method and experts were asked to compare each pair regarding the importance and priority of parameters on poultry performance based on the nine levels of preference proposed by Saaty (2008) (Table 1). This way, the paired comparison matrix was calculated from arithmetic means of the comparison matrices provided by the experts. Then using the Expert Choice 11.1 software, paired comparison questionnaires were analyzed and inconsistency rate was determined. If inconsistency rate is less than 0.1, paired comparisons are acceptable (Saaty, 1994).

Table 1 – Paired comparison scores in multi criteria decision making using AHP.

Description	Definition	Importance level
Two elements are equally important.	Equal priority	1
One element is relatively more important than the other.	Relative priority	3
One element is much more important than the other.	High priority	5
One element is very much more important than the other.	Very high priority	7
One element is exceptionally more important than the other.	Exceptionally high priority	9
	In between values between judgments	2,4,6,8

When comparing i and j elements, one of the above values is assigned to the pair.

In comparison of j and i elements, the inverse of that value is assigned ($X_{ij} = \frac{1}{X_{ij}}$)

The output of multi criteria decision-making using AHP (scores of different poultry houses) was clustered in five categories using the PROC CLUSTER procedure of SAS software (version 9.1; SAS Inst. Inc. Cary, NC) and mechanization characteristics of each category was determined.

In order to determine the relationship between production factors and animal response, performance information (final body weight (FBW), type of feed, FCR, mortality, slaughter age (SA) and production index (PI)) for each poultry house was obtained from the poultry information system of the provincial Animal Production Improvement Office during the period of 2011 to 2015. Extraordinary performances from disease conditions were omitted and data on 455 hatching periods was placed under consideration. The performances were grouped under 5 categories made by multi criteria decision making model of AHP and analyzed by PROC GLM in SAS software.

The following formula was used to calculate production index (Aviagen, 2014):

$$\text{PEF} = \frac{\text{Livability x Live Weight in kg}}{\text{Age in Days x FCR}} \times 100$$

RESULTS AND DISCUSSION

Modified weights for various criteria and their influences on mechanization, production and productivity of poultry houses, calculated using multi criteria decision method are presented in Table 2. The results showed that ventilation (air flow fans, air inlet system, and damper) was deemed by the experts to be of the highest priority while its share in controlling environmental conditions can be accounted for up to 37%. Insulation of walls and roof was the second priority, with 29%, while equipments including feeders and drinkers, as well as temperature, humidity, and gas sensors were the third in terms of their relative importance. House heating and automation were the next priorities. In this study, inconsistency index was calculated at 0.06, indicating the acceptable consistency of weights given by experts for various parameters.

Table 2 – Average relative weight for the main criteria influencing the mechanization of poultry houses according to the opinions of experts, calculated using AHP multi criteria decision method.

Criterion	Sub Criteria	Relative Weight		Priority
Ventilation	Fan	23	37	1
	Air inlet	12		
	Damper	2		
Insulation	Roof	17	29	2
	Wall	12		
Heater and Fuel Type	Heater	10	11	4
Fuel Type		1		
Equipment	Drinker	4	15	3
	Feeder	4		
	Sensors	7		
Management	automatic system	8	8	5

The results regarding the number of poultry breeding houses along with their breeding capacity and stocking density based on AHP priority model are presented in Table 3. In this study, poultry houses ranked 1 had the highest technology coefficient. In the lower ranks the degree of technology penetration was reduced so that poultry houses ranked 5 had the minimum technology coefficient and degree of mechanization influence. Categories 4 and 2 had the highest number of poultry houses. Although poultry houses did not have any significant difference in terms of breeding capacity, in terms of stocking density significant differences were observed (p=0.03), whereby poultry houses ranked 1st and 3rd had higher stocking density compared with the 5th.

Table 3 – Average number of poultry houses, breeding capacity and stocking density based on AHP model.

Rank	Number	%	Breeding Capacity (birds)	Number of birds (per m^2)
1	15	14	26700	12.3^{a}
2	30	28	26150	11.1 ^{ab}
3	16	15	29118	11.9 ^{a}
4	32	29	31296	11.5 ^{ab}
5	15	14	27800	10.6 ^{b}
SEM			3443	0.46
p-Value			0.71	0.03
mean			28213	11.5

Hatching density is determined considering environmental and climate conditions. The effects of higher stocking density on the bird performance have been shown in many studies. High density may have detrimental effects on environmental conditions of the house and bed quality, which have negative influence on comfort, health and performance of the birds (Knizatova *et al.*, 2010). Dawkins *et al.* (2004) reported that increasing density in breeding houses reduces air quality and negatively influences bird performance. They indicated that ventilation volume relative to density has more influence on poultry performance and better ventilation can reduce the negative effects of higher density. Therefore, breeding houses with more efficient ventilation, insulation, heating and cooling installations as well as feeders and drinkers may accommodate higher stocking densities. A study in Netherlands showed that from 1985 to 2008, the number of poultry farms declined while the number of poultry increased as much as 33%; in the same interval, average capacity of the farms increased to 86257 from the previous capacity of 35483. It is reported that bigger poultry houses tend to have higher profitability, better risk taking, and higher efficiency while releasing lower amounts of ammonia. However, the size of the house does not affect the broiler mortality, antibiotics consumption, equipment types (feeders and drinkers) and animal health (van Horne & Leenstra, 2010).

Results regarding the air flow fans and ventilation used in poultry houses in each rank, based on AHP model, are shown in Table 4. In this study, ventilation fans used in poultry houses are considered in three groups of small diameter (60-90 cm), large diameter (120-140 cm) and combined (small and large). The results indicated that 42% of the poultry houses benefited from ventilation fans with small diameters, 18%utilized fans with large diameters and 40% used a combination of the two. The results showed that by increasing rank and in poultry houses with a lower degree of mechanization, use of large fans was reduced. This number in 5th ranking houses reached zero. Higher ranking poultry houses in terms of mechanization tended to use longitudinal or tunnel ventilation mostly taking advantage of large fans. In 5th ranking houses, all of the houses used transversal ventilation systems. These systems tended to use small diameter fans (Table 4).

One important factor for gaining productivity is to provide a suitable breeding environment with air quality, temperature and humidity control as well as ventilation volume (Zhao *et al.*, 2015). Dust or airborne particles are among the most recognized pollutants in the air of poultry houses (Mitchell *et al.*, 2002). Considerable ammonia absorbed by airborne particles may create biological complications (Zhao *et al.*, 2014). Therefore, proper ventilation of poultry houses is essential for providing adequate oxygen, expulse toxic gases (carbon dioxide, ammonia and hydrogen sulfide), and humidity as well as reducing extra heat in hot seasons. Ideally, ventilation systems must move the air in the poultry houses and create an even flow of air throughout the place. This is not possible, if the fan capacity is not enough for handling the volume of air. Tunnel ventilation is the best accessible instrument in order to prevent thermal stress and broiler mortality in hot seasons (Lacy & Czarick, 1992). Kaur *et al.* (2017) indicated that broilers in tunnel ventilated houses, had better weight and FCR compared with birds in houses using ordinary ventilation.

Table 4 – Fan and ventilation used in various poultry houses by their respective rank determined through AHP (%).

Rank	Fan			Ventilation			Damper
	Small^{a}	Large^{b}	Combined^{c}	Transverse	Longitudinal	Combined	
1	33	20	47	33	54	13	87
2	34	28	38	47	37	16	83
3	38	25	37	44	50	6	75
4	47	16	37	63	37	0	81
5	60	0	40	100	0	0	73
mean	42	18	40	57	36	7	80

[a] Small: diameter 60-90 cm. [b] Large: diameter 120-140 cm. [c] combined: Small and Large.

Regarding the insulation of the roof, walls and windows, the results indicated that 74% of the poultry houses in the province lacked proper roof insulation, simply made with fiberglass, while 26% of the houses had suitable insulation of the roof (fiberglass, polystyrene and corrugated plastic) in order to prevent heat loss. With increasing rank and decreasing degree of mechanization in poultry houses, the percentage use of properly insulated roofs and 35cm walls were reduced. In general, about 11% of poultry houses in Zanjan province did not have windows and 89% of them had windows, whereas 100% of the houses in 5th ranking had windows (Table 5). Considering the great temperature variations between day and night in various seasons and in order to maintain suitable breeding conditions for the birds, insulation of poultry breeding buildings is quite important (Hristov *et al.*, 2017). Roof and wall covering greatly influences heat exchange and thermal resistance. Therefore, proper insulation can minimize the heat loss. This promotes health and performance of the poultry while significantly reducing energy costs.

Table 5 – Insulation of roof, walls and windows of industrial poultry houses by their ranking based on AHP method (%).

Rank	Roof		Wall		Window	
	Weak[a]	Good[b]	25 cm	35 cm	Window	Windowless
1	0	100	53	47	87	13
2	70	30	43	57	80	20
3	100	0	25	75	94	6
4	100	0	50	50	84	16
5	100	0	93	7	100	0
mean	74	26	53	47	89	11

[a] Weak: cement sheet, Fiberglass and wire mesh.

[b] Good: cement sheet, Fiberglass, polystyrene and corrugated plastic.

According to the results of this study, 17% of the heaters used in poultry houses were inside the houses (Jet Fan), 58% were outside and 25% were a combination of the two (Table 6). It is observed that in all the poultry houses, percentage of outside heaters were greater than inside and combined ones. Heater usage inside the building probably increases FCR by increasing concentrations of carbon dioxide, carbon monoxide and combustion fumes within the house, in turn reducing oxygen concentration.

The results indicated that 42% of the poultry houses had humidifiers, 90% had thermostats and 3% had ammonia sensors (Table 6). The results showed that with an increase in ranking and a decrease in mechanization degree, the use of humidifiers and temperature sensors were reduced. Percentage use of gas sensors (Ammonia Gauges) were generally low and in this respect no significant difference was observed between various poultry houses. Getting benefit from temperature, humidity and gas sensors can improve management in poultry houses and enhance their performance.

Table 6 – Heater and sensors used in poultry houses by ranking based on AHP method (%).

Rank	Heater			Sensors		
	Inside	Outside	Combination	Humidifier	Thermostat	Ammonia Gauge
1	27	53	20	60	100	0
2	17	43	40	50	90	7
3	6	56	38	37	94	0
4	16	69	15	44	87	9
5	20	67	13	20	80	0
Mean	17	58	25	42	90	3

As for the feeder and drinker systems used in poultry houses, the results indicated that 37% of houses used plate feeders, 47% used chain feeders and 16% used manual feeding (Table 7). Based on the multi criteria priority model, it is observed that with lower degree of mechanization, the percentage use of manual feeding increased and the use of plate feeders decreased. Poultry houses in 3rd, 4th and 5th ranking mostly utilized the chain feeders while 2nd ranked houses equally used chain and plate feeders. Also the results showed that 52% of the poultry houses used nipple drinkers and 45% used hanging drinkers while 3% used manual ones (Table 7). It is observed that poultry housed ranked 1st and 4th tended to use nipple drinkers while houses in 2nd, 3rd and 5th ranking mostly profited from hanging drinkers.

Table 7 – Feeder and drinker systems used in poultry houses by their ranking based on AHP method (%).

Rank	Feeder			Drinker		
	Manual	Chain	Plate	Hanging	Nipple	Manual
1	7	40	53	13	87	0
2	7	47	46	57	43	0
3	19	50	31	56	38	6
4	22	50	28	38	59	3
5	27	46	27	60	33	7
mean	16	47	37	45	52	3

Drinker and feeder systems are important during the early phases of broiler development, particularly during the first week. Therefore, feeders and drinkers must be placed in a way so as to be easily accessible to broilers. Otherwise, dehydration and loss of body water may lead to their weakness and ultimate death (Sainsbury, 2000). In a study by Stamps & Andrews (1995) three types of drinkers were investigated which showed no difference in mortality rates. However, the results indicated that drinker type is important during the first week (perhaps because after the first week the broilers should have learned how to find water).

Comparison of performance parameters of poultry houses by their ranking is presented in Table 8. The results indicated that all of the performance parameters except for mortality and slaughter age had significant differences among various ranks (p<0.05). Poultry houses in the 4th and 2nd rankings had the highest and lowest feed intake, respectively. The 5th ranking houses which had the lowest mechanization coefficients, demonstrated minimum body weight. When it comes to the FCR, the results indicated that by improving mechanization coefficient, FCR was reduced so that 1st ranking poultry houses had the lowest FCR. Considering that buying chicken is carried out on the basis of body weight, and the fact that slaughter age is a function of body weight, no significant difference was observed between slaughter ages in various ranks. Production index, which is an important economic parameter in evaluation of poultry houses, showed significant variations among various ranks (p=0.015) so that the highest production index belonged to poultry houses ranked 1st and the lowest values were related to the 5th ranking.

Table 8 – Comparison of performance parameters by poultry house ranking based on the AHP method.

Rank	Number of Records	Feed intake (g)	Body weight (g)	FCR	Mortality (%)	Slaughter age (days)	PI
1	54	5555 ^{ab}	2900 ^{a}	1.92 ^{b}	10.90	51.76	262.4 ^{a}
2	115	5337 ^{b}	2760 ^{bc}	1.93 ^{b}	10.64	51.70	247.2 ^{bc}
3	60	5562 ^{ab}	2873 ^{a}	1.94 ^{b}	9.35	52.15	259.5 ^{ab}
4	135	5583 ^{a}	2804 ^{ab}	2.00 ^{a}	11.28	51.55	245.2 ^{c}
5	61	5431 ^{ab}	2681 ^{c}	2.03 ^{a}	10.10	51.64	232.2 ^{d}
SEM		79.29	38.16	0.019	0.68	0.43	4.56
p-Value		0.04	0.001	0.04	0.27	0.89	0.015
mean		5488	2796	1.97	10.63	51.72	248.05

^{abc} Dissimilar letters under each column or parameter indicate significant differences (p<0.05).

Today, management and feeding are the most important issues in poultry industry. Better management and nutrition helps supply more quality products while reducing cost. This makes production economically viable and reduces environment pollution due to reducing the indiscriminate use of nutrients and reduce their disposal (Pope & Emmert, 2001). It is reported that improvements in buildings, installations and equipment as well as management methods can enhance performance parameters in poultry houses (MacDonald, 2008; Liang *et al.*, 2013). Today, modern poultry houses with proper insulation, well designed ventilation, controlled environment conditions and automatic equipment inside the house, make it possible to breed birds in higher densities (Liang *et al.*, 2013). Some researchers have suggested the use of controlled environmental conditions in order to achieve better performance and higher density in tropical regions (Mendes *et al.*, 2014; Farhadi & Hosseini, 2016; Kaur *et al.*, 2017). Daily feed of poultry is directly related to the energy and nutrients of the feed and environment temperature as well as age, body weight and production level of the poultry. FCR is the key factor in optimal production of a broiler breeding farm and some researchers believe various factors to be related to it. Therefore, any improvement in this regard can reduce cost and enhance the economic profitability (Sheppard, 2004). Our results indicated that an increase in mechanization rank led to higher FCR which could be due to energy loss in houses with lower mechanization level. Also this may be a result of low quality of rations used in these farms causing birds to consume more feed in order to obtain their requirements.

CONCLUSIONS

In general, the results demonstrated ventilation system and insulation of roof and walls in a poultry house to have 66% contribution in determining the technology coefficient. First ranking poultry houses mostly used tunnel ventilation with a combination of small and large fans. They utilized fiberglass, polystyrene and corrugated plastic for insulation of the roof and had their heaters installed outside the house. Feeder and drinker systems showed to be of insignificant importance in productivity and most of the poultry houses used plate feeders and nipple drinkers. No difference was found between various rankings in terms of mortality and slaughter age. However, improvements in FCR and production indices were observed as economic parameters of this category of houses.

REFERENCES

Aviagen. Ross broiler management manual. Midlothian: Aviagen; 2014.

Daghir NJ. Poultry production in hot climates. Wallingford: CABI; 2008.

Dawkins MS, Donnelly CA, Jones TA. Chicken welfare is influenced more by housing conditions than by stocking density. Nature 2004;427(6972):342-4.

Farhadi D, Hosseini S. Evaluation of growth performance, carcass characteristics, litter quality and foot lesions of broilers reared under high stocking densities. Iranian Journal of Applied Animal Science 2016;6(1):187-194.

Glatz P, Bolla G. Production systems, poultry. In: Jensen WK, editor. Encyclopaedia of meat sciences. Amsterdam: Elsevier; 2004. p.1085-1092.

Hristov A, Degaetano A, Rotz C, Hoberg E, Skinner R, Felix T, et al. Climate change effects on livestock in the Northeast US and strategies for adaptation. Climatic Change 2017:1-13.

Kaur M, Sharma A, Gupta R, Singh Y, Sethi A, Singh C. Resource use efficiency of broiler production in tunnel-ventilated environmental control vis-à-vis open-sided conventional shed during summer. Tropical Animal Health and Production 2017;49(8):1591-1596.

Knizatova M, Mihina S, Broucek J, Karandusovska I, Macuhova J. The influence of litter age, litter temperature and ventilation rate on ammonia emissions from a broiler rearing facility. Czech Journal of Animal Science 2010;55(8):337-345.

Lacy M, Czarick M. Tunnel-ventilated broiler houses:Broiler performance and operating costs. The Journal of Applied Poultry Research 1992;1(1):104-109.

Liang Y, Kidd M, Watkins S, Tabler G. Effect of commercial broiler house retrofit:A 4-year study of live performance. The Journal of Applied Poultry Research 2013;22(2):211-216.

MacDonald JM. The economic organization of US broiler production. Washington: United States Department of Agriculture, Economic Research Service; 2008.

Mendes LB, Tinoco IF, Ogink NW, Rocha KS, Osorio S, Jairo A, et al. Ammonia emissions from a naturally and a mechanically ventilated broiler house in Brazil. Revista Brasileira de Engenharia Agrícola e Ambiental 2014;18(11):1179-1185.

Mitchell B, Buhr R, Berrang M, Bailey J, Cox N. Reducing airborne pathogens, dust and Salmonella transmission in experimental hatching cabinets using an electrostatic space charge system. Poultry Science 2002;81(1):49-55.

Pope T, Emmert J. Phase-feeding supports maximum growth performance of broiler chicks from forty-three to seventy-one days of age. Poultry Science 2001;80(3):345-352.

Saaty TL. Decision making with the analytic hierarchy process. International Journal of Services Sciences 2008;1(1):83-98.

Saaty TL. How to make a decision:the analytic hierarchy process. Interfaces 1994;24(6):19-43.

Sainsbury D. Poultry health and management–chicken, ducks, turkeys, geese, quail. London: Black Well Science; 2000.

Sheppard A. The structure and economics of broiler production in England. Exeter: Centre for Rural Policy Research, University of Exeter; 2004.

Stamps L, Andrews L. Effects of delayed housing of broiler chicks and three different types of waterers on broiler performance. Poultry Science 1995;74(12):1935-1941.

Van Horne P, Leenstra F. Broiler farm size in relation to sustainability aspects. Proceedings of 13th European Poultry Conference; 2010 Aug 23-27; Tours, France. Beekbergen: Word's Poultry Science Association

Zhao Y, Aarnink AJA, De Jong MCM, Groot Koerkamp PWG. Airborne microorganisms from livestock production systems and their relation to dust. Critical Reviews in Environmental Science and Technology 2014;44(10):1071-1128.

Zhao Y, Shepherd TA, Li H, Xin H. Environmental assessment of three egg production systems–Part I:Monitoring system and indoor air quality. Poultry Science 2015;94(3):518-533.