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Chickens, sheds, feed conversion ratio, mortality, welfare.

Broiler-Housing Conditions Affect the Performance

ABSTRACT

In the last decades animal production has considerably increased worldwide to sustain an ever-growing human population. Among animal reared for consumption purposes, chickens are undoubtedly one of the most successful, mainly due to their rapid growth rate. The development of broiler farming has been accompanied in recent years by a substantial attention to animal welfare. This study is aimed at assessing the effects of different housing conditions on both feed conversion ratio and mortality of male broiler flocks through a large-scale study (more than 100 million birds) involving 977 farms belonging to one major producer. For this, we evaluated nine features of the housing system using a linear model with random effect. The features were: roofing, floor, drinkers, feeders, water source, color curtain color, management, light and ventilation. A total of 3516 poultry flocks were assessed. Positive ventilation, metal and clay roof, dirt floor and owner management were shown to reduced mortality. Concrete floor, negative ventilation, blue curtains, fluorescent lightening, owner management, tap water and well water significantly improved FCR. We discuss our findings in relation with economic constraints and provide advices to encourage farmers using simple devices that will improve both production and chicken survival.

INTRODUCTION

Breeding for faster growth rate has been associated with welfare problems encountered in commercial broilers. Pressured by consumers (Broom & Reefmann, 2005), growing attention has been paid worldwide to increase broiler welfare (Gocsik *et al.*, 2016). In 2007 the major world private certification agency: GLOBAL Good Agricultural Practice (GAP) was created (GLOBALGAP, 2016). GLOBAL-GAP is a pre-farm gate standard for good agricultural practices and covers different aspects of food safety, environmental protection and animal welfare (Holzapfel & Wollni, 2014). Besides that, it provides standards for countries in the world. This includes Brazil, the first exporter of chicken meat worldwide (UBA, 2014). Most recommendations have been done in relation to stocking density, with the goal to avoid overcrowding, since over a density of 30 kg/m², growth rate is significantly reduced (Feddes *et al.*, 2002). Many studies focused on broiler density, assessing welfare and growing were done (Cravener *et al.*, 1992; Muniz *et al.*, 2006; Ravindran *et al.*, 2006). However, a study involving commercial broilers showed that housing conditions are more important than stocking density *per se* regarding welfare (Dawkins *et al.*, 2004). Some other studies confirm the importance of environmental conditions (Bueno & Rossi, 2006; Zi-guang *et al.*, 2014).

Housing and management of broiler are designed to ensure optimum performance. Several aspects of broiler production have



been overlooked such as food quality/quantity (Weeks *et al.*, 2000; Apajalahti *et al.*, 2004) and breeder (Griffin & Goddard, 1994), in the same way as little is known about the role of different features of sheds in improving production. Some studies have focused in these gaps (Abreu *et al.*, 2011), such as, performance in concrete floor or cage (Swain *et al.*, 2002; Santos *et al.*, 2012). No consensus has been obtained regarding the floor that should be used to maximize growth while maintaining welfare and meat quality. For instance, heater position and number of drinkers in the house have explained 56% of the variations in litter moisture and both season and ventilation explained 73% of the variation in air (Weaver & Meijerhof, 1991; Nahm, 2003; Lovanh *et al.*, 2007; Miles *et al.*, 2011). Several other factors such as; feeder type, drinker type, type of lighting and even curtain colours, might also have an impact on environment quality affecting both performance and welfare (Dozier *et al.*, 2005; Cordeiro *et al.*, 2010; Hameed *et al.*, 2012).

The present study was designed with the objective of determining the impact of features of different housing system on the feed conversion ratio (FCR) and indirect measure of bird welfare: Mortality.

MATERIALS AND METHODS

The data were kindly given by JBS Foods Brazil (one of the biggest companies producing broilers in Brazil), so that the owner gave full permission to use it. This did not involve endangered species.

As it is a statistical analysis of the biggest dataset of broiler production in the world, we do not have other information regarding sacrifice procedure other than those provided by certification. Indeed, a large number of chicken producing units of the JBS Foods are certified by international bodies such as: Global GAP, BRC, Alo Free and follow important codes of good practices of production and slaughter of global customers (GLOBALGAP, 2013).

Data collection: All data was collected over one year (2012) from 3516 commercial chicken flocks located in north region to state of Santa Catarina-Brazil, raised on 977 different farms belonging to one major producer company. The daily slaughtering of the production unit is about 160,000 chickens, essentially meant for export.

Flock is defined as a group of chickens placed in a house and present in the house at the same time. Typical commercial flock size was between 10,000 and 30,000 birds (Figure 1), with a mean of 29,340

individuals. The performance results of different broiler flocks were collected as well as the features of the shed from which they belonged. This represents data for 103,160,987 male broiler chickens.

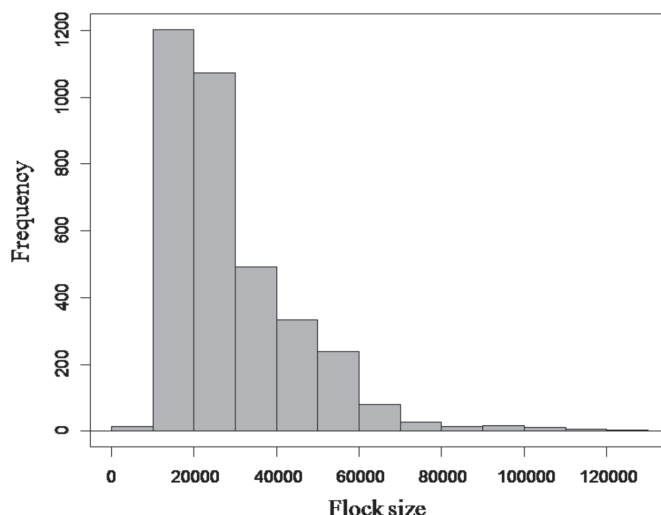


Figure 1 – Distribution of the number of individuals per flocks.

Birds and feed: Male broiler chicks Ross 308® breed were reared from one day old to forty-two day old. The chickens were fed *ad libitum* with a diet specific for each phase of growth, following the recommendations of the broiler management manual, which also lists the dry bulb temperatures required to achieve good growing performances. The air temperature inside the sheds for the first day was around 30°C, slightly decreasing in the course of chicken development to attain a temperature of approximately 20°C at 42 days of age, following commercial recommendations. None of the farms controlled humidity directly, humidity varied between 60-70%. All individuals were fed the same feed, provided by veterinary specialists from the major producer.

Features of sheds: A typical rearing house (also called a shed or barn) showed the following features: The size predominant was 40 by 400 feet (12 m × 120 m), insulated ceiling, and exterior curtain side walls. The mean density of chickens was 12 birds per m², to ensure not to exceed the threshold of 33 kg/m². Daylight duration was between 13 hours in December and January and 10 hours in July.

We recorded the following information for each shed:

- Feeder type: Chain feeder or individual pans;
- Drinker type: Nipples or bell;
- Type of management of the broilers (owner or keeper). Owner: persons owning the holding



where chickens are kept; Keeper: legal person responsible for or in charge of chickens

- Type of ventilation system (negative or positive): For negative, the air is forced from inside to outside, while fans work the opposite way for positive system.
- Floor type: concrete or dirt (beaten earth). All producers with concrete floor had the Global Gap certificate. Litter (wood shavings) to cover the floor. The litter was reused and disinfected for seven consecutive flocks with the same protocol in all farms for this study (Muniz *et al.*, 2014).
- Origin of the water: spring water, tap water or well
- Type of lighting: incandescent or fluorescent (the same lighting program)
- Color of the curtains: blue or yellow
- Roofing material: clay, metal or concrete.

These data were then confronted with data of performance (Food conversion rate) and welfare (assessed through percentage of mortality of each flock).

Performance: Aiming at standardizing data to allow more accurate analysis, feed conversion ratio was adjusted to 2.0 kg live weight. Live weight was adjusted by dividing total flock weight by days until slaughter. Feed conversion ratio (FCR) was calculated dividing total flock feed intake by total flock weight gain during the grow-out. Corrected feed conversion ratio (cFCR), using cFCR for 2.0 standard live weight, was calculated using the following equation (Patricio *et al.*, 2012):

$$\text{cFCR} = (\text{SW} - \text{AW})/3.2 + \text{FCR}.$$

Where: SW = standard weight, AW = average flock weight, 3.2 = correction factor, FCR= flock feed conversion ratio. Mortality was assessed at the end of the growing process.

Data analysis: The cFCR was correlated to mortality using a linear model with mixed effects (LMM) to take into account farm effects, which was added as random effect for the intercept. LMM are designed to handle grouping in the data and some farm delivered many data, such as an autocorrelation of the data likely occurred. To assess the impact of environmental variables on mortality, we first used a linear model. Model-fitting began with a saturated model including all variables (9 variables). Then we applied the step AIC function that allows performing stepwise model selection based on the AIC, and as such allows selecting the more parsimonious model.

Once this selection process was applied, the more parsimonious model was run using LMM. The same procedure of model selection was applied to assess the impact of environmental variables on cFCR.

All statistical analyses were performed using R software (R Development Core Team 2009), in particular the “MASS” package (Venables & Ripley, 2002) for the step AIC function, the “lme4” package (Bates & Maechler, 2009) for linear model with mixed effects and the “effects” package for the design of graphs.

RESULTS

Mortality averaged was 4% and cFCR averaged 1.4. Neither mortality nor cFCR were correlated to the size of the flock (mixed linear model, p-value: 0.37 and 0.07 respectively). cFCR was positively and significantly correlated to mortality (linear model with mixed effects, *P*-value: 0.007, Figure 2), although the adjusted R-squared of the linear model was really low (adjusted R-squared = 0.001).

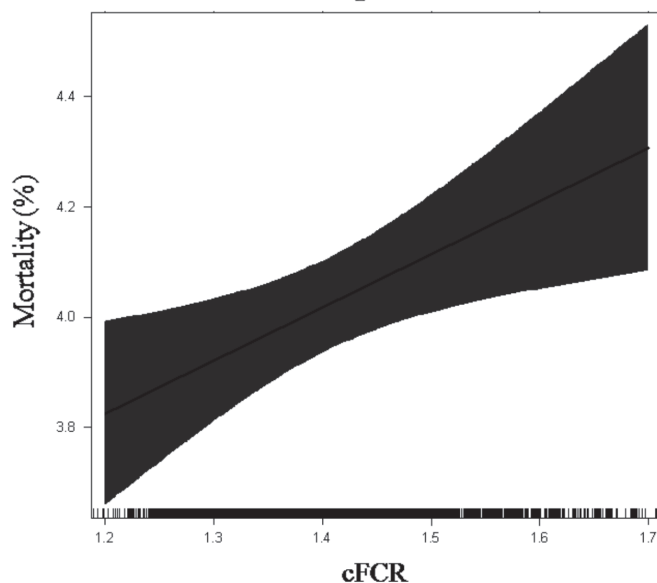


Figure 2 – Correlation between corrected feed conversion ratio (cFCR) and mortality. The black line represents the linear model with mixed effects (LMM) and the shaded area is the 95-percent confidence envelope around the fitted effects.

In the most parsimonious model, explaining mortality variance, the following variables were selected: Color of the curtains, feeders, ventilation type, roofing material, management and floor type. Among these variables, ventilation type, roofing material, management and floor type significantly impacted the mortality in our linear model with random effects (Table 1). Positive ventilation, metal and clay roof, dirt floor and owner management led to lower mortality (Table 1, Figure 3).



Table 1 – Effects of different variables on mortality

Linear mixed model fit by REML				
Random effects:				
Groups Names	Variance	Std.Dev.		
Farm (Intercept)	0.5943	0.7709		
Residual	2.8364	1.6842		
Number of observations: 3516				
Group Farm 977				
Fixed effects:				
	Estimate	Std. Error	t value	p-value
(Intercept)	4.96	0.13	38.68	< 0.001***
Color.curtainsYellow	0.10	0.09	1.13	> 0.05
FeedersManual	0.18	0.11	1.61	> 0.05
Ventilation.typePositive	-0.25	0.11	-2.37	< 0.001***
Roofing.materialsConcrete	0.20	0.08	2.46	< 0.001***
Roofing.materials Metal	-0.62	0.38	-1.64	> 0.05
Management.Owner	-0.35	0.09	-3.83	< 0.001***
FloorDirt	-0.92	0.10	-8.95	< 0.001***

Table 1 : Outputs of the linear mixed model (LMM) testing the effects of the colour of the curtains, type of feeders, type of ventilation, roofing material, management type and floor type on mortality. The farm was used as a random effect. REML: Residual Maximum Likelihood estimation criterion ***Significant value < 0.001.

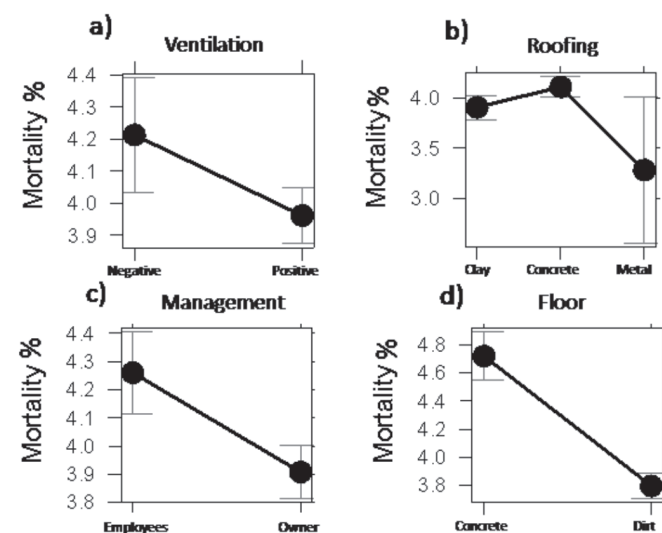


Figure 3 – Fitted values for the variables a) ventilation type, b) roofing material, c) management type and d) floor type, that significantly impacted mortality. Graphs represent only significant terms from the linear model with random effects (see Table 1). Black bar: 95% interval for the fitted value.

In the most parsimonious model, explaining cFCR variance, the following variables were selected: roofing material, ventilation type, floor type, feeders, color of the curtains, type of lighting, management and origin of the water. Among these variables, the ventilation type, the floor type, the color of the curtains, the type of lighting, the management and the origin of the water significantly impacted the male cFCR in our linear model with random effects (Table 2). All, concrete floor, negative ventilation, blue curtains, fluorescent lightening, owner management, tap water

and water coming from the well significantly improved the male cFCR efficiency (Table 2, Figure 4).

Table 2 – Effects of different variables on corrected feed conversion ratio (cFCR)

Linear mixed model fit by REML			
Random effects			
Groups Name	Variance	Std.Dev.	
Farm (Intercept)	0.0013	0.037	
Residual	0.0061	0.078	
Number of observations: 3516			
Groups Farm: 977			
Fixed effects:			
	Estimate	Std. Error	p-value
(Intercept)	1.4	0.007	< 0.001***
Roofing: Concrete	0.0036	0.004	> 0.05
Roofing: Metal	-0.019	0.018	> 0.05
Ventilation: Positive	0.01	0.005	< 0.01**
Floor: Dirt	0.024	0.005	< 0.001***
Feeders: Manual	-0.01	0.005	> 0.05
Curtains: Yellow	0.03	0.004	< 0.001***
Lighting: Incandescent	0.015	0.004	< 0.001***
Management: Owner	-0.045	0.004	< 0.001***
Water origin: Tap water	-0.04	0.009	< 0.001***
Water origin: Well	-0.02	0.004	< 0.001***

Table 2: Outputs of the linear mixed model (LMM) testing the effects of roofing materials, ventilation type, floor type, feeder type, colour of the curtains, lighting, management and water origin on corrected feed conversion ratio (cFCR). The farm was used as a random effect. REML: Residual Maximum Likelihood estimation criterion ***Significant value < 0.001 and **Significant value < 0.01.

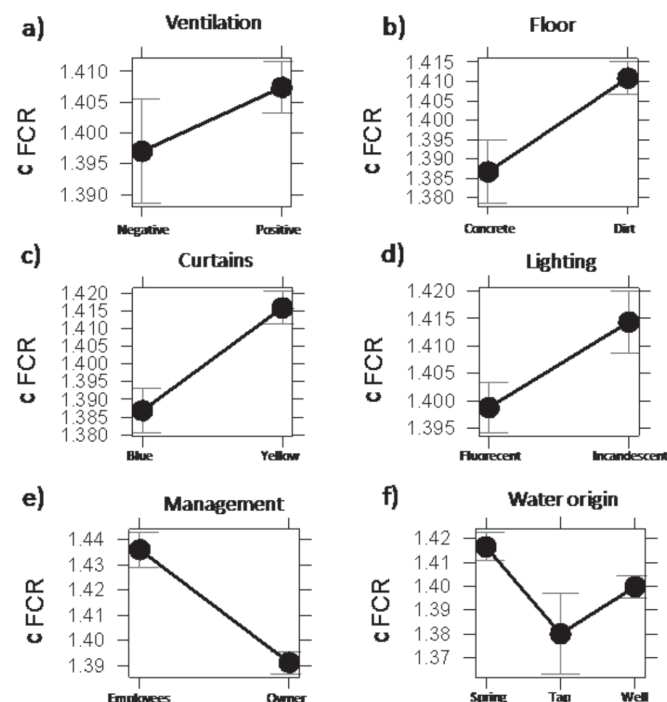


Figure 4 – Fitted values for the variables a) ventilation type, b) floor type, c) curtains color, d) type of lighting, e) management type and f) water origin, that significantly impacted corrected feed conversion ratio (cFCR). Graphs represent only significant terms from the linear model with random effects (see Table 2). Black bar: 95% interval for the fitted value.



DISCUSSION

Mortality was independent of flock size but was, however, positively correlated to cFCR such that high production efficiency (low cFCR) was also linked to low mortality. This result should however be taken with caution since it might highly depend to the very high number of flock tested (3516), owing to the low percentage of explanation (adjusted r -squared= 0.001). The positive relationship between mortality and cFCR was probably attained through the decline of stress. Indeed, mortality and impaired growth rate are highly correlated to corticosteroid levels (Dawkins *et al.*, 2004; Jones *et al.*, 2005) ammonia and diseases (Reece *et al.*, 1980; Kristensen & Wathes, 2000; Chapman *et al.*, 2002; Santana *et al.*, 2012), these conditions equally might affect both FCR and mortality. We suppose it is not only stress that might cause this positive relationship, the feed and water quality play an important role (King, 1996; Amerah *et al.*, 2007) among many other factors. Moreover all flocks used in this study were apparently healthy birds. A specific combination of housing features and management procedures have contributed to the amelioration of broiler conditions leading to high production efficiently and increased welfare (Meluzzi & Sirri, 2009; Jacobs *et al.*, 2016).

Management: Broilers kept by owners reached higher performances (cFCR) and lower mortality when compared to broilers reared by employees. Nevertheless, neither cFCR nor mortality was significantly affected by flock size and bigger flocks tended to have better cFCR (P -value: .07). As a general rule, performance of human managers might vary greatly in livestock production, with some producing consistently better results than others. Concerning present data, it is likely that owners were more dedicated than employees in keeping the flock either through their experience of managing broiler production (compared to new employees) or by being directly linked to their financial investment. To the best of our knowledge, this is the first report to highlight the relevance of the producers within the system.

Water origin: In several regions of the world, water availability is the most limiting factor for producing broilers. In other regions, it is rather the water quality that will directly affect production (Barton, 1996). In the present study both tap water and water coming from wells improved feed conversion ratio. In general, it is more difficult to maintain a consistent water quality when using spring water compared to tap water or water coming from wells, although poor storage might also negatively influence quality (Penz, 2003).

Water has several physico-chemical (Barton, 1996) and microbiological (Lee & Cole, 1994; Grizzle *et al.*, 1997) characteristics affecting broilers' performances. The better cFCR observed with tap water could be the result of a rigorous water management undertaken by the public system. The constant flow chlorination might have improved the microbiological quality of the water by diminishing the relative number of faecal coliforms (Valias & Silva, 2001), therefore enhancing broiler performance. While nipple drinkers were associated with possible injuries (Jones *et al.*, 2005) the present study failed at finding an effect of drinker type on both cFCR and mortality.

Curtains: Although the curtain colors could, at first, appear anecdotic, some studies highlighted its importance on birds' growth and welfare (Olanrewaju *et al.*, 2006; Abreu *et al.*, 2011). Blue curtains were selected in the more parsimonious model, explaining lower mortality (although not significant) and birds raised in houses with blue curtains achieved a significantly better cFCR than those raised in houses equipped with yellow curtains. Present results are in contradiction with those obtained by (Abreu *et al.*, 2011), who found that broilers reared in houses with yellow curtains presented on average the best FCR (although this depended on flock, season and lighting program). The main difference between studies relies on the number of birds; while Abreu *et al.* (2011) conducted their study on experimental conditions (200 birds per flock, $n=6$), we used a more realistic approach by providing data on commercial houses. Present results are in line with the assumption that blue curtains would lead to high performance through the lowering of physical activity and energy expenditure in darker conditions (Lewis & Morris, 2000). However, Abreu *et al.* (2011) showed that curtain colour (yellow or blue) did not influence light intensity inside the houses, and positive effects of blue curtain might rather be mediated by light properties. In broilers, both blue and green lights were shown to promote growth (Rozenboim *et al.*, 1999a; Rozenboim *et al.*, 1999b; Rozenboim *et al.*, 2004), probably linked to effective stimulation of testosterone secretion (Cao *et al.*, 2008). In addition, blue light wave length was shown to stimulate immunity and alleviate stress response (Xie *et al.*, 2008). In addition, exposure of the broilers to blue light just before slaughtering showed potential to be used in modern slaughter houses to offer a comfortable atmosphere (Barbosa *et al.*, 2013). In other taxon, such as fish, blue light was also shown to reduce stress compared to both white and green light (Volpato & Barreto, 2001; Pereira Silva *et al.*, 2012).



Lightening: Artificial lights differ consistently from natural light in terms of intensity, color and flicker intensity. Light is highly important for several life history traits such as reproduction and growth (Huth & Archer, 2015b; Olanrewaju *et al.*, 2016b). In the present study, light source did not affected mortality, while it impacted cFCR, with fluorescent lightening providing better results compared to incandescent lights. A decade ago, incandescent bulbs were the standard “reviewed in Olanrewaju *et al.* (2006)”, but fluorescent lamps are increasingly used, mainly due to their longer lifetime (approximately 20,000 hours)(Darre & Rock, 1995). When the choice between two types of light was given to chickens, the birds clearly chose fluorescent lamps over incandescent lamps (Widowski *et al.*, 1992; Kristensen *et al.*, 2004). Kristensen *et al.* (2006), compared two different fluorescent light sources and did not detect any effects on feed intake, weight gain and mortality. To our knowledge, this is the first report assessing the difference in FCR between fluorescent lamps and incandescent bulbs. The fact that fluorescent lamps improve poultry performance is of great interest, since it will also allow long-term economic benefits (Andrews & Zimmermann, 1990) due to their higher performance when compared to incandescent bulbs with much shorter lifetime (*i.e.* about 750-2000 hours) (Darre & Rock, 1995). Moreover, the poultry industry is currently undergoing a shift to alternative lighting sources such as light-emitting diode (LED) bulbs, that have associated increased energy savings, they may affect the bird's growth and well-being (Huth & Archer, 2015a; Olanrewaju *et al.*, 2016a). In addition, chickens exposed to LED bulbs presented better performance than chickens under the fluorescent lamps (Mendes *et al.*, 2013b).

Roofing: This result was surprising, it does not affect the performance of the birds in our statistical model, but the concrete roof appears to influence mortality of chickens. Explaining this could appears tricky, since there are no specific studies assessing the effect of various materials for roofs in broiler sheds. To this result we dare suggest the hypothesis that clay tile can act in a more thermal manner in comparison to concrete tile, in other words, the clay could act as an insulating medium between the external environmental conditions and the inside of the shed, on the contrary the cement could pass more easily the external conditions to the interior, though this is just a hypothesis in which could run an experiment.

The role of ventilation type: Ventilation plays a key role in poultry production since it allows counter balancing negative effects of stocking density by

improving air quality (Puron *et al.*, 1995; Mendes *et al.*, 2013a), allowing heat dissipation and removing excessive moisture. Keeping the litter dry and providing sufficiently oxygen to meet the birds' metabolic demand are highly important to improve animal welfare (Cordeiro *et al.*, 2010; Amaral *et al.*, 2011). For negative pressure, the air is forced from inside to outside, while fans works the opposite way for positive pressure. Negative pressure generally results in effective mixing of air and higher air uniformity within the shed compared to positive pressure. This feature has a considerable impact on both cFCR and mortality. Negative pressure was associated with high growing performances, even at high densities (Feddes *et al.*, 2002). Interestingly, negative pressure appeared to significantly improve cFCR in the present study, while its effects were deleterious considering overall bird welfare. Respiratory disease generally results from a combination of negative variables such as microorganisms and type of gases encountered in the shed, mainly ammonia. Heier *et al.* (2002), showed that broiler mortality was lesser when fans were used in comparison with low-pressure systems.

A poor ventilation system is probably related to bad litter quality which is in turn related to foot pad dermatitis (Martrenchar *et al.*, 2002), disease that prejudice the welfare and performance of the birds (Kaukonen *et al.*, 2016).

Concrete Floor: Concrete floor significantly improved cFCR, compared to hard-packed dirt floors. This finding does not support results from Abreu *et al.* (2011) who reported no difference in broilers' performance according to the type of floors. When comparing floor and cage, broilers reared on concrete floor consumed significantly more feed than in cage (Swain & Sundaram, 2000; Rodríguez *et al.*, 2005). However, regarding bird welfare, dirt floor significantly diminished mortality when compared to concrete floor. Again, our results are in disagreement with Abreu *et al.* (2011) findings, who stressed that both total mortality and sudden death were higher when broilers were raised on hard-packed dirt floors. Differences between studies are mainly explained by differences in the number of birds used and by experimental procedure, as underlined above. There is empirical evidence that concrete floor produce wetter litters than dust floor (Kunkle *et al.*, 1981). Litter quality is of high importance since broiler chickens generally spend their entire life in contact with it (Smith, 1956). The fact of being raised on wet litter might inhibit dust-bathing. This behavior is essential since it allows diminishing stress; particularly in young chicks as scratching behavior disappear with



ontogeny (Bessei, 2006). However, concrete floors are recommended by the GLOBAL-GAP since it promotes poultry house disinfection (GLOBALGAP, 2016).

Economic consequences and recommendations:

To date, Brazil is the third largest producer of broiler in the world (after The United States and China) employing directly or indirectly 3.6 million people (producers, processing companies and exporters) principally in the Southern and South-eastern states (UBA, 2014). As such, identifying factors that will allow improving both survival and performance would not only benefit Brazilian farmers, but also farmers from other developing countries.

Like in many South-American countries, Brazilian legislation is outdated and does not specifically address animal welfare issues (Silva *et al.*, 2011). Most producers rely on information given by the GLOBAL-GAP that is starting to take into account welfare preoccupation, though most recent analyses on the subject highlighted that more rigorous standards should urgently be developed (Silva *et al.*, 2011). Welfare is currently also being recognized by consumers as an essential point to purchase products (Vanhonacker & Verbeke, 2009; Gerini *et al.*, 2016). For instance, in a survey conducted in 2011 in Brazil, 76 % of the consumers worried about welfare and 63 % of consumers expressed willingness to pay more if this implied an improvement for the chicken welfare (Silva *et al.*, 2011).

Density of broilers account noticeably for their welfare, with higher density often associated with heat-related issues (Shanawany, 1988; Buijs *et al.*, 2009; Abudabos *et al.*, 2013). Nevertheless some studies reported that a certain threshold of bird density is necessary to increase feeding through socially facilitated behaviors (Collins & Sumpter, 2007). Assuming no reduction in the performance of broilers, total production cost (\$/kg) should decrease drastically with increasing density (Feddes *et al.*, 2002). Hence, a good compromise should be attained in order to not impair both FCR and survival, while conserving low economic inputs in a competitive market place. Long-term good results should be achieved by using a combination of factors related to housing conditions (Manning *et al.*, 2007). In Brazil, most farmers use hard-packed dirt floors, mainly linked to their lower building cost relative to concrete floor (Fioretin, 2006). On the one hand, concrete floor improve consistently cFCR. On the other hand, dirt floors provide much better results regarding survival, than concrete floors. cFCR increased using concrete floor compared to dirt floor, while mortality decreased using dirt floor relative

to concrete floor (total mortality 3.8% compared to 4.7%, roughly 300 broilers for a representative farm). Considering that survival rate is the most useful indirect measure for animal wellbeing, we would thus recommend using dirt floor for broiler welfare. Conversely, while positive pressure might slightly improve survival, it might greatly impair cFCR, and we would thus recommend the use of negative pressure, with fan forcing the air from inside to outside. Regarding our results, other recommended features are blue curtains, fluorescent lightning and either tap water or water coming from wells.

Considering both the span of the evaluation (comparing about 1000 farms) and the number of chicken used (more than 100million), the present study provide rich material and assess, with a strong statistical support, the importance of various basic an necessary housing conditions in improving both cFCR and mortality in broiler production, we believe it is imperative to explore all alternative approaches allowing maximizing the production, while improving welfare standards. We emphasize the importance of the management of birds given by the owners compared to employees, as well as the positive impact of the type of water, color of the curtains and ventilation system on the welfare and performance of the broilers.

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