Engenharia Agrícola

ISSN: 1809-4430 (on-line)

www.engenhariaagricola.org.br

Scientific Paper
Doi: http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v42n4e20220050/2022

FUZZY CONTROLLER APPLIED TO TEMPERATURE ADJUSTMENT IN INCUBATION OF FREE-RANGE EGGS

Dian Lourençoni[1*], Déborah C. T. C. de Brito[1], Pablo T. L. de Oliveira[2], Silvia H. N. Turco[1], Jeonan da S. Cunha[1]

[1*]Corresponding author. Universidade Federal do Vale do São Francisco/Juazeiro - BA, Brasil.
E-mail: dian.lourenconi@univasf.edu.br | ORCID ID: https://orcid.org/0000-0003-1173-2381

KEYWORDS

thermal control,
hatchability of eggs,
energy efficiency,
fuzzy modeling,
temperature.

ABSTRACT

Temperature variation in egg incubation can negatively affect the hatching time and weight gain of chicks, hence improving the incubator temperature accuracy can improve hatching rates. Controllers based on the fuzzy methodology have shown great potential for use in controlling incubator temperature variations. Therefore, the objective of this study is to develop and evaluate a fuzzy logic-based controller for egg incubation. Four identical incubators were configured: two with a fuzzy controller and two with a conventional controller. After evaluation and validation, a case study of the incubating eggs of free-range chickens was conducted on where 12 incubation cycles consisting of 20 eggs per incubator. The variables obtained include hatchability and electricity consumption. The results showed that the fuzzy logic-based controller maintained uniform internal temperature and a 10.68% saving on electricity usage when compared with the conventional controller. Thus, the fuzzy methodology has great potential for use in the incubation of free-range eggs.

INTRODUCTION

Hatcheries are common on breeder farms and are considered a favorable environment for poultry production because they promote the development of day-old chicks from fertile eggs in quantities, terms, and quality required by industrial poultry farming (Melo et al., 2018).

The creation of low-cost and high-efficiency equipment, ensures suitable egg incubation conditions and sustainable production from autonomous small and medium producers. Poultry production in family farming is practicable and requires minimal labor, with a relatively quick financial return due to the production cycle of birds, moreover being a source of food for the family (Fernandes & Silva, 2001; Arruda et al., 2019). Free-range strains are the most applicable in family farming, owing to their robustness and ease of handling.

Understanding and controlling the conditions required for egg incubation and hatching is of utmost importance, since the embryonic period of birds represents approximately 30% of broiler lifespan (Gonçalves et al., 2013). Incubation temperature is an important factor in embryonic development and hatchability (Flores et al., 2016). Several authors mentioned that high temperatures increase embryonic mortality, in addition to accelerating embryonic development and premature birth (Willemsen et al., 2010; Van Der Pol et al., 2014, Ozlu et al., 2018). In contrast, embryonic development and chick hatching are delayed on low temperatures (Marques, 1994).

Several authors have evaluated incubation temperatures to determine the optimal temperature. Nakage et al., 2003; and Maatjens et al., 2016 observed a divergence of the ideal temperature during incubation, ranging from 36.5 to 38.3 °C, with greater consensus in the 36.7 to 37.8 °C range. Incubator temperature variation that occurs during egg incubation is another factor that can affect hatch time and chick weight gain after hatching (Shim & Pesti, 2011, Costa et al., 2017).

Therefore, improving the temperature accuracy in an incubator can improve the hatchability. The majority of small-sized incubators have no relative humidity control, and

---

[1] Universidade Federal do Vale do São Francisco/Juazeiro - BA, Brasil
[2] Instituto Federal de Educação, Ciência e Tecnologia do Sertão Pernambucano/Petrolina - PE, Brasil.

Area Editor: Héliton Pandorfi
Received in: 4-4-2022
Accepted in: 7-20-2022

temperature controllers are made of precision thermostats. However, these mechanisms have no control of the power dissipated in the resistances, hence maximum power is dissipated each time a thermostat triggers a resistance.

Among the developed controllers, artificial intelligence-based controllers using fuzzy methodology have shown great applicability in egg incubation. The feasibility of the controllers has been demonstrated in research relevant to thermal comfort of animals (Ferraz et al., 2014; Schiassi et al., 2015; Julio et al., 2015).

Fuzzy systems enable closer approximation of expert thinking in improving the control and monitoring of an incubator. This results in temperature stability through load balancing, where only the required load is used to maintain the desired temperature, without variations. Consequently this reduces energy costs and improves the conditions for the incubation of eggs.

Therefore, this study aims to develop and evaluate a fuzzy logic-based controller used for incubating eggs.

MATERIAL AND METHODS

This research was conducted in the Laboratory of the Nucleus for Applied Studies in Animal Ambience and Technological Innovations of the Federal University of São Francisco Valley, Juazeiro-BA Campus. It is divided into the following stages: constructing the incubators, modeling and program implementation in Arduino, evaluation and validation of the incubators, and case study.

The climate of the region under study is classified as BSwh using Köppen's climate classification. The BSwh type is characterized as a semi-arid climate with an average annual precipitation of approximately 542 mm, maximum air temperature ranging from 29.6 °C to 33.9 °C, and average relative humidity ranging from 62% to 67%.

Constructing the incubators

Figure 1 shows the four identical handmade incubators constructed using four resistance heaters of rating 200 W/220 V, four Arduino UNO R3 platforms, two NTC 10 K temperature sensors, two dimmers of rating AC 10 A/250 VAC, four 9 V power supplies, two on-off controllers, four egg turning trays, two single-phase Nansen Lumen energy meters, as well as OSB wood panels and pine slats.

FIGURE 1. Configuration of the four incubators used in this study.

Each incubator comprised of the following dimensions: 0.58 m width, 0.40 m height, and 0.40 m depth. In addition, an egg tray with holding capacity of 56 chicken eggs was positioned on a height of 0.05 m from the incubator floor. Two water trays with capacity of 0.5 L each, were positioned below the egg tray.

Fuzzy modeling and program implementation in Arduino

The temperatures of the incubators were monitored for 10 days, with sampling conducted every 1 min using 16 sensor recorders (HOBO ± 3% reading accuracy, ± 1°C temperature accuracy, and ± 5% relative humidity accuracy). To evaluate temperature variations, the sensors were placed on four equidistant points inside the incubator.

During the evaluation period, the resistance power was adjusted by 5% every 1-h interval with the aid of an electronic AC 10A/250VAC dimmer to achieve the required resistance power.

The inference method proposed by Mamdani (1976), was used to develop our fuzzy model. The output is a fuzzy set originating from the combination of input values with their respective degrees of pertinence through the minimum operator, and then the superposition of the rules through the maximum operator (Leite et al., 2010). The dry bulb temperature (DBT) and relative humidity (RH) were defined as input variables, with pertinence curves adjusted based on the experimentally obtained values.

The fuzzy rules were linguistic sentences based on the experimentally collected data and assistance of four animal ambience and fuzzy modeling experts. Selection of the experts was conducted using the methodology proposed by Lourençoni et al. (2019).

The fuzzy model predicts the output variable and resistance power (%) based on the input variables and experimental data. Load balancing is then implemented to stabilize the temperature. Simulation modeling was conducted using MatLab's fuzzy logic toolbox.

The fuzzy model was embedded in the Arduino UNO platform consisting of an ATmega328P microcontroller, and open-source board based on a simple input/output circuit. The model was then developed in a library that handles C/C++ programs. Compatibility between the fuzzy logic and Arduino was addressed by using the embedded logic library (eFLL) developed by the State University of Piauí’s Robotic Research Group.

Evaluation and validation of the incubators

Incubator efficiency was evaluated by installing a fuzzy controller on two incubators and installing a conventional on-of controller, set to maintain a temperature of 36.7 ºC, on the remaining two incubators.

To evaluate the ability of the incubators to keep the temperature constant, we waited first for the temperature to stabilize. After stabilization, the temperatures of the incubators were monitored for approximately 72 h. Sampling was conducted every 1 min using 16 sensor loggers (HOBO) arranged on four equidistant points inside each incubator.

Four replicates were produced, and the variance test, standard deviation, and mean temperature deviation were analyzed In addition, he correlation coefficient was analyzed for possible temperature variations in the internal space of the incubators.

The experimental design adopted a randomized block design (RBD), where each block was a replicate, totaling four blocks, and the treatment was an incubator. The incubator was split into two, namely: incubator with a fuzzy controller (IFC) and an incubator with an on-off conventional controller (ICC). Statistical analyses were performed using SISvar software (Ferreira, 2011).

Case study: Use of fuzzy controller in the incubation of free-range eggs

Evaluation of the efficiency of the incubators consisted of performing 12 incubation cycles on fertile eggs of free-range chickens obtained in the region. Each treatment had 20 eggs which were incubated until hatching at the established temperature of 36.7 ºC. Relative humidity was maintained using water trays placed under the eggs. The eggs were turned every 1 hour, as recommended by Oliveira et al. (2020).

After completion of the hatching process, the number of eggs with complete hatching (ECH), eggs with not complete hatching (ENCH), non-fertilized eggs (NFE), and dead embryos (EDE) were counted in each incubator. Using these values, [eq. (1)] gives the hatching rate as a function of the total number of eggs (HRTE). Equation 2 gives the hatching rate as a function of fertilized eggs. (HRFE), The hatching rate as a function of the total number of eggs, considering the eggs that failed to hatch (HRTE+) is given by [eq. (3)]. Equation 4 defines the hatching rate as a function of fertilized eggs, considering the eggs that failed to hatch (HRFE+).

$$\text{HRTE} = (\text{ECH} / \text{NTE}) \times 100 \qquad (1)$$

$$\text{HRFE} = (\text{ECH} / (\text{NTE} - \text{NFE})) \times 100 \qquad (2)$$

$$\text{HRTE+} = ((\text{ECH} + \text{ENCH}) / \text{NTE}) \times 100 \qquad (3)$$

$$\text{HRFE+} = ((\text{ECH} + \text{ENCH}) / (\text{NTE} - \text{NFE})) \times 100 \qquad (4)$$

Where:

NTE = number of total eggs.

In addition, the electrical energy consumption of the incubators was measured using two single-phase Nansen Lumen energy meters. One meter was installed per each pair of IFC and ICC.

The randomized block design (RBD) was adopted in accordance to the statistical model shown in [eq. (5)].

$$y_{ijk} = \mu + t_i + \beta_j + \varepsilon_{ijk} \qquad (5)$$

Where:

μ represents the population mean;

t_i type of incubator (IFC or ICC);

β_j j-th test, (four tests in total), and

ε_{ijk} experimental error. Statistical analyses were performed using SISvar software (Ferreira, 2011).

RESULTS AND DISCUSSION

Fuzzy modeling and program implementation in the Arduino

The data-set was represented by triangular pertinence curves shown in Figure 2, that plotted based on the experimentally obtained values and dry bulb temperature (DBT) input variable (Schiassi et al., 2015, Lourençoni et al., 2019).

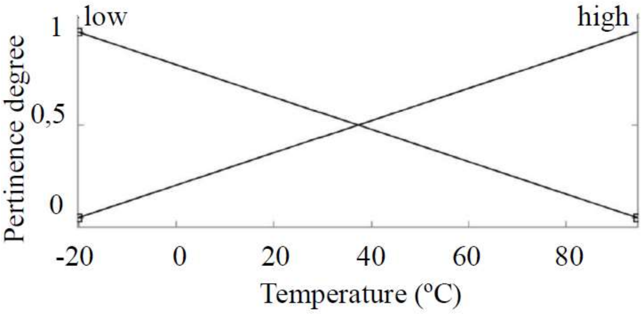

FIGURE 2. Pertinence function for the input variable dry bulb temperature (DBT).

The fuzzy model predicted the output variable resistance power (RP) based on the input variable and experimental data used as a reference. Triangular pertinence curves shown in Figure 3 were used to characterize the output variable resistance power.

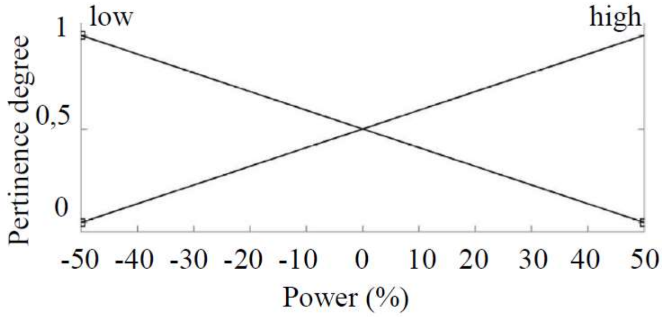

FIGURE 3. Pertinence function for the output variable resistance power (RP).

The rules of the fuzzy model are shown in Table 1. They are linguistic sentences based on experimentally collected data and assistance of four animal ambience and fuzzy modeling experts. Since the rules had equal importance in determining the system response, a weighting factor of one was adopted.

TABLE 1. Rules of the fuzzy system.

Rule	Air dry bulb temperature (DBT)	Resistance power (RP)
1	High	Low
2	Low	High

Evaluation and validation of the incubators

The incubator with the fuzzy logic (IFC) controller had a temperature correlation of 83.75%, while the conventional on-off incubator (ICC) had a correlation of 73.31%. Therefore, the IFC showed greater uniformity in internal temperature during the evaluation, thereby proving that it is more efficient in distributing heat in the internal area of the incubator. No significant difference was observed between the evaluated treatments ($p < 0.05$, F test), and the standard deviation, variance, and mean deviation presented in Table 2.

TABLE 2. Standard deviation, variance and mean deviation of the temperatures in the incubators.

	Incubator with fuzzy controller (IFC)	Conventional on-off incubator (ICC)	p-value
Standard Deviation	0,130 a	0,230 a	0,1285
Variance	0,025 a	0,106 a	0,0919
Mean Deviation	0,105 a	0,206 a	0,1073

Averages followed by different letters, differed due to the Tukey test on 5% probability

Shim & Pesti (2011) discussed how variations in temperature uniformity in the incubator can affect the hatching time and weight gain of chicks. In addition, Santana et al. (2014) mentioned that the exposure time to temperature oscillations can influence the response of embryos.

Baballe (2021) stated that temperature fluctuations due to rising temperatures can be detrimental to embryo development. This is because of the accelerated growth rate caused by high temperatures, resulting in the abnormal development of embryos in the early stages and decrease in hatchability. Thus, maintaining an optimal temperature improves embryonic development and hatchability (Nawaz et al., 2021)

Case study: Use of fuzzy controller in incubation of free-range chicken eggs

A significant difference in incubation indices was observed between the evaluated treatments ($p < 0.05$, F Test) and eggs with complete and incomplete hatching, non-fertilized eggs, and eggs with dead embryo. The observations are shown in Table 3.

TABLE 3. Percentage indices of eggs with complete hatching (ECH, %), eggs with incomplete hatching (ENCH, %), non-fertilized eggs (NFE, %), and eggs with dead embryo (EDE, %) in the incubators.

	Incubator with fuzzy controller (IFC)	Conventional on-off incubator (ICC)	Coefficient of variation CV (%)
OEC	58,91 a	40,93 b	30,71
OENC	14,09 a	7,87 a	89,21
ONF	16,20 a	41,50 b	53,11
OEM	10,78 a	9,69 a	56,39

Averages followed by different letters differed due to the Tukey test on 5% probability.

The IFC presented a higher percentage of ECH than the ICC due to the fact that ICC presented a large number of non-fertilized eggs, which masked the absolute values of fully hatched eggs. In this study, it was observed that a large number of the acquired eggs were not fertilized, either due to the quality of the breeders or the insufficient number of breeders in the flock. This was also observed in a study conducted by Cardoso et al. (2020), who evaluated the incubability and quality of Peloco and Caneludo do Catolé chicks.

The high index of ENCH and EDE may be a factor in egg quality, which according to previous studies, can be influenced by the age of the layer (Araújo et al., 2017; Jabbar & Ditta, 2017; Silva et al., 2017; Okur et al., 2018; Gharahveysi & Kenari, 2018). Old layers produce thin egg shells, which easily crack. The size of the egg (Rocha et al., 2008; Veldsman et al., 2020) also influences egg quality since large-sized eggs have difficulty losing heat at the end of the incubation period, increasing mortality. In addition, the quality of the birds' nutrition, water consumption, and local temperature (Sesti; Ito, 2009), as well as the birds' rearing system (Leite et al., 2021) affect egg quality. The egg storage time until incubation can influence the number of incomplete hatches and dead embryos (Melo et al., 2020; Nasri et al., 2020; Molapo et al., 2021)

The EDE values obtained in this study (10.78 and 9.69%) were below the 11.11 and 24.21% obtained by Gholami et al. (2018) who evaluated the incubation of fertile broiler eggs using methods of sealing microcracks.

However, the ENCH values can be explained by the different egg shapes, which change the resistance of the shell. These variations in egg shape make them more fragile or resistant during beak trimming (Schmidt et al., 2003).

Another important variable in the evaluation of incubation is the hatching rates shown in Table 4. A significant difference between the evaluated treatments ($p < 0.05$, Test F) for HRTE and HRTE+ was observed.

TABLE 4. Hatching rates for HRTE, HRFE, HRTE +, and HRFE+.

	Incubator with fuzzy controller (IFC)	Conventional on-off incubator (ICC)	Coefficient of variation CV (%)
TEOT	58,91 a	49,92 b	30,71
TEOF	68,95 a	70,11 a	19,73
TEOT+	73,01 a	48,80 b	23,25
TEOF+	86,01 a	83,74 a	8,63

Averages followed by different letters differed by the Tukey test on 5% probability.

While the HRTE and HRTE+ variables showed significant differences, they considered all incubated eggs, including the unfertilized eggs. Consequently, the absolute values of fully hatched eggs were masked, as a high percentage of unfertilized eggs was obtained in the ICC (Rocha et al., 2008; Sesti; Ito, 2009; Araújo et al., 2017; Jabbar & Ditta, 2017; Cardoso et al., 2020; Leite et al., 2021; Molapo et al., 2021). The rates that considered only fertile eggs (HRFE and HRFE+), both showed no significant differences, indicating that both incubators showed equal responses.

HRFE+, referred to as hatchability by some authors, had values of 86.01 and 83.74 % for IFC and ICC, respectively. This study validates with previous work conducted. Gholami et al. (2017), obtained hatchability rates of 72.92 and 86.22 % for sealed and unsealed eggs, respectively using methods of sealing microcracks. Ross (2016) proposed a hatchability performance goal of 88.6% for Ross 308 hens. Cardoso et al. (2020) evaluated the hatchability and quality of caipira chicks of Peloco and Caneludo do Catolé, and obtained hatchability values of 77.15 and 74.10%, respectively.

Table 5 proves that a significant difference in energy consumption existed between the treatments evaluated ($p < 0.05$, Test F). An incubator with a fuzzy controller (IFC) obtained an energy efficiency of 10.68% compared with the conventional one, which demonstrated the energy saving potential of this system. This has been the subject of several studies that seeked the development of hatcheries with higher energy efficiency (Kapen et al., 2020; Tsamaase et al., 2019; Kommey et al., 2022).

TABLE 5. Values obtained for energy consumption (kWh) in each treatment evaluated.

	Incubator with fuzzy controller (IFC)	Conventional on-off incubator (ICC)	Coefficient of variation CV (%)
Energy (kWh)	46,00 a	51,50 b	1,69

Averages followed by different letters differed due to the Tukey test on 5% probability.

The energy saving is due to the fact that the fuzzy controller in the IFC performs the load balancing in the resistor. therefore controlling the power with which it is activated. The conventional controller on the other hand, has a resistor that is always activated on 100% power.

CONCLUSIONS

The controller developed based on fuzzy logic has great potential for use in the incubation of free-range eggs. The fuzzy logic-based controller kept the internal temperature more uniform and obtained desired results for hatchability statistically equal to conventional incubators, however with a savings of 10.68% of electricity.

REFERENCES

Araújo ICS, Leandro NSM, Mesquita MA, Café MB, Mello HHC, Gonzales E (2017) Water vapor conductance: a technique using eggshell fragments and relations with other parameters of eggshell. Revista Brasileira de Zootecnia 46(12):896-902.

Arruda MD, Gouveia JWF, Lisboa ACC, Abreu ACL, Abreu AKF (2019) Avaliação da qualidade de ovos armazenados em diferentes temperaturas. Revista Craibeiras de Agroecologia 4(1):e7681.

Baballe MA (2021) A study of the impact and challenges faced using artificial egg incubation. Global Journal of Research in Engineering & Computer Sciences 1(1):18-20.

Cardoso AS, Faria Filho RV, Fernandes KTG, de Lima MR, Braga LGT (2020) Incubabilidade e qualidade dos pintos caipira dos Peloco e Caneludo do Catolé. Research Society and Development 9(7):e979974928.

Costa RF, Diniz MJ, Meira AS, Batista JO (2017) Desempenho e eficiência térmica de forros de cobertura composto de EVA + resíduos para instalações avícolas. Revista Espacios 38(46):10.

Fernandes CM, Silva M (2001) Implantação do sistema alternativo de engorda de aves caipiras através de técnicas de agricultura familiar e associativismo. In: Encontro Técnico Científico do Centro de Ciências Exatas e da Terra. Belém, Universidade Federal de Belém.

Ferraz PFP, Yanagi Junior T, Julio YFH, Castro JO, Gates RS, Reis GM, Campos AT (2014) Predicting chick body mass with artificial intelligence-based models. Pesquisa Agropecuária Brasileira 49:559-568.

Ferreira DF (2011) Sisvar: a computer statistical analysis system. Ciência e Agrotecnologia 35(6):1039-1042.

Flores F, Naas IA, Garcia RG, Souza LI (2016) Thermal simulation of Ross-lineage embryos on a commercial scale. Ciência Rural 46:1668-1674.

Gharahveysi S, Kenari TA (2018) Compare the Chick length and weights of the Ross broiler breeders at different ages and farms. Egyptian Journal Veterinary Sciences 49(1):43-47.

Gholami J, Seidavi A, Corazzin M (2018) Efficacy of three sealing methods on hatchability of micro-cracked eggs from broiler breeder hens. Revista Colombiana de Ciencias Pecuarias 31(3):223-228.

Gonçalves FM, Santos VL, Contreira CL, Farina G, Kreuz BS, Gentilini FP, Rutz F (2013) Nutrição in ovo: estratégia para nutrição de precisão em sistemas de produção avícola. Archivos de Zootecnia 62(1)45-55.

Jabbar A, Ditta YA (2017) Effect of broiler breeders age on hatchability, candling, water loss, chick yield and dead in shell. World's Veterinary Journal 6(1):40. DOI: http://dx.doi.org/10.5455/WVJ.20170493

Julio YFH, Yanagi Junior T, Pires MFA, Lopes MA, Lima RR (2015) Fuzzy system to predict physiological responses of Holstein cows in south-eastern Brazil. Revista Colombiana de Ciências Pecuárias 28:42-53.

Kapen PT, Youssoufa M, Foutse M, Manfouo H, Njotchui Mbakop FO (2020) Design and prototyping of a low-cost, energy efficient eggs incubator in developing countries: A case study of Cameroon. Scientific African 10:e00618.

Kommey B, Akudbilla D, Doe G, Amponsah CO (2022) A low-cost smart egg-incubator. Sustainable Engineering and Innovation 4(1):22–33.

Leite MS, Fileti AMF, Silva FV (2010) Desenvolvimento e aplicação experimental de controladores fuzzy e convencional em um bioprocesso. Revista Controle & Automação 21(2)147-158.

Leite RG, Salgado DDA, Neto MM (2021) Comportamento de galinhas poedeiras em sistema cage free em diferentes idades e a qualidade de ovos. Research, Society, and Development 10(4):e6010413833.

Lourençoni D, Yanagi Junior T, Abreu PG de, Campos AT, Yanagi SNM (2019) Productive responses from broiler chickens raised in different commercial production systems - part I: fuzzy modeling. Engenharia Agrícola 39(1):1-10.

Maatjens CM, Van Roovert-Reijrink IAM, Engel B, Van Der Pol CW, Kemp B, Van Den Brand H (2016) Temperature during the last week of incubation. I. Effects on hatching pattern and broiler chicken embryonic organ development. Poultry Science 95(4):956-965.

Mamdani EH (1976) Advances in the linguistic synthesis of fuzzy controllers. International Journal of Man-Machine Studies 8(6):669-678.

Marques D (1994) Do ovo ao pinto. Principais anormalidades em incubação e suas causas prováveis. Manual do Incubador. Campinas.

Melo LD, Cruz FGG, Rufino JPF, Melo RD, Feijó JC, Costa APGC (2018) Turnos de coleta e períodos de transferência de ovos de matrizes semipesadas sobre processos de incubação artificial. Archives of Veterinary Science 23(2). DOI: http://dx.doi.org/10.5380/avs.v23i2.48477

Melo EF, Araújo ICS, Triginelli MV, Castro FLS, Baião NC, Lara LJC (2020) Effect of egg storage duration and egg turning during storage on egg quality and hatching of broiler hatching eggs. Animal 15(2):100-111.

Molapo SM, Mahlehla M, Kompi PP, Taoana M (2021) Effect of egg storage length on hatchability and survival of koekoek chickens. Journal of World's Poultry Research 11(1):31-35.

Nakage ES, Cardozo JP, Pereira GT, Boleli IC (2003) Effect of temperature on incubation period, embryonic mortality, hatch rate, egg water loss and partridge chick weight (Rhynchotus rufescens). Revista Brasileira de Ciência Avícola 5(2):131-135.

Nasri H, van den Bran H, Najjar T, Bouzouaia M (2020) Egg storage and breeder age impact on egg quality and embryo development. Journal of Animal Physiology and Animal Nutrition 104(1):257-268.

Nawaz S, Satheeskumaran S, Venkatesan C, Suhas AR, Niranjan L (2021) Design and implementation of chicken egg incubator for hatching using IoT. International Journal of Computational Science and Engineering 24(4):363-372.

Okur N, Eleroglu H, Turkoglu M (2018) Impacts of breeder age, storage time, and setter ventilation program on incubation and post-hatch performance of broilers. Brazilian Journal of Poultry Science 20(1):027-036.

Oliveira GS, Santos VM, Rodrigues JC, Nascimento ST (2020) Effects of different egg turning frequencies on incubation efficiency parameters. Poultry Science 99(9):4417-4420.

Ozlu S, Shiranjang R, Elibol O, Brake J (2018) Effect of hatching time on yolk sac percentage and broiler live performance. Brazilian Journal of Poultry Science 20:231-236

Rocha JSR, Lara LJC, Baião NC, Cançado SV, Baião LEC, Silva TR (2008) Efeito da classificação dos ovos sobre o rendimento de incubação e os pesos do pintainho e do saco vitelino. Arquivo Brasileiro de Medicina Veterinária e Zootecnia 60(4):979-986.

ROSS (2016) Ross 308 Broiler: performance objectives. Midhlotian. (UK): Aviagen.

Santana MHM, Givisiez PEN, Figueredo Júnior JP, Santos EG (2014) Incubação: principais parâmetros que interferem no desenvolvimento embrionário de aves. Revista eletrônica nutritme 11:3387-3398.

Schiassi L, Yanagi Junior T, Reis GM, Abreu LHP, Campos AT, Castro JO (2015) Modelagem fuzzy aplicada na avaliação do desempenho de frangos de corte. Revista Brasileira de Engenharia Agrícola e Ambiental 19:140-146.

Schmidt GS, Figueiredo EAP, Ávila VS (2003) Fatores que afetam a qualidade do pinto de corte. Informe Embrapa Suínos e Aves. In: Avicultura industrial. Paro Feliz, Gessulli Agribusiness.

Sesti L, Ito NMK (2009) Fisiopatologia do Sistema Reprodutor. In: Bercheri Junior A, Silva EM, Di Fabio J, Sesti L, Zuanaze MAF. Doenças das Aves, 2ª ed, Facta, Campinas, p315- 380.

Shim MY, Pesti GM (2011) Effects of incubation temperature on the bone development of broilers. Poultry Science 90:1867–1877.

Silva GF, Pereira DF, Salgado DD, Ramos DD, Freitas LG (2017) Incubation yield as a function of broiler breeder age. Brazilian Journal of Biosystems Engineering 11(3):287-293.

Tsamaase K, Motshidisi K, Kemoabe R, Zibani I, Moseki R (2019) Construction and operation of solar powered egg incubator. International Journal of Engineering Research & Technology 8(12):675-677.

Van Der Pol CW, Van Roovert-Reijrink IA, Maatjens CM, Van Den Anker I, Kemp B, Van Den Brand H (2014) Effect of eggshell temperature throughout incubation on broiler hatchling leg bone development. Poultry Science 93(11):2878-2883.

Veldsman LM, Kylin H, Bronkhorst P, Engelbrecht I Bouwman H (2020) A method to determine the combined effects of climate change (temperature and humidity) and eggshell thickness on water loss from bird eggs. Environmental Geochemistry and Health 42(3):781-793.

Willemsen H, Kamers B, Dahlke F, Han H, Song Z, Pirsaraei A, Tona K, Decuypere E, Everaert N (2010) High and low temperature manipulation during late incubation: Effects on embryonic development, the hatching process, and metabolism in broilers. Poultry Science 89:2678-2690.