

# Influences of Types of Incubators on Hatchability of Eggs

Mohammedjuhar Musa Adame\*, Yesihak Yusuf, Nabiyu Tilahun Kuda

College of Agriculture and Environmental Sciences, School of Animal and Range Science, Haramaya University, Dire Dawa, East Ethiopia

## Email address:

bekanmoh@gmail.com (Mohammedjuhar Musa Adame), yesihakyus@gmail.com (Yesihak Yusuf),

nabiyutilahun@gmail.com (Nabiyu Tilahun Kuda)

\*Corresponding author

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**Abstract:** The egg incubator is a technology that is used to produce chicks without the mother hen's consent. Depending on the energy source used to power the incubator, there are various types of artificial incubators commercially available. Various types of incubators have their own influences and merits on the hatchability of eggs. If the influences of various types of incubators on the hatchability of poultry eggs are properly identified and promoted through scientific reviews, they could be an important and prominent tool in maximizing the production and productivities of the birds. In this case, there is a lack of information about the impact of various types of incubators on the hatchability of the egg. Therefore, the purpose of this paper is to review current information on the influences of different types of incubators on the hatchability of poultry eggs. Incubators can be powered by electricity, solar, kerosene, gas, coal, or fire. Modern electric incubators are powered by electricity and have automatic egg turning devices, so they are better than conventional ones due to their ease of control and monitoring, as well as their efficiency in saving energy. A smart incubator can face frequent power outages, which can affect its efficiency. In such conditions, the hatchability rate ranges between 27 and 33%. The low hatchability of the fertile eggs was attributed to a frequent power outage during the incubation period. On the other hand, poultry farmers in rural communities often use bush lamps and kerosene stoves to heat their hatcheries, which can lead to environmental pollution, fire outbreaks, and toxic gases that can lower the hatchability of eggs. Solar energy is becoming increasingly popular as an alternative energy source. A solar-powered chicken egg incubator, which found that hatchability was 35-75%. In general, solar energy application was the most attractive option for a sustainable energy supply in poultry production.

**Keywords:** Hatchability, Humidity, Incubators, Temperature

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## 1. Introduction

Over the past 10 years, global chicken meat demand has increased from 83 million tons in 2012 to 100.5 million in 2020. The projected global chicken meat demand is around 102 million tons in 2021 [1]. Optimizing production is important to meet this demand for chicken meat. In order to meet this high demand for poultry meat, artificial incubators are highly needed to maximize chick production [2, 3]. Artificial incubators are machines that simulate the hen's role.

Providing optimal environmental conditions for embryonic development until hatching is achieved by incubating fertile eggs [4, 5]. Egg incubators are a technology that enables farmers to produce chicks from eggs without the mother hen's participation and is one method of transforming eggs

into chicks [2].

Artificial incubation of eggs has been practiced for thousands of years, with the Chinese and Egyptians credited with originating artificial incubation procedures. The Chinese burned charcoal to supply heat, while the Egyptians constructed large brick incubators that were heated with fires in the same rooms where the eggs were incubated. Incubators have been refined and developed over the years, with fully adjustable vital factors for the incubation process [6]. One of the most important factors in incubation efficiency is maintaining a constant temperature required over a specific period for the embryo's development [7]. Humidity is also important because if the air is too dry, the egg will lose too much water to the atmosphere, resulting in hatching difficulties. As incubation proceeds, the eggs will normally

become lighter, and the air space within the egg will normally become larger due to evaporation from the egg [7].

Chick quality is highly influenced by the conditions during incubation, which have a significant impact on subsequent chick performance. The embryo's temperature has a significant influence on its development and chick performance. Embryonic development is a continuous process that can roughly be divided into three phases: differentiation, growth, and maturation [5]. Differentiation of organs occurs in the first days of incubation, while growth and maturation of organs occur in later phases of development. Each of these phases requires specific incubation conditions. As the embryo grows, its metabolic rate increases, which is accompanied by increased heat production [2]. Artificial incubation is the process of artificially assisting the development of a fertilized egg from an embryo to a live chick at the right time by providing vital factors such as heat, humidity, ventilation, and turning the eggs [2].

Incubators may be classified as "still air" or "forced air" depending on how air is circulated. Still air incubators are the most common, with inside air circulated by convection but creating temperature strata when the air is heated. Forced air incubator types have a fan and circulate air around the eggs [8]. There are various types of artificial incubators available today, depending on the energy source used to power the incubator. Incubators could be powered by electricity, solar, biogas, solid fuel (charcoal), or fossil oil (kerosene or gas, a diesel-powered generator), according to Okeoma, F. U. [9]. Different energy sources can influence the quality of the incubator, such as temperature and humidity control, which are important factors in successful hatching. Various types of incubators have their own influences and merits on the hatchability of eggs [10]. Therefore, this paper aims to review current information on the influences of different types of incubators on the hatchability of poultry eggs.

## 2. Literature Review

### 2.1. Historical Aspects of Incubation

The practice of egg incubation dates back to ancient Egypt around 3,000 B.C. [6]. Hatchery methods were passed down from generation to generation among certain families. Local farmers would bring their fertile eggs to the hatchery, and the hatchery owner was required by law to return two chicks for every three eggs received. Therefore, they needed to have at least a 75% hatchability rate of fertile eggs to make a profitable business out of it [11]. The Egyptian incubators consisted of thousands of eggs, which were placed in piles on the floor of each incubator room [6]. The Egyptians supplied heat to the incubator by using fire in the area where the eggs are incubated and burning charcoal. Air was drawn through a floor opening, passed through a central hole in the fire ring, and exited through roof vents [11, 6].

Chinese artificial incubation of eggs was practiced as early as 246 BC, with two successful methods that spread through Southeast Asia. The first method was a simple one, using

rotting manure to produce heat [11]. The second method was more widely used and is still functional in the present day. The eggs were placed inside muslin bags, loaded into egg baskets made of woven straw, and placed in a container filled with ashes. The temperature was tested through the eyelid of the operator. Every seven days, a new bag of eggs was added to each basket, and after the first three weeks, they would turn off the fire and allow the heat of the eggs to continue the incubation process. At day 16, the eggs were removed and covered with a blanket [11].

Egypt and China are two countries credited with artificial incubators. The Chinese used rotting manure and muslin bags placed in baskets made of woven straw to incubate eggs, while Egyptians used fire and burning charcoal. Over the years, incubators have been refined and developed so that they are almost completely automatic [6].

### 2.2. Type of Incubator

The two primary types of artificial egg incubators are the still incubator and the forced draft incubator. The still air incubator includes a heating element, a thermostat, an egg tray for turning, a thermometer to measure air temperature, a tray for water, and a hygrometer for humidity measurement. Convection circulates the air. The heated air expands and rises to the top. The amount of air that flows in the incubator is determined by the amount of air outside the incubator box in order to maintain perfect air ventilation. Inside the incubator, the warm air moves towards the top, so different temperatures will be recorded at different levels.

The forced draft incubator maintains a uniform temperature with the help of a fan, which circulates air and keeps the temperature of the air around the egg constant. The humidity is measured using a wet bulb thermometer. Compared to still-air incubators, these types of incubators maintain consistent temperature, humidity, and oxygen levels. This method decreases cracked, spoiled, and premature egg incubation [8].

There are various types of artificial incubators available today, depending on the energy source used to power the incubator. Incubators could be powered by electricity, solar, biogas, solid fuel (charcoal), or fossil oil (kerosene or gas, a diesel-powered generator), according to Okeoma, F. U. [9]. The various types of incubators have their own influences and merits on the hatchability of eggs [10].

### 2.3. Influence of Incubators on Hatchability

#### 2.3.1. Factors Influencing Hatchability

During the incubation stage, the chick embryo requires the proper temperature, humidity levels, ventilation, and positioning to develop and hatch successfully. Proper maintenance of the incubator machinery is crucial to ensure the resulting chick quality and hatchability [12].

##### (i). Temperature

Temperature is the most critical parameter in the incubation process. Studies show that temperature change influences embryo oxygen consumption and heat production

during incubation [13, 7]. It is recommended that the minimum and maximum temperatures for the first eighteen days be between 37.7°C and 39.3°C, respectively. After the eighteen days of incubation, the temperature should be reduced from 37.8°C to 36.0°C until the chickens are hatched. For the whole period of incubation, the temperature should be maintained within the range of 36°C and 39°C (Lourens et al., 2005; Theraja and Theraja, 2001). Overheating the egg is much more critical than underheating because it will speed up the rate of growth, cause abnormal embryo growth in the initial stages, and lower the percentage of hatchability. A rise in temperature above 40.5 °C is fatal [14].

#### **(ii). Humidity**

Eggs lose water during incubation, and the relative humidity maintained within the hatching chamber affects the rate of water loss. The relative humidity in the incubator between setting and three days before hatching should remain at 58–60%. After the 18th day, the relative humidity should be increased from 55% to 71% until the end of the incubation period [15, 16]. Lower relative humidity during incubation affects hatchability, and adequate relative humidity during incubation may prevent the embryo from sticking to the shells [17]. The egg's weight must decrease by 12% during incubation if good hatches are expected [16].

#### **(iii). Air Ventilation**

Ventilation plays a role in cooling an overheated machine as well as ensuring that oxygen-carbon dioxide exchange is maximized. The internal fan speeds are important [18]. Turning the egg several times each day is important to prevent the embryo from sticking to the shell membranes. With hand-turning systems, an odd number of times turned per day (five to seven times) will ensure that during successive overnight periods, the egg is always oriented in the opposite direction from that of the previous night [15].

#### **(iv). Turning**

Turning the egg several times each day is important to prevent the embryo from sticking to the shell membranes. With hand-turning incubators, the eggs should be turned at least three times a day, while automatic turning incubators should turn the eggs at least six times per day [16]. Proper positioning of the eggs is also crucial, as improper placement can lead to malpositions that can cause death or deformities in the chick [19].

In conclusion, maintaining appropriate temperature, humidity, ventilation, and positioning is essential for successful egg incubation and hatching. Regular maintenance of the incubator machinery is crucial to ensure optimal hatchability and chick quality. With proper care and attention to detail, artificial egg incubators can provide a reliable and efficient method of hatching chicks.

### **2.3.2. Examples of How Incubators Influence Hatchability**

There are various types of artificial incubators available depending on the energy source used to power them, such as electricity, solar energy, kerosene, gas, coal, or fire [9]. The

merits and influences of each type of incubator on egg hatchability vary [10].

#### **(i). Electric-Powered Incubator**

The majority of modern electric incubators are powered by electricity and have automatic egg turning devices that are equipped with automatic controls to maintain proper temperature and humidity levels [20, 21, 18, 22, 23]. These smart incubators can control the temperature, humidity, and eggs automatically using a microcontroller, making them more efficient than conventional incubators. They are also easy to control and monitor, and they save the farmer's energy.

However, electric-powered incubators may face frequent power outages, especially in developing countries where electricity supply is inadequate and unreliable [24]. Gbabo, A. et al. [25] designed and evaluated the performance of an electric-powered egg incubator that had a hatchability rate of 33% out of the 25 eggs loaded. The study recommended that a constant supply of electricity is needed to ensure unobstructed operation of the incubator.

Additionally, Rogelio, B. P. and Vinyl, H. O. [26] designed and developed a microcontroller-based egg incubator for small-scale poultry production that was powered by electricity. The egg incubator was tested by loading 20 chicken eggs, but the percentage of egg hatchability was found to be only 27%. The low hatchability rate was attributed to frequent power outages of 2 to 6 hours a day during the entire incubation period.

In conclusion, electric-powered incubators are efficient and reliable, but they require a constant supply of electricity to operate optimally. Farmers in areas with inadequate or unreliable electricity supply may need to consider alternative methods of meeting their energy needs for poultry production.

#### **(ii). Solar Powered Incubator**

Solar energy has become increasingly popular as a reliable source of alternative energy that can provide a solution to farmers' frequent power outages. The author [27] stated that focusing on solar energy harvesting and utilization can eventually solve the problem of energy scarcity by balancing the nation's energy demand. The author [28] found that solar energy application was the most attractive option for a sustainable energy supply in poultry production.

Mansaray, K. G. et al. [29] designed, fabricated, and tested a solar-powered chicken egg incubator that loaded 30 chicken eggs for evaluation. The results obtained indicated that the hatchability of the eggs was 23.1%. The low hatchability rate was attributed to time and energy wasted in turning the eggs manually. However, the solar-powered incubator does not face the problem of power outages, making it a more reliable option for farmers in areas with inadequate or unreliable electricity supply.

In conclusion, solar-powered incubators are a reliable and environmentally friendly option for farmers who face frequent power outages or have limited access to electricity. They provide a sustainable energy supply for poultry production and can contribute to solving the problem of

energy scarcity.

### **(iii). Coal or Fire Energy Incubator**

In many developing countries, the majority of poultry farmers in rural communities operate their farms on a small scale and/or at subsistence levels. These farmers often use a collection of bush lamps and kerosene stoves to provide the heating requirements of small hatcheries and brooders for day-old chicks [28]. However, these systems have significant problems, ranging from environmental pollution to fire outbreaks. The use of fossil fuels produces toxic gases that are harmful to eggs and poultry, and solid fuel (fossil, oil, or biogas) incubators generate soot and other combustion products that could lower the percentage of hatchability of eggs [10, 30].

In conclusion, the use of bush lamps and kerosene stoves as a source of heat for small-scale poultry farming is not an efficient or environmentally friendly option. The harmful effects of fossil fuels on eggs and poultry make it necessary to consider alternative energy sources for small-scale poultry production. Solar-powered or electric-powered incubators may be a more reliable and sustainable option for farmers in rural communities..

## **2.4. Evaluation of Incubator Performance**

Several researchers have evaluated the performance of incubators in terms of hatchability, embryonic mortality, dead in the shell, and chick performance.

### **2.4.1. Hatchability**

In terms of hatchability, [31, 24] researched passive solar heating for poultry chick brooding and recorded percentages of fertility and hatchability of 73.1% with a 21-day incubation period. This indicates that solar energy is a sustainable energy supply for poultry production. The authors [29, 32-34] concluded that the average percent hatchability of Mani-hatchery ranged between 27% and 75%.

Sand-based mini-hatcheries resulted in the highest hatching percentages for both chicken and duck eggs, with 80-85% and 70-72%, respectively, compared to 70-75% and 65-68% for rice husk incubators and 75-80% and 60-62% for rice husk and quilt incubators [40].

In conclusion, researchers have evaluated the performance of incubators in terms of hatchability, and the results show that solar energy is a sustainable energy supply for poultry production. Sand-based mini-hatcheries resulted in the highest hatching percentages for both chicken and duck eggs compared to other types of incubators.

### **2.4.2. Dead in the Shell and Embryonic Mortality**

Different types of incubators have varying percentages of dead in the shell and embryonic mortality [35] reported that the dead-in-shell rates in rice husk incubators and electric incubators were 20.4% and 10.1%, respectively, while embryonic mortality rates were 17.1% and 4.6%, respectively. Inadequate ventilation, heat, and humidity can cause embryonic mortality [36]. El-Ayadi et al. [37] reported that dead-in-shell rates were almost equal in Baladi and White

Leghorn eggs, at 19% and 20.0%, respectively.

In conclusion, the type of incubator used can affect the percentage of dead in the shell and embryonic mortality. Proper ventilation, heat, and humidity control are essential to reduce embryonic mortality rates.

### **2.4.3. Chick Performance**

Chick performance is affected by various factors in the hatchery. Roovert-Reijrink [38] stated that optimizing factors such as incubator design, incubation process, eggshell temperature, and carbon dioxide concentrations can maximize chick quality and performance. Enibe, S. O. [39] observed that incomplete healing of the umbilical cord mostly occurs due to incubator defects such as reduced air flow, decreased temperature, and increased relative humidity [35] reported that normal chicks from electric and rice husk incubators were 97.4% and 90.1%, respectively. Goodhope, R. G. [40] stated that the average chick weight for broody hen incubation and rice husk incubation was 27 g.

In general, the quality and survival rate of day-old chicks depend on various factors such as the genetic line of the breeders, breeder age, egg weight, egg storage conditions and duration, and incubation conditions such as temperature, humidity, gas levels, and altitude [41, 42].

In conclusion, optimizing various factors in the hatchery can maximize chick quality and performance. Proper incubator design and incubation process, as well as maintaining appropriate temperature, humidity, and gas levels, are essential for optimal chick performance.

## **3. Conclusion**

In recent years, understanding the impact of different types of incubators on the hatchability of poultry eggs has become increasingly important. This review aims to summarize and discuss studies on the influences of different types of incubators on the hatchability of poultry eggs. The type of incubator used can significantly affect the success rate of hatching poultry eggs, with temperature, humidity, and air circulation being crucial factors.

Modern electric incubators with automatic egg-turning mechanisms and controls for humidity and temperature are more efficient than conventional egg incubators. However, they can face frequent power outages, which can affect hatchability rates. Some researchers developed a microcontroller-based egg incubator for small-scale poultry production, which had a hatchability rate of 27%. However, frequent power outages during the incubation phase affected the hatchability of viable eggs.

Poultry farmers in rural communities often use bush lamps and kerosene stoves to heat their hatcheries, which can lead to environmental pollution, fire outbreaks, and toxic gases that can lower the hatchability of eggs.

Solar energy has emerged as a reliable alternative energy source that can provide a solution to farmers' frequent power outages. Some studies have reported successful hatching rates of up to 75% using solar-powered incubators for

chicken eggs. The application of solar energy is a sustainable energy supply for poultry production and is not affected by power interruptions.

In conclusion, the use of solar-powered incubators is recommended for small and medium-scale poultry farmers in both urban and rural areas, particularly in developing countries with high electric fluctuations. It is a sustainable and reliable alternative energy source that can improve hatchability rates and reduce environmental pollution.

## References

- [1] Shahbandeh, M. (2021). Global Chicken Meat Production 2012-2021. Available at: <https://www.statista>.
- [2] Boleli, I. C., Morita, V. C., Matos, J. R., Thimotheo, M., and Almeida, V. R. (2016). Poultry egg incubation; integrated and optimizing production efficiency. *Brazilian Journal of Poultry Science*, 2 (spe2), 1–16. <https://doi.org/10.1590/1806-9061-2016-0292>
- [3] Roy, B. C., H. Ranvig, S. D. Chowdhury, M. M. Rashid and M. R. Faruque, 2004 Production of day-old chicks from crossbred chicken eggs by broody hens, rice husk incubator and electric incubator and their rearing up to 6 weeks, *Livestock Research Rural Development*, 16.
- [4] Shittu, S. Olasunkanm J. N. Muhammad A. S., Jimoh M., and Muhammad A. S. 2017. Development of an automatic bird-egg incubator. *Journal of Embedded System and Applications*, 5 (1), 1-11.
- [5] Yalcin, S, Özkan, S. and Shah, T. 2022. "Incubation Temperature and Lighting: Effect on Embryonic Development, Post-Hatch Growth, and Adaptive Response." *Frontiers in Physiology*, vol. 13, Frontiers Media SA, May Crossref.
- [6] Ogbeh, g. o. (2019) 'design and implementation of automatic fixed factors. *International journal for innovative research in multidisciplinary field*, 5 (6): 2455-0620.
- [7] Benjamin N. and N. D. Oye, 2012. Modification of the Design of Poultry Incubator, *International Journal of Application or Innovation in Engineering and Management*, 1 (4): 220-224.
- [8] Brinsea. 2016. Incubation Handbook, Weston Industrial Estate, USA Available [Brinsea\\_Handbook.pdf](#)
- [9] Okeoma, F. U. 2016. Design, Construction and Performance Evaluation of a Liquefied Petroleum Gas Incubator. Department of Mechanical Engineering, Faculty of Engineering, Ahmadu Bello University, Zaria, Nigeria 159 pp.
- [10] Adewunmi, B. A. 1998. Development of a Free Convention Kerosene Fueled Incubator. *Transaction of the Nigeria Society of Engineers*, 33 (2): 30-40.
- [11] Wafadar, F., and Puls, I. 2011. Improving Hatching and Brooding in Small-Scale Poultry, *Agromisa Foundation and CTA, Wageningen, Netherlands* 80 pp.
- [12] Geneve, N. 2013. Classroom Chick Hatch Program Guidebook, Nova Scotia Department of Agriculture, Bible Hill, Nova Scotia, Canada, North Amercia, 3: 6, 54-88.
- [13] Abu. M. B. MohdAdid, 2008. Development of smart Egg Incubator System for Various types of Egg (SEIS). Bachelor Thesis (Hons) Electronics. Faculty of Electronics Engineering. Universiti Malaysia Pahang.
- [14] Tona, K., V. Bruggeman, O. Onagbesana, F. Bamelis, M. Gbeassor, K. Mertens, and E. Decuyper. 2005. Day-old chick quality: Relationship to hatching egg quality, adequate incubation practice and prediction of broiler performance. *Avian Poultry Biological Review*. 16: 109–119.
- [15] Abiola, S. S. 1999. Effects of turning frequency of hen's eggs in electric table type incubator on weight loss, hatchability and mortality. *Nigeria Journal Agricultural* 30: 77-82.
- [16] Oluyemi, J. A. and Roberts, F. A. 1988. *Poultry Production in Warm Wet Climates* Macmillan Publishers Limited, London and Basingstoke, United Kingdom 102 pp.
- [17] Ogunwande, G. A., Akinola, E., O., and Lana, A. R. 2015. Development of a biogas-powered poultry egg incubator. *IFE Journal of Science* 17 (1), 219-228.
- [18] Sanjaya, W. S., Maryanti, S., Wardoyo, C., Anggraeni, D., Aziz, M. A., Marlina, L., and Kusumorini, A. 2018. The development of quail eggs smart incubator for hatching system based on microcontroller and Internet of Things (IoT). Paper presented at 2018 International Conference on Information and Communications Technology. Yogyakarta, Indonesia. doi: 10.1109/icoiact.2018.8350682.
- [19] King'ori A. M. 2011. Review of the Factors That Influence Egg Fertility and Hatchability in Poultry. *International Journal of Poultry Science* 10 (6): 483-492.
- [20] Adegbulugbe, T. A., Atere, A. O. and Fasanmi, O. G. 2013. Development of an automatic electric egg incubator, *International Journal of Scientific and Engineering Research*, 4 (9): 914-918.
- [21] Okpagu, P. E. and Nwosu, A. W. 2016. Development and temperature control of smart egg incubator system for various types of egg. *European Journal of Engineering and Technology*, (4) 2: 2056-5860.
- [22] Kalubarme, P., Jambhale, P., Adate, P., and Pawar, P. 2018. Hatching eggs automatically. Paper presented at 2nd National Conference on Modern Trends in Electrical Engineering. Vijayawada, Pradesh, India.
- [23] Adeosun, O. J. 1997. Development (Design and Construction) of a Low-Cost Incubator, Department of Agricultural Engineering, Faculty of Technology, Obafemi Awolowo University, Ile-Ife, Nigeria 66 pp.
- [24] Ahiaba, U. N., Theresa, U. V., and Obeta, S. E. 2015. Development and evaluation of a passive solar powered system for poultry egg incubation. *International Journal of Engineering Research and General Science*, 3: 748-760.
- [25] Gbabo, A., Liberty, J. T; Gunre, O. N. and Owa, G. J. 2014. Design, Construction and Performance Evaluation of an Electric Powered Egg Incubator. *International Journal of Research in Engineering and Technology*, 3: 521-526.
- [26] Rogelio, B. P. and Vinyl, H. O. 2016. Design and development of a microcontroller-based egg incubator for small scale poultry production *Global Journal of Science Frontier Research*, 16 (2), 1-7.
- [27] Osanyinpeju K. L., Aderinlewo A. A., Adetunji O. R., and Ajisegiri E. S. A. 2018. Performance Evaluation of a Solar Powered Poultry Egg Incubator, *International Research Journal of Advanced Engineering and Science*, 3 (2): 255-264.

- [28] Okonkwo, W. I. 2005. Passive Solar Heating for Poultry Chick Brooding in Nigeria, Presented at International Workshop on Renewable Energy for Sustainable Development in Africa, Trieste, Italy 12 pp.
- [29] Mansaray, K. G. and Yansaneh, O. 2015. Fabrication and Performance Evaluation of Solar Powered Chicken Egg Incubator. *International Journal of Emerging Technology and Advanced Engineering*, 5: 31-36.
- [30] Adewunmi, B. A. and Falayi, F. R. 1999. Design, Fabrication and Testing of a charcoal fueled incubator, *Nigeria Journal Animal Production* 26: 111-114.
- [31] Irtwange, S. V. 2003. Passive solar poultry eggs incubator: II development and preliminary performance evaluation. *Journal of Applied Science, Engineering and Technology*, 3 (2), 30-36.
- [32] Okonkwo W. I. and Chukwuezie O. C. 2012. Characterization of a Photovoltaic Powered Poultry Egg Incubator, 2012 4th International Conference on Agriculture and Animal Science, IACSIT Press, Singapore, Asia pp 1-6.
- [33] Iqbal, J., Khan, S. H., Mukhtar, N., Ahmed, T., and Pasha, R. A. 2014. Effects of egg size (weight) and age on hatching performance and chick quality of broiler breeder. *Journal of Applied Animal Research*, 44 (1), 54–64.
- [34] Othman, R. A., Amin, M. R., and Rahman, S. 2014. Effect of egg size, age of hen and storage period on fertility, hatchability, embryo mortality and chick malformation in eggs of Japanese quail (*Coturnix coturnix japonica*) *Journal of Agriculture And Veterinary Science*, 7 (1): 101-106.
- [35] Dev N C, Hamid M A, Islam M A and Howlider M A R 1993 Hatchability of chicken eggs in five different incubators in Bangladesh; *Poultry Advisor*. 26: 6, 45-50.
- [36] Dafwang, I. I., Odiba J. Y. and Ikani, E. I. 2005 Hatchery management practices in poultry. *Extension Bulletin No. 86, Poultry Series No. 5*, National Agricultural Extension and Research Liaison Services Ahmadu Bello University, Zaria.
- [37] El-Ayadi, M. N. 1956. Fertility and hatchability as related to quality in Baladi commercial eggs. *Poultry Science*, 41 (2): 1707-1712.
- [38] Roovort-Reijrink, I. 2018. Incubation effects chick quality Retrieved from <https://www.poultryworld.net/Genetics/Articles/2013/5/Incubation-effects-chick-quality-1183725W/retrieved>
- [39] Enibe, S. O. 2002. Performance of a natural circulation solar air heating system with phase change material energy storage. *Renewable Energy*, 27 (1), 69-86.
- [40] Goodhope, R. G. 1991. First week broiler mortality–Influence on production. Second Western Meeting of Poultry Clinicians and Pathologists. Accessed Nov. 7, 2007.
- [41] Agboola, A. K., Olaniyi, O. M., Aliyu, S. O. and Ayanwale, B. A. 2013. Increasing livestock production in Nigeria: Development of cost-effective models for bird-egg incubator, *International Journal of Emerging Technology and Advanced Engineering*, 3 (3): 707-716.
- [42] Osanyinpeju. K. L., Aderinlewo A. A., Adetunji O. R., and Ajisegiri E. S. A. 2018. Output Power and Voltage-Time Characteristics of Mono-Crystalline Photovoltaic Panel at Federal University of Agriculture, Abeokuta (FUNAAB), Alabata, Ogun State, Nigeria Under FUNAAB Weather Condition. *International Journal of Advanced Engineering Research and Applications*, 3 (12): 349-360.