Nigerian Journal of Technology (NIJOTECH)
Vol. 43, No. 1, March, 2024, pp.189 - 197
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
https://doi.org/10.4314/njt.v43i1.20

ENERGY SOURCES FOR POULTRY EGG INCUBATORS' EFFICIENCY AND HATCHABILITY

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ARTICLE HISTORY:
Received: 10 November, 2023.
Revised: 09 January, 2024.
Accepted: 10 January, 2024.
Published: 31 March, 2024

KEYWORDS:
Incubation, Hatchery, Energy, Sources, Hatchability, Poultry

ARTICLE INCLUDES:
Peer review

DATA AVAILABILITY:
On request from author(s)

EDITORS:
Ozoemena Anthony Ani

FUNDING:
TETFUND NRF grant (Project Code: TETF/ES/DR&DCE/NRF2020/CC/32/VOL.1)

Abstract
Artificial incubation is needed to multiply the chicken yield especially in the upcoming economies where the provision falls short of its demand. Heat is the major factor among the indispensable requirements of successful egg incubation. Hence, the main focus of this work is to identify the sources of energy used in poultry egg incubations and to determine the hatchability rate of the poultry egg incubators based on energy source used. The method of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) was used. Series of eligibility/exclusion criteria were applied: only journal articles, peer reviewed conference papers and government publications were selected; articles in English publications were chosen as well. Only papers published from April, 2022 downwards were covered. The study found that sources of energy for egg incubation are categorized into grid supply electricity, solar system, fossil fuel, biogas and thermochemical materials. From the reviewed articles, 50% identified grid-supplied electricity as energy source for poultry egg incubation and hatchability ranges from 80.9% - 98.39%. However, due to erratic nature of electricity supply and non-availability in rural areas especially in developing nations, the study recommends increased research interest on other energy sources to improve their hatchability.

1.0 INTRODUCTION
The mechanism of managing fertilized egg to yield live-chick is referred to as [1]. Natural form of incubation can at best handle average of twelve eggs hence, the need for artificial form to meet the ever growing demand for poultry products [2]. Artificial incubation which dates back to 1000BC is used to improve the yield of chicks and protein nutrient availability, mostly in the evolving nations where on daily basis only less than twelve grams of protein from animal is assessable to an individual far below the recommended minimum of about 35g [2 – 4]. The supply of poultry meat falls short of its demand especially in developing countries [5].

Heat is an essential factor in a typical incubation process. The basic design guideline is to create conducive space of temperature and relative humidity between 36^{0}C - 39^{0}C and 50% - 75% respectively required for poultry egg embryos development [6]. The heat requirement to sustain the required temperature involves taking into account the energy losses of the incubator (Figure 1). As shown in Figure 2, the other factors that affect incubation process include the amount moisture in the air, the pattern and

HOW TO CITE:
Okonkwo, W. I., Ojike, O., Ezenne, G., Nwoke, O. A., and Ohagwu, C. J. "Energy Sources for Poultry Egg Incubators' Efficiency and Hatchability", *Nigerian Journal of Technology*, 2024; 43(1), pp. 189 – 197; *https://doi.org/10.4314/njt.v43i1.20*

rate of air flow, consistent egg turning, parent stock age, and pre-incubation storage conditions, genetics, egg weight, levels of CO_2 and O_2, egg age, rearing and husbandry method, in addition to pattern of mating [2], [5], [6], [7] [8].

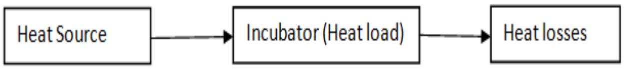

Figure 1: Energy Flow diagram of a poultry egg incubator

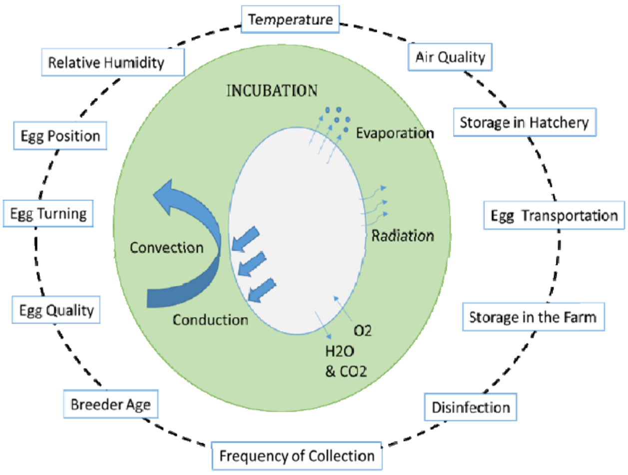

Figure 2: Environmental factors during egg incubation [9]

Incubators can be broadly classified as flat-type (still-air) incubators and cabinet (forced-air) incubators [2]. The flat-type usually handles less than 500 eggs per batch while the cabinet handles quite enormous number per incubation process. Equally, artificial incubators could be operated as a multistage incubation system (MS) or a single-stage incubation system (SS) [10], [11]. MS is continuous loading of eggs into an incubator of up to four sets per week such that eggs in an incubator are at different stages of embryonic development while SS is batched system of incubation. To characterize an incubator, a test is usually conducted [6]. This involves both the physical and biological evaluation of the incubator respectively. The former is made up of studying the flow pattern of temperature and the relative humidity of the system in addition to the ambient environment. This helps to set the physical characteristic boundaries of the incubators.

The biological evaluation comprises of the loading of the system with eggs in addition to observing its behavioural pattern up to the hatching of the eggs. Equations 1 and 2 respectively are then used to give the percentage fertility *(%F)* and hatchability *(%H)* of any given egg incubator where N_{fe}, N_{inc} and N_{ch} represent the number of fertilized eggs, total number of eggs loaded in the incubator and number of chicks hatched by the incubator respectively.

$$\%F = \frac{N_{fe}}{N_{inc}} \times 100 \quad (1)$$

$$\%H = \frac{N_{ch}}{N_{fe}} \times 100 \quad (2)$$

Mesquita et al. [12] compared the hatchability of MS and SS incubation systems. The results of their study revealed that single stage type recorded higher hatchability ($P < 0.05$). A study carried out by Zhu et al. [13], revealed that at least about 8% of all incubated eggs generally fail to hatch, causing enormous waste in time, space, labour force and energy.

The major objectives of this study are: To undertake identification of sources of energy used in poultry egg incubations and to determine the efficiency /hatchability rate of the poultry egg incubators based on energy source used. In many developing countries, epileptic electric power supply hampers smooth operation of a typical incubation process [6], [14], [15]. This leads to sourcing for alternative power for poultry egg incubation. Then the research question is: "what are the sources of energy used for poultry egg incubation"

2.0 METHODOLOGY

2.1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)

The process of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) was used in this study. It includes the categorizing of literature databases (in this case, Google Scholar and Public records) in order to undertake a systematic review, establish eligibility and exclusion criteria, set-out the review process (identification, filtering, eligibility) in addition to data separation and analysis. Sierra-Correa and Cantera Kintz [16] established that, PRISMA shows remarkable advantages for its adoption in a literature review programme. The advantages include figuring out the vivid study questions which allows a systematic research, confirm and adopt inclusion and exclusion standards, evaluating extremely large literature databank in a space of limited period [17], [18]. The PRISMA gave room for absolute inquiry of the keywords in energy sources in poultry egg incubators.

2.2 Resources

As indicted the study was based on the Google Scholar, a major journal database as well as public records. Google Scholar is a rich repository that is made up of various research work especially journal papers and conference publications from different publishing organizations, groups, expert individuals, professional bodies and institutional archives important for a thorough review.

2.3 Eligibility and Exclusion Criteria

Various eligibility/exclusion conditions were defined. Foremost on this being the type of literature; this was limited to basically to journal papers, peer reviewed conference papers in addition to government publications implying that book series, book, and chapter in book are all excluded. Equally, studies that were produced in English language were chosen. Hence, the study did not include studies that were not presented in English. Lastly, the review covered studies that were published from April, 2022 downwards.

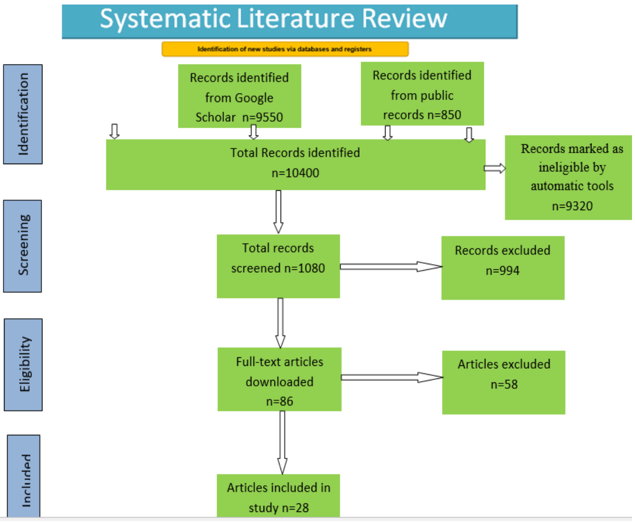

Figure 3: PRISMA Diagram indicating levels in data extraction

2.4 Systematic Review Process

The whole review work was classified into four. The first level of the review was definition of keywords to be used in the search. As shown in Table 1 the keywords regarded as important for the review were link to Poultry, incubators, chicken, Egg, efficiency and hatchability. Additionally, this level included critical separation of identical publications from the databank leading to 10400 studies hefted across this level. The second level re-examined the chosen papers from which 9320 publications were drop out. 1080 studies scaled through to the next level of the evaluation. Nevertheless, 994 studies after critical scrutiny were removed due to the fact that they did not meet the inclusion conditions of Energy sources for Poultry Egg Incubators. In the fourth stage as shown in Figure 3 only 28 publications were chosen for the subjective evaluation (see Figure 4).

2.5 Data Extraction and Analysis

The selected studies were retrieved and examined carefully with focus on fundamental part which are related to the formulated research questions. This was carried out beginning with scrutinizing the abstracts then searching through the entire segment (in-depth) of the publications to draw out important data (See Figure 4). A detailed meta-analysis was carried out to pick-out subject matters connected to Energy sources for Poultry Egg Incubators. The inclusion and exclusion criteria are shown in Table 1, whereas the search strings used for the review are shown in Table 2.

Table 1: The inclusion and exclusion criteria

Criterion	Inclusion	Exclusion
Type of Literature	Journal papers, peer reviewed conference proceedings, Gray literature	Book chapters
Language	English	Non-English
Time-line	April, 2022-Downwards	
Indexes	Google Scholar	

Table 2: The search string used for the systematic review study

Google Scholar	Intitle: "(("poultry * AND chicken * AND hatchability * AND egg * AND incubators * AND efficiency OR hatchability OR chicken -feed -gene -nutrient -milk – insemination"))

3.0 RESULTS AND DISCUSSION

3.1 Scope of Energy Sources used in the Literature

The reviewed articles showed the source of energy for incubation are categorized into Electricity, solar system, Fossil fuel, Biomass and Thermochemical Materials as shown in Table 3 and Figure 4. The reviewed exercise revealed that, of the Twenty- eight (28) papers discussed, Fourteen (14) of them which were on energy sources for poultry egg incubation identified explicitly electricity as the energy source. Six of the articles explicitly identified solar system as the energy source. Only one article reported the use of biogas explicitly while another paper discussed fossil fuel as an explicit energy source for incubation of poultry eggs respectively. The rest of the papers discussed hybrid energy sources for incubation operations.

3.2 Electricity as an Explicit Source of Energy for Poultry Egg Incubation

As could be seen from Figure 4, 50% of all reviewed articles identified grid-supplied electricity as energy source for poultry egg incubation. Kommey et al. [5] developed a low-cost smart egg-incubator to meet the ever increasing demand for poultry products in Ghana. The need for this arose as a result of high-cost nature of large – scale poultry incubators which made them unaffordable to Ghanaian farmers. Temperature and humidity sensors were utilized to identify corresponding readings inside the incubator and transmit the same to a microcontroller that controls the incubator to execute automated tasks. Al-Zaidi [19] used an electric powered incubator to consider the optimum design calculations of an egg incubator. The study used 1056 eggs to determine the percentage fertility and hatchability of the system which were 96.1 7% and 98.39 %respectively. The article argued that the failure to achieve 100% in hatchability was due to the long storage time and non-uniformity of the size of the eggs. Yunaldi and Yohandri [20] worked on an automatic chicken eggs Hatcher using DHT 22 sensor and DC motor gearbox based on arduino. The incubator which has a capacity of 120 eggs in addition to an electronic egg turning set-up recorded a hatchability rate of 89.65%.

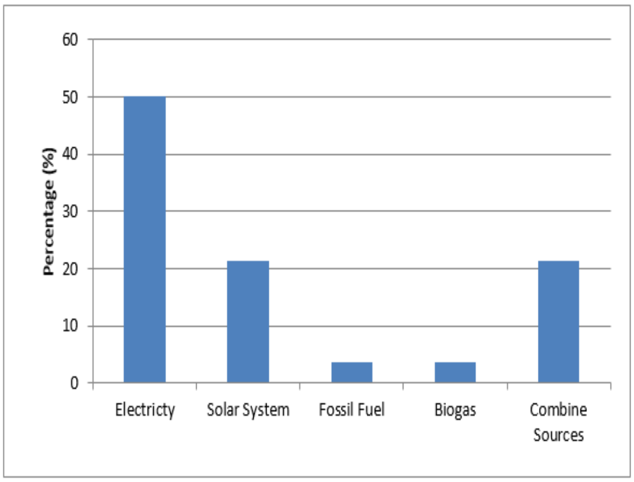

Figure 4: Percentage Contribution of Energy Sources

Hassan et al. [22], in characterising an electric incubator recorded a hatchability percentage of 80.9% and concluded that the major challenge of incubators that work with electricity are the excessive billing rate, erratic power supply as well as the complete absence of electricity in remote regions. Equally, most of the incubators in developing countries like Nigeria operate at 60% below designed capacity due fluctuating grid-electric supply [28]. Olaoye et al. [23] developed a 120 egg capacity electric incubator. The system which was coupled with three 100 watts electric bulbs produced 75.2% fertility in addition to hatchability rate of 64.8%. Mohammad et al [36] carried out a performance evaluation of a designed HEFINC840 Micro-controller based Incubator. The system with a capacity of 840 chicken eggs produced a hatchability and fertility rates of 88.21% and 95.83% respectively. Adegbulugbe et al. [26] developed an automatic electric egg incubator using a forced draft principle with a capacity of 540 eggs. The performance analysis of the system showed a hatchability rate of 84.06%. Agidi et al [28] developed and evaluated an electric powered egg incubator. The system showed 33% hatchability.

Yadav et al. [29] analysed a developed automatic horizontal egg incubator. A motor clamped mechanism controlled by a micro-controller was used to adjust the egg trays horizontally. The system yielded a hatchability of 72.22%. Abd El-Mottaleb [30] worked on a local semi-mechanical incubator. The evaluation of the incubator resulted to a hatchability of 90% under the temperature, relative humidity and egg tray turning number of 37.5° C, 55% and 12 times per day respectively. Metwally [32] developed an egg incubator using lighting circuit with switching power supply. The study focused on developing LED lighting circuit used in an egg incubator for improving the hatchability rate of incubators. With a total of 720 eggs the system gave a maximum hatchability of 86.88%. Agboola et al. [33] work on cost effective models for egg incubation. Among the four models used, the embedded computer based Model incubator loaded with 468 eggs produced a hatchability rate of 94%.

Ogunwande et al [24] studied a still-air hatchery that has a non-thermostatic control. The system uses electric bulbs as the heat source with a resistance-varying component as temperature control. With three times daily of the eggs, the system achieved 62% hatchability rate. Harb et al. [40] studied a 60 capacity poultry egg incubator for small farmers in Egypt. The authors recorded a hatchability rate of 82.6%. Soeb et al [39] developed a low-cost incubator that is made up of an embedded controller incorporated to an egg turning trays with a hatchery apartment of 116 egg capacity for Bangladesh market. The manual and automatic evaluations of the developed hatchery showed a 79.3% and 87.1% hatchability rate respectively. The eggs were turned both manually and automatically as the case may be at intervals of 6 hours.

Grid supplied electricity has been identified to be the conventional energy source in poultry industry [6]. However, because of the unpredictable nature of supply and unavailability in rural areas especially in developing nations of the world, alternative sources are been sought by energy experts to sustain the poultry industry.

Table 3: Papers considered

	Author	Title	Thermal Energy source used	Year of publication	Hatchability (%)	Reference
1	Olorunnisola and Ewemoje	the development and evaluation of a flat-plate wooden incubator	Electricity supported with kerosene during outage	1998	76	[2]
2	Al-Zaidi	Optimum Design Calculation of Eggs Incubator	Electricity	2022	98.39	[19]
3	Yunaldi and Yohandri	Automatic Chicken Eggs Hatcher Using DHT 22 Sensor and DC Motor Gearbox Based on Arduino	Electricity	2021	89.65	[20]
4	Mansaray and Yansaneh	Fabrication and performance of solar power egg incubator	solar PV system	2015	23.1	[21]
5	Hassan et al	Using Thermochemical Materials as a Heat Source for Poultry Egg Incubation	Electricity	2021	80.9	[22]
6	Hassan et al	Using Thermochemical Materials as a Heat Source for Poultry Egg Incubation	Thermochemical Materials	2021	71.4	[22]
7	Olaoye et al	An Electrically Operated Incubator for Household	Electricity	2013	64.8	[23]
8	Ogunwande et al	Development of A Biogas-Powered Poultry Egg Incubator	BIOGAS	2015	59.7	[24]
9	Mohammad et al	Design and Performance of HEFINC840 Micro-controller Based Incubator	Electricity	2022	88.21	[25]
10	Adegbulugbe et al	Development of an Automatic Electric Egg Incubator	Electricity	2013	84.06	[26]
11	Ikpeseni et al	Design and Fabrication of a Local Solar-Powered Poultry Egg Incubator for a Low-Income Country	solar PV system	2022	77	[27]
12	Agidi et al	Design, construction and performance evaluation of an electric powered egg incubator	Electricity	2014	*33*	[28]
13	Yadav et al	Design, Fabrication, and Performance Analysis of an Automatic Horizontal Egg Incubator	Electricity	2021	72.22	[29]
14	Abd El-Mottaleb	Developing a local Semi-Mechanical Incubator for Minimum Production Cost	Electricity	2010	90	[30]
15	Divagar et al	Development of an Automated Solar-Driven Hybrid Egg Incubator	SOLAR PV		81.72	[31]
16	Metwally	Development of an Egg Incubator Using Lighting Circuit with Switching Power Supply	Electricity	2018	*86.88*	[32]
17	Agboola et al	Increasing Livestock Production in Nigeria: Development of Cost-Effective Models for Bird-Egg Incubator	oil lamp	2013	86	[33]
18	Agboola et al	Increasing Livestock Production in Nigeria: Development of Cost-Effective Models for Bird-Egg Incubator	Electricity	2013	94	[33]
19	Osanyinpeju et al	Development of solar powered poultry egg incubator	solar pv	2016	44	[34]
20	Olasunkanmi	Development of a GSM based DC Powered Bird Egg Incubator	Battery powered	2015	94	[35]
21	Muhammad et al	Development of Thermoelectric Egg Incubator Integrated with Thermal Energy Storage System	solar pvthermal storage system containing (PCM)	2021	73.3	[36]
22	Ogunwande et al	Development of a Still-Air Incubator with a Non-Thermostatic Control	Electricity	2010	62	[37]
23	Oniya	Development of a Low-Cost Semi-Automated Incubator	back up inverter	2013	91	[38]
24	Soeb et al	Design and Fabrication of Low-Cost Incubator to Evaluate Hatching Performance of Egg	Electricity	2021	87.1	[39]
25	Harb et al	Energy Consumption for Poultry Egg Incubator so Suit Small Farmer	electricity	2010	82.6	[40]
26	Niranjan et al	Design and implementation of chicken egg incubator for hatching using IoT	Solar PV	2021	81, 92 and 86	[9]
27	Dalangin and Ancheta	Performance Evaluation of the Developed Solar Powered Poultry Egg Incubator for Chicken.	Solar PV	2018	73	[41]
28	Uzodinma et al	Performance study of a solar poultry egg incubator with phase change heat storage subsystem	solar System with phase change material (PCM)	2020	62.37	[6]

3.3 Solar System as an Explicit Source of Energy for Poultry Egg Incubation

Next to grid-supplied electricity is solar energy as source of energy for egg incubation (Figure 4). One of the basic explicative challenges of incubators that function with electricity is the outrageous nature of its billing system, the power outage with its unavailability in remote regions. The incubators operating with fossil fuel emit unhealthy gases which affect the embryos as well as the surrounding environment. Due to this fact, efforts are now been made to adopt renewable or clean energies as the energy source for the incubation operations [6], [42], [43]. Solar energy is free, clean and easily accessible especially in the tropical regions of the world. Mansaray and Yansaneh [21] developed a solar power egg incubator that achieved temperature range of 36.8-37.9^{0}C. The evaluation of the system yielded a percentage fertility and hatchability of 43.3% and 23.1% respectively. The study concluded that the low level of hatchability was as result of several external influences such as an overcast weather, improper egg storage, time and energy loss in turning of eggs, faulty eggs etc.

Ikpeseni et al. [27] worked on a Local Solar-Powered Poultry Egg Incubator for Low-Income nations. The parts of the system included an electronic temperature component together with a solar photovoltaic network. The incubation temperature of the system sustained between 36–39°C. The system produced percentage hatchability of 77%. Divagar et al. [31] evaluated an automated solar-driven hybrid egg incubator. The system achieved a hatchability percentage of 81.72%. Osanyinpeju et al. [34] worked on the development of solar powered poultry egg incubator. The heat produced by metabolic activities of 150 eggs in the system was 21.9W. The percentage fertility of 64% in addition to 44% hatchability rate was observed with the system. The low hatchability was attributed to the faulty hygrometer used which led to increase in the number of opening made at the last stage. Niranjan et al. [9] developed a chicken egg incubator using IoT integrated with smart phone effective monitoring and control. The system temperatures were set at the different temperatures of (*H1*) 36.5°C, (*H2*) 37.5°C and (*H3*) 38°C. The hatchability percentages of the three temperatures were (*H1*) 81%, (*H2*) 92% and (*H3*) 86% respectively.

Dalangin and Ancheta [41] did characterization of a solar powered poultry egg incubator for chicken. The incubator yielded a hatchability value of 73% with mean temperatures of 37.72, 37.94 and 37.83°C in the morning, afternoon and evening respectively.

3.4 Fossil Fuel as an Explicit Source of Energy for Poultry Egg Incubation

Studies and current global trends have shown that the use of fossil fuel is no longer sustainable couple with negative effects on climate change [6]. However, few works have been carried out using fossil fuel as a source of egg incubators. Agboola et al [33] work on cost- effective models for egg incubation. Among the four models used, the oil lamp incubator with forced air produced a hatchability rate of 83% while oil lamp with still air yield a 33% hatchability rate. In this study, apart from energy source used, air flow rate has been shown to affect the hatchability of the system.

3.5 Biogas as an Explicit Source of Energy for Poultry Egg Incubation

Ogunwande et al [24] developed a biogas-powered poultry egg incubator that utilizes biogas as a fuel to provide thermal energy via a heater situated at the base. The system produced temperature range of 36-39.4°C within the incubating compartment. At the end of an evaluation test, a hatchability percent of 59.7% was realized.

3.6 Using Combine Sources of Energy as a Heat Source for Poultry Egg Incubation

Several studies have shown that energy from various sources could easily be used in combined or alternating form to meet the energy requirement of poultry egg incubators. Hassan et al [22] studied the use of thermochemical storage media set-up as a thermal source for hatching of poultry eggs. In the study, three forms of activated TCMs were utilized as energy containing medium. The media are Silica gel self-indicating (blue/pink), white Silica gel, as well as Natural Zeolite. The TCMs were activated using electricity. Equally, the incubator was partly powered by electricity and partly by the TCMs. The heat recapture operation helps to release the stored heat in TCMs. The system's hatchability percentage was 71.4% compared to a solely electric powered conventional incubator with 80.9 percent hatchability. However, The TCM incubator gave energy savings of 41.8% when compared with the conventional electric type.

Muhammad et al [25] studied a thermoelectric egg incubator coupled to a heat storage system. The thermoelectric component is utilized in the daytime process while a heat storage system made up of phase change materials (PCM) which provides thermal energy during off-sunshine (especially nights) periods is the complimentary heat source. The electric energy that is changed to heat for starting the operation is provided with the arrays of the solar PV. The result of the 300 egg capacity system showed that temperature inside incubation chamber was between 36-39°C with 73.3% hatchability. Olasunkanmi et al [35] developed a GSM based DC battery powered poultry egg incubator. The system is remotely tracked. The major components of the incubator were the DC motor, humidifier, ventilation fans, in addition to a custom-made low-power DC heater provided for controlling the turning of eggs, humidity, ventilation and temperature, respectively. The hatchery could either be powered using solar PV system, grid powered electricity via an inverter or any medium that could charge the DC battery.

The system produced a hatchability percentage of 94 with temperature fluctuating between 37ºCand 38ºC. Oniya et al [36] developed a 160 egg capacity low cost semi-automated incubator powered by a back up inverter. The inverter could either be powered with an AC or DC electric system. The major components of the system were a heat source (100W bulb), a thermistor, 12 V battery, 1000 W inverter and 0.14 W electric fan. A replicated analysis on the system showed a temperature variation between 36 and 39 °C with hatchability of 91%. Uzodinma et al [6] carried out a characterization of a hybrid solar powered poultry egg incubator. The hybrid incubator is made up of a double-glazed flat plate solar collector coupled with paraffin PCM in addition to a PV subsystem. The evaluation of the system revealed that the incubating temperature was maintained between 36 and 39 °C in addition to a mean hatchability rate of 62.37%.

4.0 CONCLUSION

This study revealed that sources of energy for incubation can be categorized into five namely: Electricity, Solar system, Fossil fuel, Biogas and Thermochemical Materials. Out of the Twenty- eight (28) articles discussed, Fourteen (14) of the published literature on energy sources for poultry egg incubation identified explicitly electricity as the energy source. Six of the articles explicitly identified solar system as the energy source. Only one article reported the use of biogas explicitly while another paper discussed fossil fuel as an explicit energy source for poultry egg incubation respectively. The rest of the papers discussed combination energy sources for incubation operations. Among the five categories, grid-supplied electricity was found to have the highest percentage hatchability that ranges from 80.9% - 98.39%. Although, some developing countries that also use electricity as source of energy for incubation have lower percentage hatchability due to epileptic electric power supply.

Electricity is the most used source of energy for incubation but the major challenges the users face are the high billing rate, erratic power supply and the unavailability of electricity in remote areas; hence, the need for alternative sources of energy. Other identified sources of energy like solar system, fossil fuel, biomass and thermochemical materials do not have some of these mentioned challenges but they too have their own peculiar problems.

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