E-ISSN: 2346-7290

Seasonal variations in egg fertility and hatchability in layer-breeder hens under two climatic conditions

Abioja, M. O. *, Williams, T. J., Abiona, J. A. and Iyasere, O. S.

Department of Animal Physiology, College of Animal Science and Livestock Production, Federal University of Agriculture, PMB 2240 Abeokuta, Nigeria.

*Corresponding author (Email: abiojamo@funaab.edu.ng; dimejiabioja@yahoo.com; Phone:+234-803-395-2155)

ABSTRACT

Data involving 6,148,609 eggs obtained from *Hubbard* layer-breeder flocks raised between 2002 and 2006 in Ibadan (humid-tropics) and Jos (montane vegetation) were subjected to analysis of variance to compare egg fertility (FERT) and hatchability of set (HATCHS) and fertile eggs (HATCHF). Pearson correlation analysis was carried out. Average annual temperature in Ibadan and Jos were 28.1 and 21.3^{o}C respectively. HATCHF was significantly ($P<0.05$) affected by location but FERT and HATCHS were not ($P>0.05$). Ibadan had higher overall HATCHF than Jos. FERT, HATCHS and HATCHF were similar over months in Ibadan except for slight depression in August. In Jos, highest values were obtained in August-September while the lowest was in February. The parameters were similar ($P>0.05$) in the 2 locations in January, May, October, November and December. Jos recorded significantly lower values in February to April and higher in June to September than Ibadan. Correlations between temperature and FERT, HATCHS and HATCHF in Jos were negative however they were positive in Ibadan. In Jos, relative humidity (RH) and rainfall were positively correlated with the 3 parameters while in Ibadan RH was negatively correlated. Therefore, it can be concluded that dry season had adverse effects on fertility and hatchability in layer breeder hens in Jos. This may be due to too low RH.

Keywords: Season; chickens; incubation; environmental temperature; relative humidity; climate change

INTRODUCTION

Ever-growing demand for poultry products by world teeming population has made the need for viable and healthy chicks extremely important. Prediction by the United Nations Food and Agriculture Organization (FAO) shows a 60% increase in demand eggs and other animal protein sources by 2050 (Javier, 2013). One of the factors that had limited the effective and efficient operations in incubators is the quality of eggs brought into hatcheries. Production of fertile and hatching eggs from breeder hens is drastically hampered by high environmental temperature (Abioja, 2010), especially in tropical regions of the world. As a result, breeder hens lay eggs with reduced fertility and hatchability (Bird *et al.* 2000). Abioja *et al.* (2012) had earlier reported variations in egg fertility and hatchability in layer breeder hens in

flocks raised in Jos, in the North Central Nigeria. The city of Jos, on latitude 09º 38'N, longitude 08º 51'É and elevation of 285.6 m above sea level, is situated at the northern edge of a pear-shaped upland known as the Jos Plateau. This upland stretches for approximately 104km. from north to south, and 80km from east to west covering an area of about 8,600km^2 or 860,000 hectares. Characterized by impressive ridges and isolated rocky hills separated by extensive plains, the Plateau exhibits a variety of land forms which provide excellent picnic resorts. Several rivers and hillocks are interspersed among the highlands giving the landscape striking scenery. It maintains an average height of 1,200m (4,000ft) above sea level, and reaches its highest peak of 1,766m (5,829ft). It is situated almost at the geographical centre of the country and has an equable climate with its average monthly temperatures ranging between 21° and 25°C, average humidity of 60% and average annual rainfall of 1,400mm.

The combination of high ambient temperature and relative humidity that characterized the humid tropical zones further aggravates the effects on the poultry production. Ibadan, a city on latitude 07º 23'26"N, longitude 3º 53'24"E and 197 metre above sea level is situated in the humid tropical zone in the south western Nigeria. Egg fertility and hatchability are important determinants of the productivity in broiler breeder flocks. Lowered fertility may results from poor quality semen from heat-stressed cocks used in natural or artificial insemination, or hen's inability to release viable ovum and effectively store spermatozoa in the semen storage tubules (SSTs) in the reproductive tract (Grieve 2003; Gonzalez-Redondo 2006). All these are results of heat stress in breeder farms. The effects of heat stress on egg fertility and hatchability differ from season to season and for different locations in various species of poultry (Joshi *et al*. 1980; Karaca *et al*. 2002a; Ipek and Sahan 2004). The higher humidity coupled with hotness during dry season usually aggravates the effects of heat stress (Karaca*et al*. 2002b). Understanding of the extent to which egg fertility and hatchability are affected by temperature and humidity in each month will bridge the gap of knowledge in this area of animal production. Therefore, the present study is to determine the monthly variations in egg fertility and hatchability in broiler-breeder flocks under humid tropical condition of southern Nigeria.

MATERIALS AND METHODS

Experimental location: The study involved two locations: Ibadan in the humid-tropical zone of the south-western Nigeria and Jos in the north-central of Nigeria. Jos has montane vegetation with relatively low environmental temperature throughout the year. Ibadan is located on latitude 07º 23'26"N, longitude 3º 53'24"E and 197 metre above sea level while Jos is on latitude 09º 38'N, longitude 08º 51'É and elevation of 285.6 m above sea level.

Meteorological observations: The data on monthly minimum, maximum and mean ambient temperatures, relative humidity and rainfall for Ibadan and Jos covering years 2002 and 2006 were collected from the Nigerian Meteorological Agency (NIMET) Office, Oshodi, Lagos.

Management of the birds: A total of six million, one hundred and forty eight thousand, six hundred and nine (4,475,603in Ibadan and 1,673,006 in Jos) eggs collected from flocks of layer-breeder hens (strain *Hubbard*) in Ibadan located in the humid tropical rain forest and Jos located in montane vegetation in the Central Nigeria (Jos Plateau) was used for this study. The birds were raised on the wood-shaving floors in open-sided housing units. Hatchable eggs from the breeder hens were collected twice daily, arranged in crates, labelled and transported straight to the setting room where they were sorted under 26ºC before setting. The eggs were kept in cold room and fumigated before setting. Set eggs stayed in the setter (N. V. Petersime® EV1/EN2 Setter, *Belgium; capacity 57600*) at 37.5 - 37.6ºC and 85% RH for 18 days before candling. Fertile eggs were thereafter transferred into the hatcher (N. V. Petersime® B-9870 Hatcher *Zulte, Belgium; capacity 19200*) at 36.9ºC and 88 – 92.5% RH for 3 days. The breeders were replaced at 80 - 90 weeks of age.

Statistical analyses

The data were subjected to analyses of variance using the general linear model procedures of SYSTAT statistical computer package (SYSTAT, 1992). Means that are significantly different were separated using Tukey procedure. The egg fertility, hatchability and climatic data were subjected to Pearson correlation analysis to determine the relationships between them.

RESULTS

Monthly mean temperature, relative humidity and amount of rainfall in the two locations between 2002 and 2006 are presented in Figures 1-3 respectively. Average annual temperature in Ibadan and Jos were 28.1 and 21.3ºC respectively. Throughout the year, monthly temperature was consistently higher in Ibadan than in Jos. The hottest month in Ibadan (30.7ºC) and Jos (24.3ºC) was February and March respectively while the coldest month was August (26.1ºC) and December (19.3ºC). The temperature decreased as rain started in April till the lowest was reached in August (26.1ºC). It increased again in September until December (Figure 1). Rainfall showed a bi-modal pattern in Ibadan, reaching peaks in June and October with characteristic 'August break' in the southern Nigeria. There was little or no rain in January to March and in November and December being the dry season (Figure 2). There was gradual increase in relative humidity from the base in January (68.6%) till a peak was reached in August (90.6%) and then it decreased from August till December. Jos was colder than Ibadan throughout the year (Figure 1). The hottest month was March (24.3ºC) while the coldest was December (19.3ºC). The temperature decreased from April to August before it increased in September and October. There was little or no rain in Jos during 1st, 2nd, 3rd, 11th and 12th months, representing the dry season. There was only one peak of rainfall in August (Figure 2). Relative humidity (RH) was low during the dry months, ranging between 17.7 and 29.3%. The RH in April to October formed a parabolic curve with maximum (274.0 mm) in August (Figure 3).

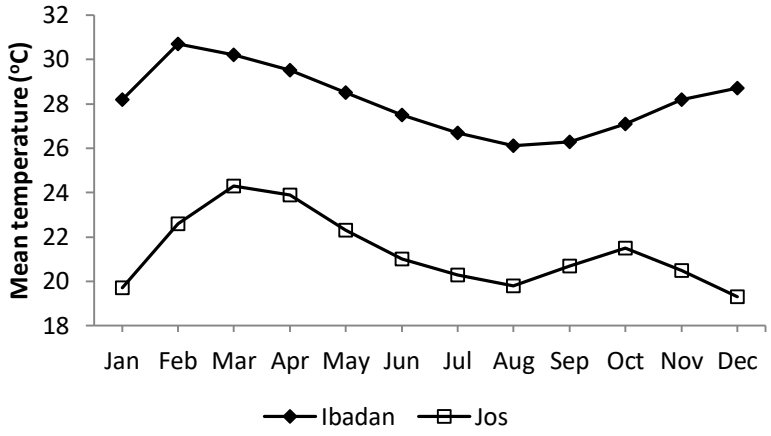

Fig.1. Mean temperature of Ibadan and Jos between 2002 – 2006

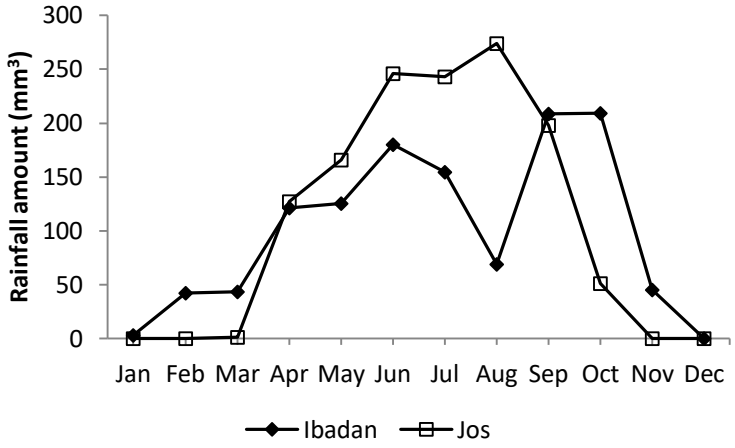

Fig. 2. Amount of rainfall in Ibadan and Jos between 2002 - 2006

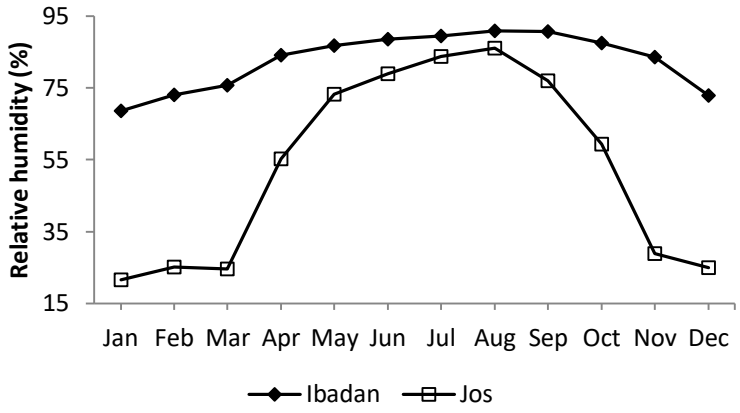

Fig. 3. Relative humidity of Ibadan and Jos between 2002 - 2006

Table 1 shows the effect of location on overall egg fertility, hatchability of set eggs and of fertile eggs in layer-breeder hens. HATCHF was significantly ($P<0.05$) affected by location but FERT and HATCHS were not ($P>0.05$). Ibadan (83.3%) had significantly higher overall hatchability of fertile eggs than Jos (80.3%). Monthly variations in egg fertility, hatchability of set eggs and fertile eggs in Ibadan and Jos are shown in Figures 4,

5 and 6 respectively. Generally, the FERT, HATCHS and HATCHF were stable in Ibadan except for slight depression in August. FERT, HATCHS and HATCHF were affected ($P<0.05$) by month of lay in Jos. Highest values were obtained in August-September while the lowest was in February.

Table 1: Comparison of overall egg fertility and hatchability of layer-breeder hens raised in Ibadan and Jos

	Mean±sem	
Parameter	Ibadan	Jos
Fertility (%)	88.5±0.15	88.2±0.62
Hatchability of set eggs (%)	74.1±0.37	71.6±1.56
Hatchability of fertile eggs (%)	83.3±0.34[a]	80.3±1.41[b]

[a,b]Means with different superscripts in the same row differ significantly ($P<0.05$)

Comparing each month in the 2 locations, FERT was similar ($P>0.05$) in the 2 locations in January however, Jos recorded significantly lower FERT than Ibadan in February to April. There was an increase in FERT in Jos from May to September when higher values were recorded than in Ibadan. Similar FERT ($P>0.05$) were recorded in October to December in the 2 locations. The pattern

for HATCHS and HATCHF was similar to that of FERT.

Correlations between mean temperature and FERT (r = 0.324), HATCHS (r = 0.340) and HATCHF (r = 0.324) were weak and positive in Ibadan (Table 2). However, the correlations were significant, strong and negative (Table 3) in Jos (r = -0.837, r = -0.794 and r = -0.707) respectively. In Jos, relative humidity and rainfall were positively correlated with the 3 parameters while in Ibadan relative humidity was negatively correlated with the parameters.

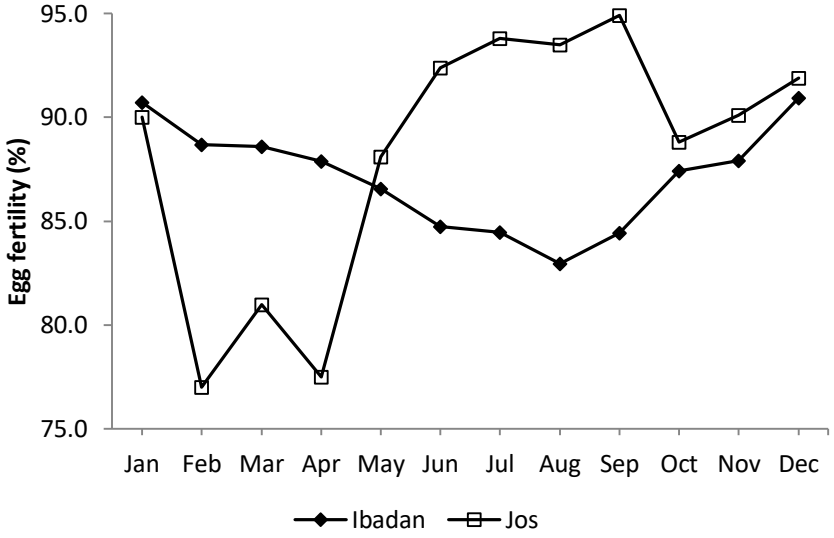

Fig. 4. Monthly variations in egg fertility in Ibadan and Jos

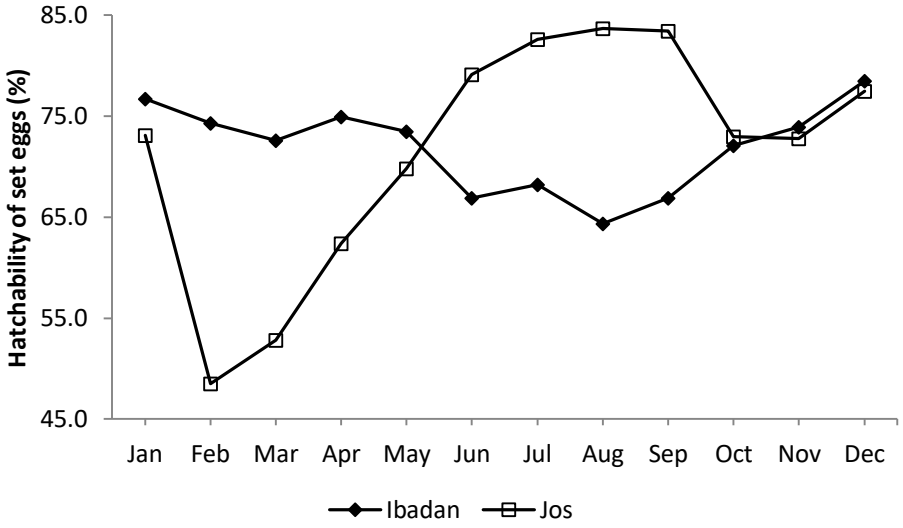

Fig. 5. Monthly variations in hatchability of set eggs in Ibadan and Jos

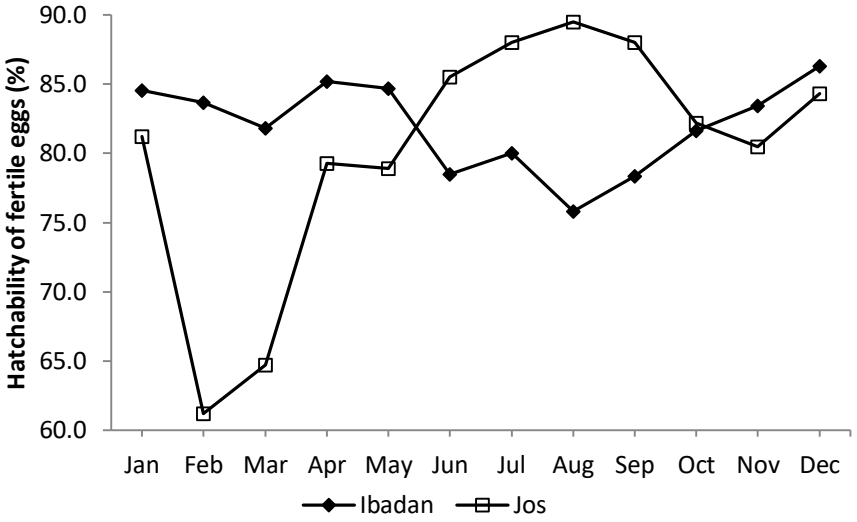

Fig. 6. Monthly variations in hatchability if fertile eggs in Ibadan and Jos

Table 2: Correlation matrix of egg fertility, hatchability and climatic variables in Ibadan

	Egg fertility	Hatchability of set eggs	Hatchability of fertile eggs	Mean temperature	Relative humidity	Rainfall amount
Egg fertility	1.000					
Hatchability of set eggs	0.980***	1.000				
Hatchability of fertile eggs	0.935***	0.984***	1.000			
Mean temperature	**0.324**	**0.340***	**0.376***	1.000		
Relative humidity	**-0.422***	**-0.393***	**-0.368***	-0.709***	1.000	
Rainfall amount	**-0.309**	**-0.295**	**-0.266**	-0.538**	0.805***	1.000

**P<0.005, **P<0.01, ***P<0.001*

Table 3. Correlation matrix of egg fertility, hatchability and climatic variables in Jos

	Egg fertility	Hatchability of set eggs	Hatchability of fertile eggs	Mean temperature	Relative humidity	Rainfall amount
Egg fertility	1.000					
Hatchability of set eggs	0.944***	1.000				
Hatchability of fertile eggs	0.850***	0.974***	1.000			
Mean temperature	**-0.837*** **	**-0.794*** **	**-0.707*** **	1.000		
Relative humidity	**0.496****	**0.624*** **	**0.650*** **	-0.150	1.000	
Rainfall amount	**0.484****	**0.616*** **	**0.637*** **	-0.183	0.962***	1.000

**P<0.005, **P<0.01, ***P<0.001*

DISCUSSION

The high elevations in Jos act to force the ascent of air, thus creating unstable air masses which result in mountainous rainfall (Adakayi, 2012).The present finding on higher hatchability in Ibadan than in Jos may be due to the variation in climatic factors. The average egg fertility recorded in this study (88.6%) was similar to value for layer-breeder chickens (88.65%) cited in the literature by Babiker and Musharaf (2008) but higher than the value reported by Fayeye *et al*. (2005) in Fulani-ecotype chickens in Nigeria (76%). Effect of season on egg fertility in layer breeder hens is contrary to the report given by Babiker and Musharaf (2008). They reported that season had no effect on fertility of eggs of egg-type parent stock (Bovans) in Sudan. However, the present finding is similar to the report of Ipek and Sahan (2004) that egg fertility is affected by season in ostrich. It is also in consonance with the report of González-Redondo (2006) that laying date affected fertility of eggs of red-legged partridge (*Alectoris rufa*). Ozcelik *et al*. (2006) reported that hatching month had effect on fertility of egg from bronze turkey. The high fertility values recorded in December and January can be adduced to the low mean temperature during the period in the locations studied (Ibadan and Jos), especially in Jos where the mean monthly temperature was 19.3 and 19.7ºC for December and January respectively. Lower fertility of eggs was recorded in February to September, the lowest being in April. The period between February and April in the locations under consideration is known for high ambient temperature compared with other months of the year. The low egg fertility during this period might be as a result of high mean temperature. Numerous reports in literatures support that exposure of breeder hens to high ambient temperature causes reduction in egg fertility (Hafez 1964; McDaniel *et al*. 1995; Bird *et al*. 2000; Ipek and Sahan 2004; Morris 2004). The fertility of an egg is affected by factors originating from the hen such as her ability to mate successfully, to store sperm, ovulate an egg cell and to produce a suitable environment for the formation and development of the embryo (Brillard, 2003). Fertility also depends on her mate's ability to mate successfully, quantity and quality of semen deposited (Wilson *et al*. 1989; Brillard, 2003). The lowered egg fertility may result from the exposure of cock to heat stress. Hood (1999) found a significant decrease in sperm-egg penetration when hens were inseminated with semen from heat-stressed males. High environmental temperature causes a reduction in the fertilizing capacity of spermatozoa in cocks (Karaca *et al*., 2002a; Grieve, 2003). Wilson (2004) stated in a report that an extreme weather condition was one of the factors responsible for infertile eggs. Though the temperature was decreasing from April till August, the fertility did not significantly improve until September through December.

The highest hatchability of total eggs set in layer-breeder hens recorded in December was not different from other months except February and March. In both Jos and Ibadan, the highest mean temperature was recorded in February and March, which fall within the hot-dry season. The present findings corroborate

the reports of Grieve (2003) and Ipek and Sahan (2004) that season affected reproductive efficiency in cocks and ostrich respectively. Similarly, Chowdhury *et al.* (2004) reported that hatchability of eggs was higher in winter than in summer in ducks. Hatchability of fertile eggs in chickens was reported to be highest during cold season by Jayarajan (1993). Mentioned among factors that affect hatchability is season (Tona *et al.* 2007; Yassin *et al*. 2008). Mo *et al*.(2007) stated that environment was of importance to egg hatchability. Van Krey *et al*.(1987) observed the stage of embryonic development at oviposition in turkey breeder hens maintained in relatively warm and cold environments. The proposition was that the lowered hatchability common with hens raised under high ambient temperature condition may result from difference in stage of embryonic development at oviposition. However, there was no difference in stage of embryonic development between hens kept in warm and cold environments.

Overall egg fertility and hatchability of set eggs were not different between Ibadan and Jos but when the parameters were compared month by month, it can be deduced that egg fertility and hatchability of set eggs were truly similar during January, May, October, November and December. Between February and April, higher values were recorded in Ibadan for the two parameters while opposite was the case between June and September. The reason for higher egg fertility and hatchability of set eggs could not be easily adduced between February and April because the temperature was lower in Jos than in Ibadan. However, one may implicate the relative humidity which was very low in Jos during the period. Egg loses moisture fast when stored under low humidity before setting.

The effects of climatic variables on reproductive hormones and mechanisms have not been adequately reported in literatures. However, some reports can be gleaned to justify variations observed in egg fertility and hatchability in layer-breeder hens. Donoghue *et al.* (1989) reported that circulating levels of luteinizing hormone (LH) were reduced in hens exposed to acute heat stress (35^{o}C). The authors suggested that the reduced reproductive efficiency observed in hyperthermic hens may be mediated by reduced LH releasing ability of the hypothalamus. The work of Rozenboim *et al*. (2007) on the effect of heat stress on ovarian function of laying hens reveals that both acute and chronic heat stress had significant negative effects on ovarian weight and number of large follicles. Similarly, Ultrasonic imagery of reproductive tract of hens exposed to long-term heat stress revealed reduction in large follicles 6 and 15 days post-exposure (Laura Marongiu and Dimauro, 2009). The same authors reported that decreased plasma LH was detected 24 h after exposing the birds to heat stress. However no significant change was found in LH concentrations during d 3, 6, 9, 12 and 15 post-exposure. Oguntunji and Alabi (2010) in a review on influence of high ambient temperature on egg production and shell quality listed malfunctioning of endocrine system, acid-base perturbations, poor physiological functioning of organs and mechanisms connected with follicular recruitment and

growth, ovulation and oviposition as some of the effects.

In the present study, environmental temperature had strong negative correlation with egg fertility, hatchability of set and fertile eggs especially in Jos. Season has effect on egg fertility and hatchability (Yassin *et al.*, 2008). This shows that exposure of breeder chickens to hot environment could limits the expected number of chicks from eggs during periods of heat spell. Heat stress affects reproductive processes in both male and female chickens (Van Krey *et al.*, 1987; Karaca *et al.*, 2002a,b). Environmental temperature imposing heat stress has been recognized as one of the major factors affecting egg fertility and hatchability. Heat stress influences rate of hormonal secretion in both hypothalamic-pituitary-adrenal and hypothalamic-pituitary-gonadal axes and the metabolic clearance (El Halawani *et al.*, 1984; Donoghue *et al.*, 1989; Rozenboim *et al.*, 2007) in chickens. Gonadal sensitivity and receptor number and concentration are affected by environmental temperature (Xie *et al.*, 2016). Relative humidity, the measure of amount of water vapour in the atmosphere, does affects reproduction in chickens (Millan, 1997). It has a synergistic effect with environmental temperature on the birds.

CONCLUSION

A depression in hatchability was observed in February and April in Jos. These months coincide with highest average temperature, and lowest rainfall and relative humidity in Jos. Management of layer breeder hens in this location must be attended to during the months of February to April if optimal fertility and hatchability will be achieved. Therefore, it can be concluded that dry season had adverse effects on fertility and hatchability in layer breeder hens in Jos. This may be due to too low RH. Egg fertility and hatchability are less affected by season in Ibadan.

ACKNOWLEDGEMENT

The management of Zartech Farms, Ibadan, Nigeria is acknowledged for permission to use their data bank for this study. The Nigerian Meteorological Agency (NIMET), Oshodi is also appreciated for the climatic data.

REFERENCES

Abioja, M. O. 2010. Temperature-humidity effects on egg fertility and evaluation of vitamin C and cold water on broiler growth in hot season. A Ph.D thesis submitted to Department of Animal Physiology, University of Agriculture, Abeokuta, Nigeria. 157pp.

Abioja, M. O., Osinowo, O. A., Smith, O. F., Eruvbetine, D. and Williams, T. J. 2012. Effects of month of lay on egg fertility in layer-breeder flocks in Jos, Nigeria. *Nigerian Poultry Science Journal* 8, 70-76.

Adakayi, E. P. 2012. An assessment of rainfall and temperature variations in selected stations in parts of northern Nigeria. *Thesis, Department of Geography and Planning, University of Jos, Nigeria*. 214pp

Babiker, M. S. and Musharaf, N. A. 2008. The effects of season on hatchability and fertility of egg-type parent stock (Bovans) in Sudan. *Research Journal of Poultry Sciences* 2(1), 5-8.

Bird, N. A., Hunton, P., Morrison, W. D. and Weber, L. J. 2000. Heat stress in caged layers. Factsheet, Ministry of agriculture, food and rural affairs, Ontario, Canada. www.omafra.gov.on.ca/english/livestock/poultry/facts/88-111.htm. assessed 21st November, 2018.

Brillard, J. P. 2003. Practical aspect of fertility in poultry. *World's Poultry Science Journal* 59(4), 441-446.

Chowdhury, M. M. I., Ashraf, A., Mondai, S. P., Mondol, N. M. A. A. N. and Hasan, M. M. 2004. Effect of season on the hatchability of duck eggs. *International Journal of Poultry Science* 3(6), 419-421.

Donoghue, D. J., Krueger, B. F., Hargis, B. M., Miller, A. M. and El Halawani, M. E. 1989. Thermal stress reduces serum luteinizing hormone and bioassayable hypothalamic content of luteinizing hormone-releasing hormone in hens. *Biology of Reproduction* 41, 419-424.

El Halawani, M. E., Silsby, J. L., Behnke, E. J. and Fehrer, S. C. 1984. Effect of ambient temperature on serum prolactin and luteinizing hormone levels during the reproductive life cycle of the female turkey (*Meleagis gallopavo*). Biology of Reproduction 30: 809–815.

Fayeye, T. R., Adeshiyan, A. B. and Olugbani, A. A. 2005. Egg traits, hatchability and early growth performance of the Fulani-ecotype chicken. *LivestockResearch for Rural Development* 17(8), Art. #94, http://www.lrrd.org/lrrd17/8/faye17094.htm

GonzalezRedondo, P. 2006. Influence of laying date on the fertility and hatchability of red-legged partridge (*Alectoris rufa*) eggs. *Journal of Applied Poultry Res*earch 15, 579-583.

Grieve, D. 2003. Heat stress in commercial layers and breeders. *Technical Bulletin* Hy-Line International, Iowa *HLST* 19(1), 1-3.

Hafez, E. S. E. 1964. Effects of temperature on reproduction. *International Journal of Biometeorology* 7(3), 223-230.

Hood, J. E. (1999). An attempt at alleviating heat stress infertility in male broiler breeder chickens with dietary ascorbic acid. M.Sc Thesis. Submitted to Mississippi State University, Mississippi State, MS.

Ipek, A., and Sahan, Ü. 2004. Effect of breeder age and breeding season on egg production and incubation in farmed ostriches. *British Poultry Science* 45(5):643-647.

Javier, G. 2013. Food safety for poultry meat and eggs as a component of food security in emerging economies. *In:* Lokman, H. I., Hasliza, A. H., Mohd, H. M. N., Mazlina, M., Hafandi, A., Hair-Bejo, M., and Zulkifli, I. (eds) Advancing poultry production for food security. Proceedings of

WPSA (Malaysia Branch) and WVPA (Malaysia Branch) Scientific Conference, November 30–December 1, 2013 at Universiti Putra Malaysia, Malaysia 24 pp.

Joshi, P. C., Panda, B. and Joshi, B. C. 1980. Effect of ambient temperature on semen characteristics of White Leghorn male chickens. *Indian Veterinary Journal* 57, 52-56.

Karaca, A. G., Parker, H. M., Yeatman, J. B. and McDaniel, C. D. 2002a. The effects of heat stress and sperm quality classification on broiler breeder male fertility and semen ion concentrations. *British Poultry Science* 43(4), 621-628.

Karaca, A. G., Parker, H. M., Yeatman, J. B. and McDaniel, C. D. 2002b. Role of seminal plasma in heat stress infertility of broiler breeder males. *Poultry Science* 81(12), 1904-1909.

Laura Marongiu, M. and Dimauro, C. 2009. Short and long high ambient temperature exposure differently affect plasma luteinizing hormone and ultrasound-assessed ovarian dynamics of laying hens. Proceedings of 2nd Mediterranean Summit of WPSA. Pp 123-126. http://www.wpsa.com/index.php/wpsa-proceedings/2009/2nd-mediterranean-summit-of-wpsa/319-6-marongiu-mps2009-pdf/file assessed 21st November, 2018

McDaniel, C. D., Bramwell, R. K., Wilson, J. L. and Howarth, B. (Jr) 1995. Fertility of male and female broiler breeders following exposure to elevated ambient temperatures. *Poultry Science* 74(6), 1029-1038.

Millan, J.R. 1997. Reproductive physiology. In: Altman, R. B., Dorrestein, G.M., Clubb, S. and Quesenberry, K. (Eds.) *Avian medicine and surgery*. W.B. Saunders, Philadelphia; pp12–26.

Mo, D., Li, K., Qiangba, Y., Tang, X., Zhu, M., Xu, R., Fan, B. and Liu, B. 2007. Effect of mating combination and environmental factors on hatchability of chicken eggs in Tibet. *Frontier Agric. China*. 1(2), 214-219.

Morris, T. R. 2004. Environmental control for layers. *World's Poultry Science Journal* 60(2), 163-176.

Oguntunji, A. O. and Alabi, O. M. 2010. Influence of high environmental temperature on egg production and shell quality: a review. *World's Poultry Science Journal* 66(4), 739-750.

Ozcelik, M., Cerit, H., Ekmen, F. and Dogan, I. 2006. Effect of the hatching month as an environmental factor on the hatching features of bronze turkeys. *Turkey Journal of Veterinary and Animal Science* 30, 243-249.

Rozenboim, I., Tako, E., Gal-Garber, O., Proudman, J. A. and Uni, Z. 2007. The effect of heat stress on ovarian function of laying hens. *Poultry Science* 86(8), 1760-1765.

Star, L., Decuypere, E., Parmentier, H. K., Kemp, B. 2008. Effect of single or combined climatic and hygienic stress in four layer lines: 2.

Endocrine and oxidative stress responses. *Poultry Science* 87, 1031–1038.

SYSTAT 1992. Systat analytical computer package (version 5.0). Systat Inc., USA.

Tona, K., Onagbesan, O., De Ketelaere, B., Bruggeman, V. and Decupere, E. 2007. A model for predicting hatchability as a function of flock age, reference hatchability, storage time and season. *Archiv fur Geflugelkunde* 71, 30–34.

Van Krey, H. P., Denbow, D. M. and Hulet, R. M. 1987. The effect of ambient temperature on turkey embryonic development at oviposition. *Theriogenology* 28(4), 489-494.

Wilson, H. R. 2004. Hatchability problem analysis (1). University of Florida Institute of Food and Agricultural Sciences (IFAS) Florida Extension Service CIR1112. pp 1-13.

Wilson, H. R., Mather, F. B., Brigmon, R. L., Besch, E. L., Dugan, V. P. and Boulos, N. Z. 1989. Feeding time and temperature interactions in broiler breeders. *Poultry Science* 68, 608-616.

Xie, L. J., Xie, X. Z., Zhou, Y. W., Liang, C., Jiang, Y. Y. and Chen, Z. 2016. Effect of heat stress on the expression of GABA receptor mRNA in thye HPG axis of Wenchang chickens. *Brazilian Journal of Poultry Science* 18(2), 277-282.

Yassin, H., Velthuis, A. G. J., Boerjan, M., Van Riel, J. and Huirne, R. B. M. 2008. Field study on broiler eggs hatchability. *Poultry Science* 87, 2408-2417.