Analytical development of bird pecking force equation for a self-metering poultry feeder

Sabbas Nwabueze Asoegwu[1], A. U. Obasi[1], S. O. Ohanyere[1], N. R. Nwakuba[1,2*]

(1. *Department of Agricultural and Bioresources Engineering, Federal University of Technology, P.M.B. 1526 Owerri, Imo State, Nigeria*;
2. *Department of Agricultural and Bioresources Engineering, Michael Okpara University of Agriculture, Umudike, P.M.B. 7267 Umuahia, Abia State, Nigeria*)

Abstract: The concept of a self-metering poultry feeder was developed. The theoretical analysis of the forces involved in its operation was done and a generalized pecking force model was developed. Mathematical expressions, logical assumptions, graphical relations and models as well as statistical analyses were adopted in the pecking force analysis. This pecking force relates to some design parameters like feed flow rate, hopper aperture, etc. The generalized equation was tested using a fabricated model of the equipment. Experimental results show that the equation can be used to predict the performance of the machine reasonably and also the level of satiety and bird vigor determine the amount of pecking force which was described by a polynomial regression relationship (of the 4th order with R^2>0.9) which increases with increasing aperture opening and time of feeding by different ages of birds. The pecking force reached 10 N for <8 weeks birds after about 40 minutes for the highest aperture opening. For the three sample categories of birds, the pecking force was consistently lower with the smallest aperture C_{a1} and highest with aperture C_{a3}. Quantity of feed consumed decreased with feeding time in a power regression relationship and the birds, irrespective of the ages, had a feel of satiety after 50 minutes of feeding with feed consumed being less than 0.1 g. The general performance of each category of bird is a function of their age and number, vigor and pecking action.

Keywords: pecking force, self-metering, poultry feeder, feed rate, pecking time

Citation: Asoegwu, S. N., A. U. Obasi, S. O. Ohanyere, and N. R. Nwakuba. 2017. Analytical development of bird pecking force equation for a self-metering poultry feeder. Agricultural Engineering International: CIGR Journal, 19(3): 183–188.

1 Introduction

Poultry refers to all domesticated species of birds including chicken, ducks, turkeys, Japanese quail, pigeons, as well as varieties of such as ostrich and emu primarily kept for production of egg and/or meat (Killebrew and Plotnick, 2010). It provides an immense supply of food for the world's population. Across the globe, poultry meat and eggs are preferred to other kinds of animal food products due to sufficiently high quantities of all the essential vitamins (both fat-soluble and water-soluble, but except vitamin C) present in them (Prabakaran, 2003). In Nigeria, poultry meat and eggs are still considered luxury foods. In most rural areas, poultry consumption is reserved for special occasions, and meat and eggs typically come from household flocks. Urban dwellers consume larger amounts of poultry due to their relatively higher income levels and greater access to fresh or frozen products in markets and fast food outlets. Eggs are daily part of the diet in urban areas, while poultry meat is consumed on occasional basis (Adene and Oguntade, 2006). Throughout the country, demand for poultry meat spikes in December, around Christmas and New Year, and in April, for Easter (Gueye, 2007). Poultry is also used for socio-cultural and religious purposes. Households give out poultry birds as gifts, and in southwestern Nigeria, chicken entrails are believed to increase libido in old men and a good foodstuff for weight-control diets and convalescents for old people who are not physically active due to its essential amino

Received date: 2016-11-19 **Accepted date:** 2016-12-09

* **Corresponding author: N. R. Nwakuba**, Department of Agricultural and Bioresources Engineering, Michael Okpara University of Agriculture, Umudike, P.M.B. 7267 Umuahia, Abia State, Nigeria. Phone: +234 803 660 8510, Email: nrnwakuba@gmail.com.

acids and higher quality protein contents, low cholesterol and calories (David, 2004).The primary production of meat and egg in poultry management is indispensable, and thus makes poultry industry one of the main sources of protein for human consumption (Olaniyi et al., 2014).

The ban on importation of poultry products into Nigeria in 2003 has spurred the growth in domestic poultry production. The Nigerian poultry industry is estimated at ₦80 billion ($600 million) and is consisted of approximately 165 million birds, which produced 650,000 Mt of eggs and 290,000 Mt of poultry meat between 2012 and 2015. From a market size perspective, Nigeria's egg production is the largest in Africa and it has the second largest chicken population after South Africa's 200 million birds in Sahel Report (2016). The Global Livestock Production and Health Atlas for 2004 placed Nigeria as the 12th world largest producer of chicken with population of about 144 million. This may have been influenced by the shift from the traditional (free range) to the modern (intensive and extensive) methods of poultry production.

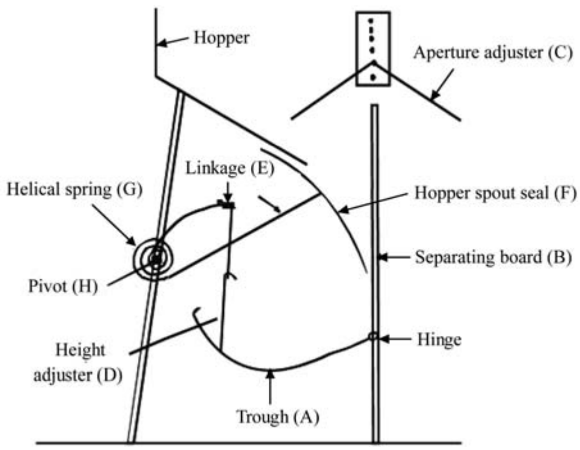
An important part of raising chickens is feeding, which makes up the major cost of production and good nutrition is reflected in the bird's health and vigor, performance and products (Fanatico, 2003). Modern poultry feeding systems make use of equipment and appliances which vary from the simple to the complex, from the most elementary designs to the most advanced electronic devices which are becoming increasingly important in poultry production as a major item for saving cost, labor, feed and water.

Birds by nature peck (pick up feed with their beak) and their pecking performance influences the transport capacity of their rostral mouth tube (Kooloos and Zweers, 1991) and thus their intake capacity as well as the design of feeders and waterers. Since feed is nearly always offered to the bird in some form of trough (long and thin or round), the guiding principles in feed trough design is that it must be: (i) easy to fill and clean (ii) built to avoid waste (iii) arranged that fowls cannot roost on them, and (iv) constructed with a durable material in such a manner that so long as they contain feed, the birds will be able to reach them (Nesheim et al., 1999). These have influenced feeding equipment development in recent times. However, for small scale production, the common types of feeders include the flat feeder, the conic or tube feeder and the trough (Geoffrey, 1993). A self-feeder is ideal for small flocks, where labor is scarce. And since feed should be available to the birds at all times, self-feeders are recommended. For the self-feeder, the hopper should contain feed for more than a few days. The space between the hopper and the trough should allow for free flow of feed by gravity. The objective of this study is to develop analytically the pecking force equation for a self-metering poultry feeder and test its validity.

2 Theoretical Analysis

2.1 Self-metering concept

This concept is illustrated in Figure 1. Its function is to allow certain quantities of feed onto the feed trough for the birds, depending on the pecking force produced by the birds pecking on the trough. The trough, A is hinged to a separating board B, on which is attached the hopper aperture adjuster, C. Supporting the unhinged end of the trough is the height adjuster D, which is hooked to one arm of the linkage, E. The other arm of the linkage supports the hopper spout seal F, while the two free ends of the linkage are joined by a helical spring G, at a pivot, H.



Note: A = Trough; B = Separating board; C = Hopper aperture adjuster; D = Height adjuster; E = Linkage arm; F = Hopper spout seal; G = Helical spring; H = Pivot.

Figure 1 Schematics of a self-metering poultry feeder

In operation, some feed is placed in the trough to attract the birds. Before this, two adjustments at C and D have been made with F completely sealing off any feed from the hopper. As the birds peck, their pecking force activates the linkages through G, which now opens F and feed from the hopper falls into the trough for the birds. The pecking action agitates the trough and the falling of the feed stimulates the birds' appetite. As the pecking force decreases, when the birds might have had their fill, a point is reached when the seal, F closes and the system stops metering feed into the trough until enough pecking force is exerted on the trough to open the seal.

2.2 Assumptions for the pecking force equation

The followings assumptions were made in developing the pecking force:

(a) The weight of the initial feed placed in the trough to attract the birds is not enough to open the hopper spout seal, F.

(b) The spring constant of the helical spring, G must be deflected when 20 birds of less than eight weeks peck on the trough, A.

(c) The spring force must always keep the hopper spout sealed until the pecking force exceeds it and so must have a direct relationship with the amount of the spout opening.

(d) The pecking force decreases with time (as the birds' appetite decreases) until it is less than the spring force which shuts the hopper spout seal, F.

(e) The pecking time determines the quantity of feed flowing through the spout seal, F into the trough.

(f) The hopper aperture adjustment, C affects the hopper spout seal, F for a constant feed flow rate.

2.3 Development of pecking force equation

To attract the birds to the feeder, an initial quantity of feed of force, F_i (N) is put into the trough but would not open the hopper seal. As the birds begin to peck, a pecking force, F_p (N) is established on the trough. Depending on the number of birds, n means pecking at a time, the magnitude of these two forces, ($n\,F_p + F_i$) must be large enough to activate the helical spring and open the hopper seal for the feed to be released into the trough as given in Equation (1) (Asoegwu and Obasi, 1989).

$$n\,F_p + F_i > F_s \tag{1}$$

where, $F_s = k\,x$ = spring force (N); k = spring constant (N/mm); x = spring deformation or seal aperture (mm).

When the hopper seal opens, F_i is replaced by the force of feed from the hopper to give Equation (2):

$$n\,F_p + Q\,t\,g = F_s \tag{2}$$

where, Q = mass flow rate of feed (g s^{-1}); t = time for feed to drop from hopper unto trough (s); g = acceleration due to gravity (m s^{-2}). From which Equation (3) is obtained as:

$$F_p = 1/n\,(k\,x - Q\,t\,g) \tag{3}$$

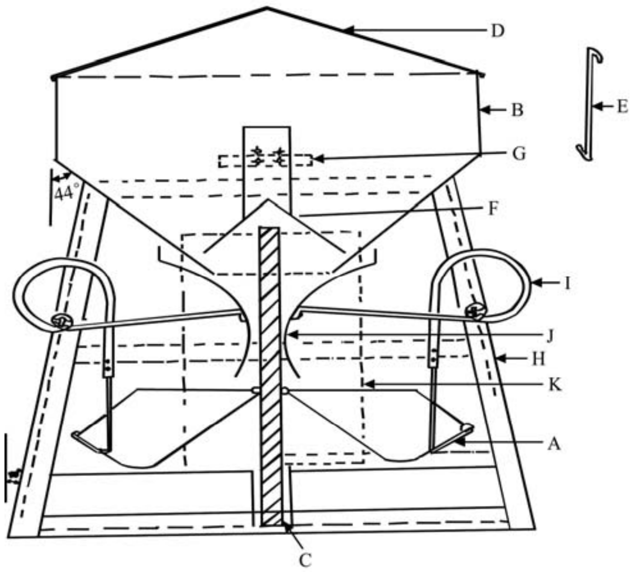
The hopper has adjustments that regulate the amount of feed passing through the seal aperture and thus control wastage by spillage. If the hopper adjustment constant = a, then Equation (4) is obtained as:

$$F_p = 1/n\,(k\,x - a\,g\,Q\,t) \tag{4}$$

This Equation (4) is the generalized pecking force equation for the self-metering poultry feeder.

3 Experimental Procedure

A prototype of the concept was fabricated as shown in Figure 2. It has a total weight of 15.1 kg with dimension: 120 cm × 30 cm × 41 cm. It was tested for functionality with 92, 60, and 45 birds each of different ages: <8 weeks old, 8-52 weeks old, and >52 weeks respectively. For each set of birds, the hopper was filled with 20 kg of poultry feeds-growers mash, broiler starter, and layers mash according to the age of the birds under test; thereafter the appropriate trough height and hopper aperture adjustments (C_{a1}, C_{a2} or C_{a3}) were made. Each bird category was allowed to feed for a total of 175 minutes for each aperture adjustment with stopwatch



Note: A = Trough; B = Hopper; C = Separating board; D = Lid cover; E = Lid holder; F = Aperture adjuster; G = Adjuster holder; H = Hopper support; I = Helical spring; J = Spout seal; K = End shield.

Figure 2 Design concept of the self-metering feeder readings at five minutes intervals. The numbers of birds pecking at a time, the weight of feed remaining in the trough and in the hopper were also measured and recorded. The quantity of feed falling from the hopper was calculated. The experiment was replicated three times.

4 Results and Discussion

The following are some of the results of the tests carried out.

4.1 Pecking force over time for different apertures

The effect of feeding time on the pecking force of the different groups of birds is illustrated in Figure 3 by polynomial regression functions. The figure generally shows that the higher the hopper aperture, the higher the pecking force for all categories of birds. This could be because at the initial time, the birds were hungry and pecked with some intensity. As time went on, they got filled and some may decide to leave. This lowers the pecking force on the feeding trough. When the birds come back the pecking force increases. It can also be observed that for the three age categories of the birds, the pecking force was consistently lower with the smallest aperture, C_{a1} and highest with aperture, C_{a3}. This is because with the smallest aperture setting C_{a1}, less quantity of feed fills up the feeding trough (from the hopper) which does not encourage the birds to peck more (irrespective of their number and length of pecking time) in order to activate the helical spring that opens the hopper seal, thus less pecking force on the feeding trough. While for increased aperture C_{a3}, more quantity of feed drops from the hopper into the feeding trough. This makes the birds to peck more (and probably faster) on the feeder in order to allow for more feed into the feeding trough from the hopper, thereby increasing the pecking force on the feeder.

For the <8 weeks old birds, their pecking force polynomial regression models are given in Equations (5)-(7).

$$F_{<8\ (Ca1)} = 2E\text{–}06T^4 - 0.0002T^3 + 0.0069T^2 + 0.0146T - 0.1218 \quad (R^2=0.9155) \tag{5}$$

$$F_{<8\ (Ca2)} = 1E\text{–}07T^4 + 9E\text{–}05T^3 - 0.0115T^2 + 0.4417T - 1.5364 \quad (R^2=0.9485) \tag{6}$$

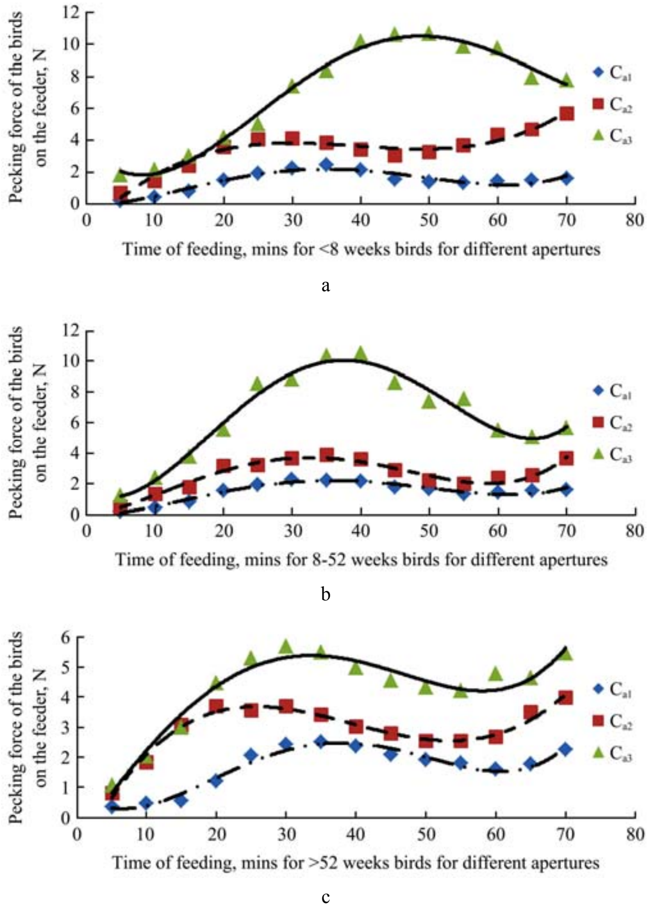


Figure 3 Effect of feeding time on the pecking force of different bird groups

$$F_{<8\ (Ca3)} = 4E\text{–}06T^4 - 0.0007T^3 + 0.0375T^2 + 0.4818T + 3.6218 \quad (R^2=0.988) \tag{7}$$

This category of birds consistently exerted more pecking force on the feeder for the three different aperture openings. The maximum pecking force of 11 N was observed after 50 minutes of the feeding time for aperture C_{a1}, followed by C_{a2} and C_{a3} at feeding times of 30 and 35 minutes respectively. This implies that at the lowest aperture opening, more frequent pecking force was exerted for a longer time (50 minutes) than the other two higher apertures.

For 8-52 weeks old birds, their pecking force polynomial functions are given in Equations (8)-(10).

$$F_{8\text{-}52(Ca1)} = 2E\text{–}06T^4 - 0.0002T^3 + 0.0068T^2 + 0.0144T - 0.0872 \quad (R^2=0.9546) \tag{8}$$

$$F_{8\text{-}52(Ca2)} = 3E\text{–}06T^4 - 0.0003T^3 + 0.0093T^2 + 0.0732T - 0.1037 \quad (R^2=0.9566) \tag{9}$$

$$F_{8\text{-}52(Ca3)} = 2E\text{–}06T^4 - 0.0002T^3 + 0.0431T^2 + 0.2646T + 1.5486 \quad (R^2=0.9709) \tag{10}$$

The maximum and minimum pecking forces of about 10 N and 4.2 N were obtained at 35 and 65 minutes of the feeding time respectively for aperture C_{a3}. For apertures C_{a1} and C_{a2}, the birds exerted a relatively low pecking forces of about 1.8 N and 3.8 N on the feeding trough at 30 and 35 minutes respectively. This indicates that the pecking force increases with increase aperture size and decreases with feeding time.

For >52 weeks old birds, their pecking force polynomial functions are given in Equations (11)-(13).

$$F_{>8\,(Ca1)} = 3E\text{–}06T^4 - 0.0004T^3 + 0.016T^2 - 0.1607T + 0.7629 \quad (R^2 = 0.9630) \qquad (11)$$

$$F_{>8\,(Ca2)} = 2E\text{–}07T^4 + 0.0001T^3 - 0.0144T^2 + 0.4801T - 1.3916 \quad (R^2 = 0.9734) \qquad (12)$$

$$F_{>8(Ca3)} = 2E\text{–}06T^4 - 0.0002T^3 + 0.01T^2 + 0.3225T - 0.7513 \quad (R^2 = 0.9554) \qquad (13)$$

The pecking force for these older birds peaked at 30 minutes feeding time with the smallest aperture opening. For apertures C_{a1} and C_{a2}, the maximum peck forces are 2.5 N and 3.5 N respectively. This generally implies that the >52 weeks old birds have relatively lower pecking force on the feeding trough per unit feeding time for all the aperture openings when compared to other bird categories. This could be explained by their low feeding vigor, poor ability to convert feed to either meat or egg and also the number of birds pecking at a time.

4.2 Feed consumption of birds over time for different apertures

The quantity of feed consumed by the birds was observed to decrease with feeding time as shown in Figure 4 for the three bird ages and apertures. The trend was explained using the power function with the exponents ranging from –0.965 to –0.629 and coefficients of correlation, R^2 ranging from 0.9424 to 0.9886.

The power regression models for the effect of feeding time on the quantity of feed eaten by the birds for the different apertures are given in Equations (14)-(22).

$$Q_{<8(Ca1)} = 1.4843T^{-0.677} \quad (R^2 = 0.9687) \qquad (14)$$

$$Q_{<8(Ca2)} = 3.509T^{-0.869} \quad (R^2 = 0.9491) \qquad (15)$$

$$Q_{<8(Ca3)} = 1.4232T^{-0.629} \quad (R^2 = 0.9886) \qquad (16)$$

$$Q_{<8\text{-}52(Ca1)} = 2.6543T^{-0.839} \quad (R^2 = 0.9515) \qquad (17)$$

$$Q_{<8\text{-}52(Ca2)} = 3.6622T^{-0.892} \quad (R^2 = 0.9494) \qquad (18)$$

$$Q_{<8\text{-}52(Ca3)} = 5.7230T^{-0.965} \quad (R^2 = 0.9424) \qquad (19)$$

$$Q_{>52(Ca1)} = 2.7157T^{-0.836} \quad (R^2 = 0.9705) \qquad (20)$$

$$Q_{>52(Ca2)} = 2.4681T^{-0.751} \quad (R^2 = 0.9479) \qquad (21)$$

$$Q_{>52(Ca3)} = 2.3278T^{-0.753} \quad (R^2 = 0.9825) \qquad (22)$$

From Figure 4, it is obvious that feeder activity decreased with time as the birds by their pecking action are taking in less feed as they are getting filled up with the attendant feeling of satiety (Asoegwu and Obasi, 1989). Adene and Oguntade (2006) had reported that hens use less than an hour a day to eat sufficient food. So as the hour time drew near, the quantity of feed taken by the birds reduced.

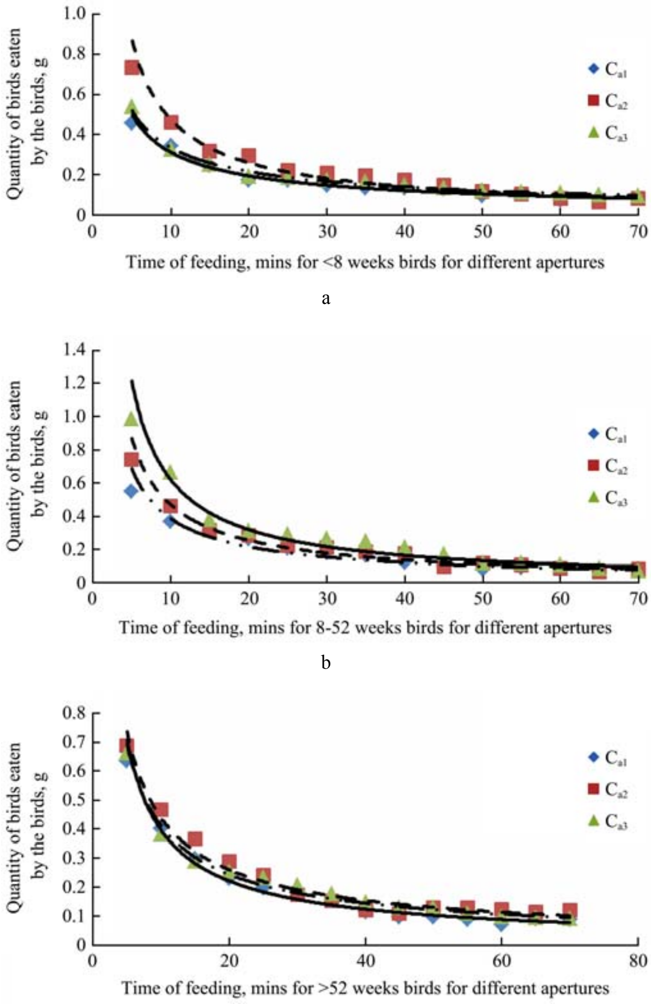


Figure 4 Effect of feeding time on the quantity of feed eaten by the birds for all apertures

5 Conclusion

The principles of pecking force analysis of a self-metering poultry feeder for different kinds of poultry birds of different ages was conceptualized through the pecking action of birds, helical spring reaction and the number of birds pecking per unit time. Mathematical expressions, logical assumptions, graphical relations and models as well as statistical analyses were adopted in the pecking force analysis and results were obtained using polynomial and power functions. High R^2-values obtained (0.9155-0.9880) illustrate high degree of correlation of pecking force parameters with different aperture openings as well as feed consumption over time. Experimental results show that the level of satiety and bird vigor determine the amount of pecking force obtained as described by the polynomial function. For the three categories of birds, the pecking force was consistently lower with the smallest aperture C_{a1} and highest with aperture C_{a3}.

The quantity of feed from the hopper consumed by the birds as described by the power function varies inversely with feeding time for the three ages of birds. It may be said to have a direct relationship with the pecking force since through their pecking action they take in less feed as they get filled up, thus gross reduction in quantity of feed eaten. The coefficient of correlation (R^2) also varies from 0.9424 to 0.9886 showing high correlation with feeding time. High quantity of feed was consumed by all the birds' category in the first 50 minutes of their pecking action. Beyond this time, high attendant feeling of satiety was observed.

Generally, the feeder was able to feed more than 90 chicks (0-8 weeks old) and more than 40 adult birds (8-52 weeks old) with 20-25 kg of feed in the hopper. Apertures C_{a1} and C_{a2} result in the lowest and highest feed drop from the hopper between 25-35 minutes and 55-70 minutes for the youngest chicks respectively; whilst aperture C_{a3} and C_{a1} gave the highest and lowest feed drop at 21-22 minutes and 61-63 minutes respectively for 8-52 weeks old birds. For the oldest birds, C_{a3} and C_{a2} had equal feed drop. All these were attributed to birds' age, number, vigor and pecking force.

References

Adene, D. F., and A. E. Oguntade. 2006. Nigeria: poultry sector country review. Available at: ftp://ftp.fao.org/docrep/fao/011/ai352e/ai352e00.pdf. Accessed 5 October 2016.

Arulogun, O. T., O. M. Olaniyi, O. A. Eke, and D. O. Fenwa. 2010. Development of mobile intelligent poultry feed dispensing system. *Journal of Engineering and Applied Sciences*, 5(3): 229–233.

Asoegwu, S. N., and. A. U. Obasi. 1989. Analysis of self-metering poultry feeder. In *13th Annual Conference of the Nigerian Society of Agricultural Engineers*, Pp. 34-38. Samaru, Zaria, 26-29 September.

David, A. M. 2004. Nigeria's poultry market: can it come back? USDA Foreign Agricultural Service. Available at: http://www.fas.usda.gov/info/agexporter/1998/August%201998/nigerias.html. Accessed 17 December, 2001.

Dennis, R. L., and H. W. Cheng. 2010. Effects of beak trimming on pecking force. *International Journal of Poultry Science*, 9(9): 863–866.

Fanatico, A. 2003. Feeding chicks for best health and performance. A National Center for Appropriate Technology (NCAT) contribution to The Poultry Site (Free Range Production Featured Articles).

Geoffrey, E. 1993. *Home Poultry Keeping*. Canada, E. P. Publishers Ltd.

Gueye, E. F. 2007. Evaluation of the impact of HPAI on family poultry production in Africa. *World's Poultry Science Journal*, 63(3): 391–400.

Killebrew, K., and R. Plotnick. 2010. Poultry market in West Africa: Nigeria. *Evans School Policy Analysis and Research Group (EPAR) Brief*, 87: 1–2.

Kooloos, J. G. M., and G. A. Zweers. 1991. Integration of pecking, filter feeding and drinking mechanisms in waterfowl. *Acta Biotheoretica*, 39(2): 107–140.

Nesheim, M. C., R. E. Austic, and L. E. Card. 1999. *Poultry Production*. 12th Ed. Philadelphia: Lea and Febiger.

Olaniyi, O. M., A. F. Salami, O. O. Adewumi, and O. S. Ajibola. 2014. Design of an intelligent poultry feed and water dispensing system using fuzzy logic control technique. *Control Theory and Informatics*, 4(9): 61–72.

Prabakaran, R. 2003. *Good Practices in Planning and Management of Integrated Commercial Poultry Production in South Asia*. FAO publishing House, Rome, Italy. Animal Production & Health Paper (FAO).

Sahel Report. 2016. An assessment of the Nigerian poultry sector. Available at: http://www.sahelcp.com/files/Sahel%20Newsletter,%20Volume%2011.pdf. Assessed 22 October 2016.