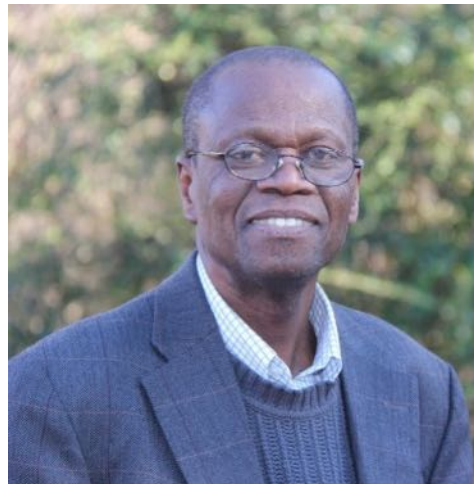


YAIKUULA (WIND-DRIVEN EVAPORATIVE COOLING) SAVES MOST GUINEA FOWL EGGS FOR HATCHING IN THE SUDANO-SAHELIAN BELT

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ABSTRACT

Guinea fowl meat and eggs are highly prized by consumers in the Sudan-Saharan belt countries such as Burkina Faso and Niger. However, compared to chicken, guinea fowl stocks in these countries are low. One of the reasons for the low stock holdings is that guinea fowl in captivity are poor at being broody hens. They do not sit on their eggs for the hatching of their keets. This problem has been addressed using synchronized surrogate chicken hens for brooding. Many chicken hens are provided with dummy eggs until they begin to brood, at which time the dummy eggs are switched to fertile guinea fowl eggs. The challenge with this solution is storing the guinea fowl eggs at room or ambient temperatures until the surrogate brooders are ready. The high room temperatures during storage initiates pre-embryo development that results in hatching unhealthy keets. Refrigerated storage is not an option, as most smallholder farmers in rural settings do not have access to electricity. The purpose of this study was to address the storage problem by introducing wind-driven evaporative cooling (YaiKuula); "Yai" is a Swahili word for "egg." YaiKuula lowers the storage temperature ~15°C below ambient temperature during the day. Viable guinea fowl eggs were stored using YaiKuula for 0-3, 4-7, and 8-14 days. Ambient temperature and refrigerated (8°C) storage were done in parallel as negative and positive controls, respectively. Twenty-four surrogate brooders with six eggs each were used to hatch the stored eggs. Early and late embryo mortality, in addition to healthy hatching were monitored. The Student's t-test was used to compare results. The highest rate ($p < 0.05$) of early embryonic mortality (65%) was obtained with refrigerated storage for 8-14 days versus 37 and 12%, respectively, for ambient and YaiKuula storage for the same length of time. The hatching rates of eggs from 0-3 days of storage showed no significant difference between the three storage methods. However, YaiKuula storage yielded significantly ($p < 0.05$) higher hatching rates of 80% versus 37 and 22% from ambient and refrigeration storage at 8-14 days, respectively, and 84% versus 65 and 61% for ambient and refrigeration storage at 4-7 days, respectively. YaiKuula has the potential to increase the number of guinea fowl among smallholder poultry farmers for increased incomes/resilience and better nutrition.

Key words: *Numida meleagris*, evaporative cooling, wind energy, Rakai chicken model



INTRODUCTION

Increasing the scale of poultry farming among the rural poor (smallholder farmers), coupled with education to encourage incorporating eggs and poultry meat into household diets, especially for children and their mothers, can be a potent contributor to preventing the endemic stunting problem throughout sub-Saharan Africa [1]. Poultry farming/keeping is often considered an activity for women in these communities [2]. In addition, in low-resource households poultry are often the most commonly owned livestock compared to larger animals [3]. For example, in a study done more than a decade ago, the average number of birds per household in Burkina Faso ranged between one and 50, with only 5% of the farmers having more than 50 birds [4]. In a Niger study, the representative flock size for chickens was one rooster, six hens and 35 young hens with 16 less than a month old, whereas, for guinea fowl, the representative flock was two young birds and 22 females [5]. In both countries, chickens predominate, followed by guinea fowl. For example, chicken and guinea fowl were 79 and 18%, respectively, of all poultry inventory in Niger [5].

There is interest in increasing guinea fowl flock size among rural and peri-urban smallholder farmers in the Sudan-Saharan belt countries for several reasons. First, compared to chicken, guinea fowl have a greater resistance to poultry diseases such as Newcastle disease and fowl pox [6], which should make the farmers less vulnerable to poultry diseases and as such more resilient. Second, in comparison to chicken, guinea fowl provide more protein (23% versus 21% and lower fat content (4% versus 7%) for their edible meat [7]. If local food security is met, this might spur the production of guinea fowl as an alternative for export not only to other African countries, but also to developed countries like France [8]. Third, compared to chicken, guinea fowl have a higher cultural standing/significance in the Sudan-Saharan belt countries; the bird and its products are given to important visitors like in-laws and as part payment of dowries in most parts of West Africa. The feathers are used in making pillows and for aesthetic purposes, such as decorations in homes, restaurants and hotels [9]. As such, guinea fowl meat or live birds sell for a higher price. Fourth, compared to chicken, guinea fowl control insects and pests better when managed using free-range systems [10].

With the comparative benefits of guinea fowl outlined above, why is the guinea fowl population in the belt countries $\leq 25\%$ of the chicken populations? There are three main reasons. First, guinea fowl hens in captivity are not good as "broody hens"; they do not sit (incubate) their eggs well to hatch keets. Typically, hatching and brooding of guinea fowl eggs is accomplished using local chicken hens as



surrogates [11]. This limits the keet productivity. Second, in the most common free-range husbandry system, the survival rate of keets to adult birds is low – mortality figures range from 63 to 80% during the first 10 weeks [12]. The keets are vulnerable to adverse weather conditions and predation. Third, due to lack of feed availability during the dry season, guinea fowl lay few if any eggs. Eggs are only laid during the wet season, limiting overall productivity [10].

The first attempt to address the “broody hen” problem was to design a solar-powered incubator that could be manufactured locally [13, 14]. The first incubator prototypes achieved total hatchability rates (average of 85%) [13]. However, during the dry season, when room temperatures are $>25^{\circ}\text{C}$, the incubator was inoperable. The incubator uses an on/off mechanism to control the temperature. To be able to operate at higher ambient temperatures, a source of cold air would be needed. Adding a source of cold air would raise capital costs beyond an acceptable price point. In the incubator usability studies, it was observed that egg storage was a second problem resulting in unacceptable hatchability rates [13]. While waiting to fully load the incubators (with a capacity of 90 guinea fowl eggs), farmers would store their eggs at room temperature. With high temperatures in Burkina Faso, the eggs would undergo pre-mature embryo development, resulting in “early mortality” embryos at the end of the incubation.

To address this problem, the incubator was replaced with the synchronized hatching of guinea fowl eggs by many surrogate brooder chicken hens, the so-called Rakai Chicken Model [15], which has been successfully implemented in Uganda [15]. The incubator capacity of 180 eggs was easily met with 10 hens, each sitting on ~18 guinea fowl eggs. The synchronization was achieved by placing fake plastic eggs under each hen, in nest boxes, and switching to viable eggs when the right number of hens simultaneously started brooding. Many keets are produced at once, leading to greater labor efficiency and lower-cost for the keets. The brooding hens controlled the incubation temperature naturally. To address the egg storage problem, a low-cost evaporative cooler based on the successful EvaKuula for milk freshness preservation [16, 17, 18], branded the “YaiKuula” was introduced. YaiKuula is a smaller version of the EvaKuula and both can be locally made, following simple engineering drawings. The objective of the study was to characterize the impact of the YaiKuula with respect to guinea fowl egg hatchability.



MATERIALS AND METHODS

YaiKuula Design

YaiKuula is a smaller version (quarter scale) of the evaporative cooling component of the EvaKuula, designed for milk freshness preservation and previously described in detail [17]. The YaiKuula is specifically configured for egg cooling and is made up of nine major components, as shown in Figure 1.



Figure 1: Wind-operated YaiKuula design

Top left (a): 1) Wind-operated suction fan and its bearing; 2) Water tank; 3) Cover on which the suction fan/bearing are fixed; 4) Egg trays; 5) Inside water trough; 6) Cooler chamber (90 cm high x 45 cm wide x 45 cm long); 7) Outside water collection trough; 8) Jute padding; and 9) Pipe work for water circuitry

Top right (b): A picture showing the inside of the cooling chamber with eggs stacked on plastic trays

Bottom (c): The YaiKuula version fabricated locally in Burkina Faso

Yai is a Swahili word for egg. The projected capacity of the YaiKuula is ~200 eggs. Briefly, the principle of operation is the so-called wet bulb temperature process, according to well-established thermodynamics principles. The jute is continuously kept wet by water dripping from the water tank. The suction fan is wind operated and sucks air through the wet jute material. The heat of evaporation is derived from inside the cooling chamber containing the eggs. As a result, the temperature in the cooling chamber drops below the ambient temperature. An inside water trough is added to serve as a “flywheel” to minimize temperature fluctuation that may result in changes in suction from differences in rotational speeds. The design has been optimized to yield a temperature drop between 10 and 15°C during the day when high ambient temperatures occur. It was hypothesized that this temperature drop should be sufficient to preserve the viability of guinea fowl eggs while in storage, waiting to accumulate enough to start synchronized hatching with surrogate brooder chicken hens.

Time-Temperature Profile

YaiKuula performance characterization was done with a load (eggs) and no load (no eggs). For the no load experiments, six empty plastic egg trays were loaded into the cooling chamber. Temperatures were recorded with thermocouples (Type K, Omega, Norwalk, CT) connected to a data logger (Gain Express AZ Instruments, Houston, Texas, USA). Four thermocouples were used. The first thermocouple was located in the cooling chamber center at the bottom of the empty egg trays. The second thermocouple was placed in the middle of the six egg trays, and the third thermocouple was placed on top of the six egg trays. A fourth thermocouple was located outside of the YaiKuula to record the outside ambient temperature. The measurements were obtained every 30 min for a 24-hr period. The no-load experiment was done in December, when high temperature fluctuations between day and night temperatures are common in Burkina Faso. For the experiment with eggs, the same thermocouple placings were implemented, with the exception of the ambient temperature measurement. The ambient/room temperature in this case was placed in the middle of six trays of eggs stored in a ventilated room.

The fourth thermocouple with eggs was placed in the middle of the six loaded egg trays. The domestic refrigerator storage temperature was obtained in a similar way with one thermocouple placed in the center of the storage egg trays. The refrigerator was located under a shed.



Egg Storage and Hatchability Experimental Designs

The guinea fowl (*Numida meleagris*) stock for producing fertile eggs comprised 108 females and 36 males. All the birds were housed in a large room with nests for egg laying. Eggs were collected daily. Eggs produced by guinea fowls were stored using three conditions, including the YaiKuula, domestic refrigerator (Compound Brand, ~8°C), and ambient temperature. Three storage times were implemented. The shortest storage was 0-3 days. Medium storage was 4-7 days, and the longest storage was 8-14 days. The choice of days for each storage period was based on an estimate of the time it takes different typical guinea fowl farmers with different stock sizes to accumulate enough eggs before implementing synchronized hatching by surrogate brooder chicken hens. More details of the experimental set-up are provided in Table 1. The storage experiment was done from March to June 2020. The data plotted was generated by first averaging the three temperature measurements from the YaiKuula cooling chamber, every 30 min (by hand). Second, the daily minimum and maximum temperatures were obtained. The data plotted for the YaiKuula is the average of the minimum and maximum temperatures of the day. One thermocouple was used each for the refrigerator and the room/ambient temperature and the data plotted for these two storage spaces are the averages of the maximum and minimum for each day. The surrogate chicken brooder (*Gallus domesticus*, age and breed unknown) flock was composed of 50 hens and five roosters. The chicken housing was fitted with enough nests to accommodate all the hens. The artificial eggs were made of plastic in the shape of eggs. As in the Rakai chicken model, the birds started brooding on their own, with one bird starting and the rest following until the whole flock was broody. Twenty-four surrogate brooder chicken hens were used for each temperature-storage time combination. Each brooder hen was considered as a replicate, making 24 replicates in total. For all the 24 replicates, $6 \times 24 = 144$ eggs were brooded. Nine days after brooding started, the eggs were candled with an electric bulb and both clear (no growth) and broken eggs were identified. Broken eggs were removed from the experiment, as they could not be classified as clear or fertile. The sum of clear and fertile eggs was used as the denominator and the number of fertile eggs as the numerator to calculate the percentage of fertile eggs. Percentage hatchability was calculated with the number of eggs hatched as the numerator and the number of fertile eggs as the denominator. Published procedures were followed to determine early and late embryo mortality [19, 20]. Briefly, eggs were candled 15 days after the commencement of brooding to determine early embryo mortality. To determine late embryo mortality, eggs were candled after 24 and 31 days of brooding. Microsoft Excel software (2013 version, Microsoft, Seattle, Washington, USA) was used for data entry, calculations and making of graphics. MINITAB statistical software (version 16, Minitab, State



College, Pennsylvania, USA) was used for basic descriptive analysis. ANOVA was then done using the GLM procedure and pairwise comparisons of means were done using Tukey test for post-hoc analysis at the 95% confidence interval.

RESULTS AND DISCUSSION

The cost of fabricating the YaiKuula in Burkina Faso is shown in Table 2. However, this is the cost of fabricating a single unit. It is reasonable to assume that by combining value-engineering (optimizing the design from a fabricating viewpoint) and fabricating 50 or more units at the same time, the fabrication cost can be reduced to between 40 and 50% of the current total. This is based on the authors' experience with a related product (the EvaKuula) made in Uganda. For example, the minimum purchase for the 10/10 sheet was half a sheet, yet the whole half a sheet was used for the one unit. Also, procuring materials in larger quantities from primary suppliers would eliminate additional costs incurred through sourcing from secondary retailers. At the projected pricing, financing the YaiKuula by a local manufacturer or a microcredit entity will facilitate technology transfer.

Figure 2 shows a representative time-temperature profile from the four thermocouples, for a 24-hr period, in the absence of eggs. The YaiKuula, met expectations. During the day when the ambient temperature is high, and when premature embryo development is likely to be initiated, the YaiKuula can drop the temperature by as much as 15°C below the ambient temperature. At night, when ambient temperatures are lower, the YaiKuula had single digit temperature drops. Figure 3 shows a representative time-temperature profile with eggs for 48-hr.



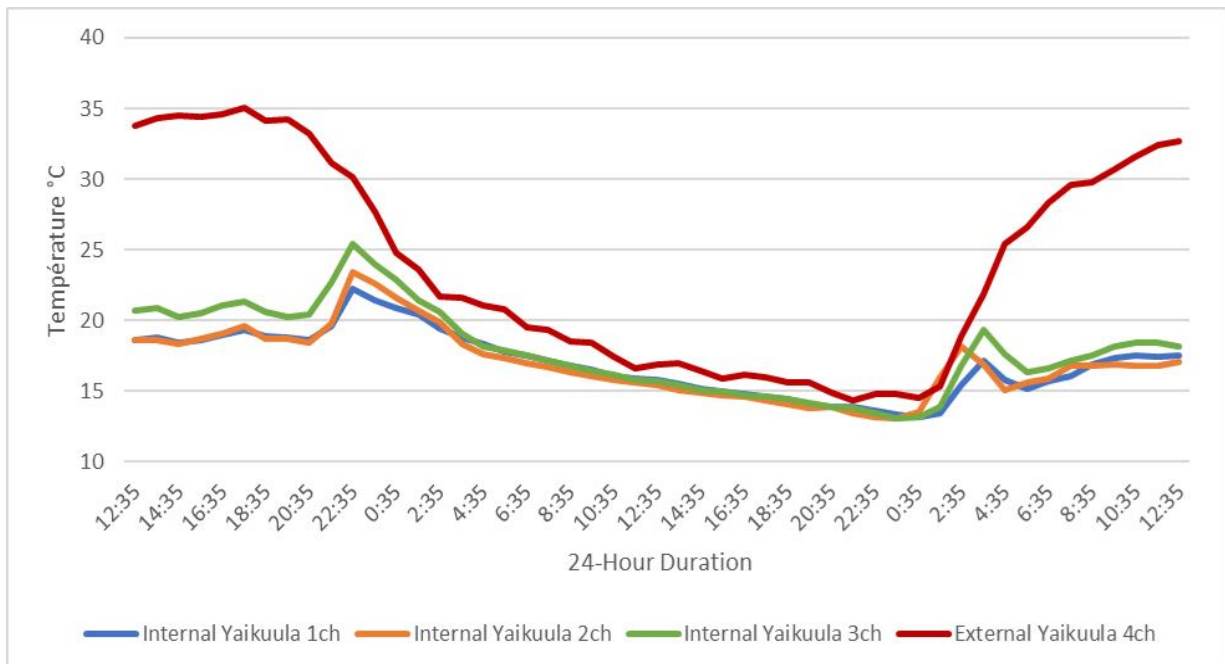


Figure 2: Representative temperature-time profile for YaiKuula cooling chamber temperature (with no eggs) over a 24-hr period. 1ch, 2ch, and 3ch thermocouples were located at the bottom, in the middle and top of six egg trays, respectively, in the cooling chamber. 4ch thermocouple was placed outside the YaiKuula to measure ambient temperature. The first reading was taken at 12:36 pm

Qualitative comparison of the profiles in Figures 2 and 3 show that the presence of eggs had no impact on the temperature-time profiles. Given that broody hen or incubation temperatures range between 35 and 40°C [21], it is understandable why ambient/room temperatures during the day that get in this range (Figures 2 and 3) would trigger embryo development in fertile eggs. The important questions were whether the YaiKuula temperature-time profile was adequate to prevent premature embryo development, and for how long in storage the protection can last.

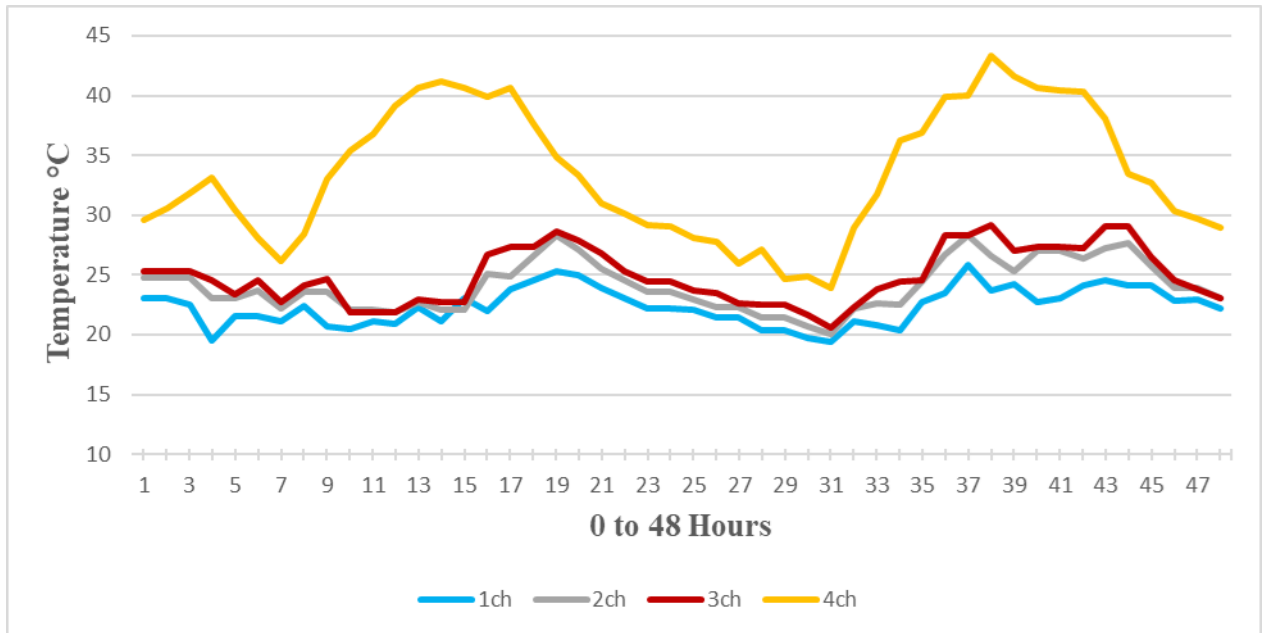


Figure 3: Representative temperature-time profile for YaiKuula cooling chamber temperature with eggs over a 48-hr period. The first reading was taken 30 min after midnight on March 30, 2020. 1ch, 2ch, and 3ch thermocouples were located at the bottom, in the middle and top of six egg trays, respectively, in the cooling chamber. 4ch thermocouple was placed in the middle six egg trays of the room or ambient storage

Figure 4 summarizes the storage temperatures.

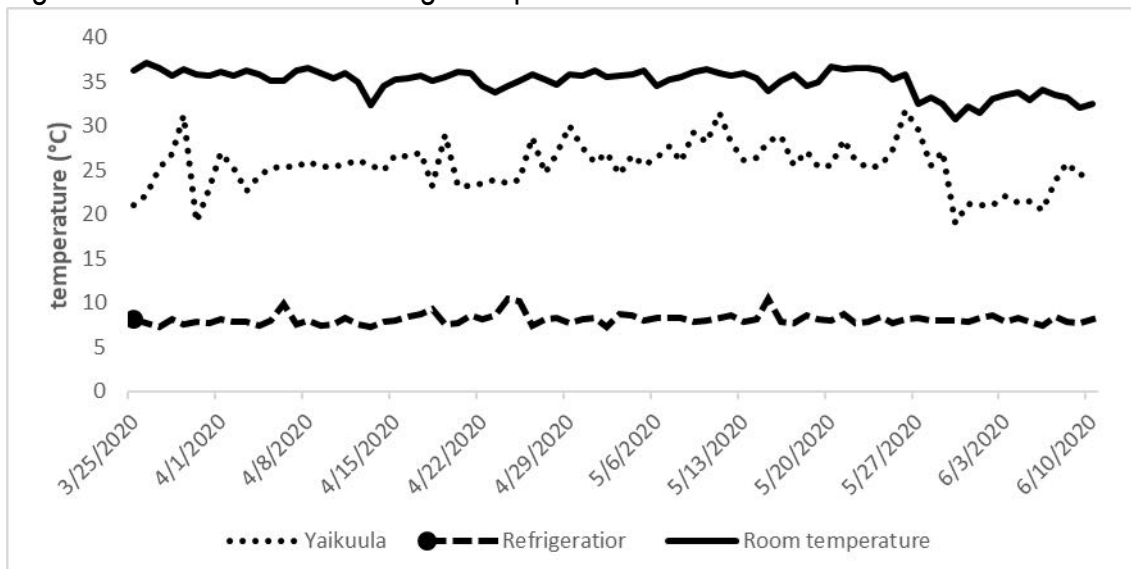


Figure 4: Mean temperatures for the three storage conditions, (•) ambient, (◦) YaiKuula, and (-) domestic refrigerator from March to June 2020

The brooding hens successfully sat on more eggs (18 eggs). The number of eggs were reduced due to limited availability. The average dimensions of the eggs were 4.9 ± 0.2 cm for the length and 3.7 ± 0.2 cm for the largest diameter. The average shape index was 0.76 ± 0.04 and the surface area of the eggs was 53 ± 3 cm². These results are consistent with previous studies [22].

The highest rate ($p < 0.05$) of early embryonic mortality (65.1%) was obtained from the refrigerated storage of eggs aged 8-14 days vs. 36.6 and 11.9%, respectively, for ambient and YaiKuula storage. The weight of the eggs was 38 ± 3 g, and the weight of the newborn guinea fowl or keets was 25 ± 3 g. The highest rate ($p < 0.05$) of late embryonic mortality (28%) was observed at ambient temperature versus 12.1% for refrigerated and 7.6% for YaiKuula storage (Table 3). The reduced embryo mortality in the YaiKuula storage was probably due to the lower storage temperature when compared to storage at room temperature. That probably prevented embryo development but was not too cold along with less possible moisture loss from the eggs (dehydration).

However, the analysis showed no significant difference ($p \geq 0.05$) between the early and late embryonic mortality rates of eggs from 0 to 3 days and from 4 to 7 days of storage. The best hatching rates ($p < 0.05$) for eggs aged 4 to 7 days and 8 to 14 days were with the YaiKuula (83.9 and 80.5%, respectively), followed by ambient temperature storage (65.1 and 37.9%, respectively) and finally refrigerated (61.8 and 22.8%, respectively) (Table 4). The hatching rates of eggs from 0 to 3 days of storage showed no significant difference between the three storage methods. The lack of difference among 0 to 3 days of storage was most likely because embryo development had not started.

Therefore, the YaiKuula was more effective in preserving the viability of fertile eggs before brooding. With ambient temperature storage, the heat evaporates water also resulting in egg dehydration. Inside the YaiKuula the humidity is continuously high, due to the continuously wetted jute surrounding the cooling chamber and the inside water trough. Unfortunately, humidity was not monitored in this study. The role of humidity in viable egg storage needs further investigation.

While the YaiKuula may be beneficial in improving the guinea fowl meat/egg value chain by removing hatchability bottlenecks, the other factor that needs to be addressed is access to feed. In a complementary study, the use of house fly larvae as a protein source in guinea fowl feed formulations [under review] obtained promising results. However, increasing guinea fowl meat and egg production does not guarantee an increase in consumption by women and children in the producing



households. Complimentary outreach programs to increase the nutritional knowledge and awareness of mothers is essential [23]. In a baseline study of nutritional and income allocation [24], mothers expressed interest in improving the socio-economic standing of their households. Expanded guinea fowl husbandry through integration of the three practices of house fly larva production for feed, synchronized surrogate chicken hen hatching of keets, and use of the YaiKuula for egg storage may be a means to improve the socio-economic and nutritional wellbeing of households.

ACKNOWLEDGEMENTS

The authors acknowledge funding through a subcontract (UFDSP00012175) from the University of Florida Livestock Systems Innovations Laboratory USAID Grant (AID-OAA-15-003). The work in this study was done with human subjects (IRB ID: PROJECT00000350) and animal use (Assurance #: D16-00276/A3437) approvals from the University of Georgia Institutional Review Board. Parallel approvals in Burkina Faso were obtained from the Avis de La Commission (Code Agreement #: CE-U01/2019-03).



Table 1: Experimental design/set-up

Storage time and temperature	0-3 days after laying	4-7 days after laying	8-14 days after laying
“Positive control” - Stored at 8°C in a domestic electric refrigerator	24 incubating chicken hens, 6 eggs each	24 incubating chicken hens, 6 eggs each	24 incubating chicken hens, 6 eggs each
“Experimental” - Stored in an evaporative cooler which maintains ~14°C below room temperature	24 incubating chicken hens, 6 eggs each	24 incubating chicken hens, 6 eggs each	24 incubating chicken hens, 6 eggs each
“Negative control” – Stored at room temperature (30 - 37°C)	24 incubating chicken hens, 6 eggs each	24 incubating chicken hens, 6 eggs each	24 incubating chicken hens, 6 eggs each

Table 2: Cost breakdown of the locally made YaiKuula

<u>Material</u>	Quantity	Unit cost (FCFA)#	Total (FCFA)	Total USD
5/10 mm aluminum-zinc sheet, 1.2 x 2.4 m	2	7,500	15,000	27
Tubes of 40 x 40 mm (5 bar capacity)	8	11,000	88,000	160
Tube of 20 x 20 mm (1 bar capacity)	1	4,000	4,000	7
Steel sheet 10/10 mm, 1.2 x 2.4 m.	0.5	15,000	7,500	14
Polypropylene random (PPR) water tubing 32 mm in diameter and plumbing supplies	1	10,000	10,000	18
Jute padding (set of 4 used bags)	1	4,000	4,000	7
Tin of paint (1 kg)	2	2,500	5,000	9
Plastic egg trays	15	50	750	1
Inside plastic water tough (see Figure 1)	1	2,000	2,000	4
Plastic water tank (250 L) and support	1	5,000	5,000	9
Miscellaneous (steel bars, cost for electricity, etc.)	1	65,000	65,000	118
Labor (~30 people-hr)	1	75,000	75,000	136
TOTAL			281,250	511

#Conversion rate: 1 US\$ = 550 Francs of the African Financial Community (FCFA)



Table 3: Effect of storage time on early and late embryonic mortality*

	Refrigerator (%)		Ambient temperature (%)		YaiKuula (%)	
	Early embryonic mortality	Late embryonic mortality	Early embryonic mortality	Late embryonic mortality	Early embryonic mortality	Late embryonic mortality
0 - 3 days	16.4 ^a (n=19)	3.5 ^a (n=4)	16.3 ^a (n=18)	4.8 ^a (n=5)	10.1 ^a (n=11)	5.3 ^a (n=7)
4 - 7 days	31.5 ^a (n=32)	6.7 ^a (n=7)	24.9 ^a (n=25)	8.7 ^a (n=9)	9.8 ^a (n=11)	5.3 ^a (n=6)
8-14 days	65.1 ^b (n=59)	12.1 ^a (n=12)	36.6 ^b (n=41)	28.0 ^b (n=34)	11.9 ^a (n=13)	7.7 ^a (n=9)

*Any two means with different superscripts in the same column are significantly different

Table 4: Effect of storage time on hatchability*

	Refrigerator (%)		Ambient temperature (%)		YaiKuula (%)	
	Fertility	Hatchability	Fertility	Hatchability	Fertility	Hatchability
0 - 3 days	83.6 ^b (n=115)	78.2 ^b (n=90)	79.0 ^a (n=111)	78.9 ^c (n=88)	81.4 ^a (n=113)	84.7 ^a (n=95)
4 - 7 days	74.7 ^{ab} (n=98)	61.8 ^b (n=59)	77.6 ^a (n=101)	65.1 ^b (n=66)	79.4 ^a (n=106)	83.9 ^a (n=88)
8 - 14 days	66.9 ^a (n=87)	22.8 ^a (n=16)	82.9 ^a (n=115)	37.1 ^a (n=42)	75.7 ^a (n=102)	80.6 ^a (n=80)

*Any two means with different superscripts in the same column are significantly different



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