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Borassus Aethiopum Ripe Fruits' Dried Pulp Powder Optimum Incorporation Rate in White Corn-Based Diets for Egg Yolk Colouration

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Abstract: The study assessed the optimum incorporation rate of *Borassus aethiopum* (*Ba*) ripe fruits' dried pulp in laying hens' feed. So, 72 Isa Brown laying hens of 37-week-old were allotted into 9 groups of 8 hens each. Then, 3 control diets including 60% yellow corn (60%YC), 55.2% yellow corn (55.2%YC) and 60% white corn (60%WC) were formulated. Additionally, 6 test diets were made by substituting 5%; 7.5%; 10%; 12.5% and 15% of 60%WC by *Ba* ripe fruits' dried pulp. Then, randomly each hens' group received one diet. The experiment lasted 90 days, week-39 - week-50. Each day, the eggs were weighed, and each week 3 eggs of similar weight were used per diet for analyses. So, the eggs shell, yolk, and albumen were weighed. Moreover, yolk colours were assessed according to their components L*, a* and b*. Finally, yolks total cholesterol contents were determined. In results, the laying rates fluctuated between 60.86±1.9% for 60%WC and 76.19±2.69% for WC+12.5%*Ba*, and egg weights fluctuated between 57.71±0.30 and 61.63±0.22 g, within 4 groups ($p<0.001$). Although WC+12.5%*Ba* generated the weightless yolks for 14.31±0.2 g compared to 15.14±0.14 for 55.2%YC, its yolks were well coloured. Also, yolk yellowness (b*) revealed 2 groups, and the good was from 60%YC, and 55.2%YC for 153.94±3.27 and 140.28±3.27, respectively ($p=0.07$). In the second group, WC+12.5%*Ba* got 90.17±5.17, and the colour was visually good. Finally, looking at the egg yolks total cholesterols contents, 55.2%YC got 30.90±1.47 mg/g, and WC+12.5%*Ba* exhibited 34.71±3.19 mg/g ($p=0.838$). To conclude, WC+12.5%*Ba* was the best incorporation rate.

Keywords: *Borassus Aethiopum*, Egg Yolk, L* a* b*, Isa Brown Layers, Total Cholesterol

1. Introduction

Poultry production is an essential resource in the animal production system in Côte d'Ivoire. Indeed, poultry farming has experienced a spectacular boom compared to that of red meat [1]. Alongside, the poultry production evolution has increased the need for raw materials such as yellow corn. Because yellow corn is used as a source of energy and natural pigments for egg yolks colouring. In fact, the egg yolk colour plays an important role in their quality perception. Especially, egg yolk colour is an important factor for consumers. Of course, egg yolk colouring is linked to carotenoids presence in the hens' diets [2]. Truly, hens are unable to synthesize the pigments deposited in the egg yolk, so these carotenoids are provided by feed intake [3, 4]. In hens, egg yolk colouring effectiveness varies according to the type of carotenoid. Admittedly, egg yolk colour is influenced by intestinal absorption, plasma transfer, tissue export efficiency and carotenoid degradation metabolism [5]. Thus, the corn is subject of direct competition between human and poultry nutrition. Then, it becomes useful to promote non-conventional alternative feed resources, which are little or not used for animal feed. Better still, their exploitation is experiencing renewed interest due to the increase in raw material prices, and the recent food crises linked with Ukraine-Russia crisis and wheat deliveries on international market, since February 2022.

Natural pigments other than that from yellow corn are increasingly used [6]. For this purpose, carrots (*Daucus carota*), yellow peppers (*Capsicum annum*), orange peels (*Citrus sinensis*), marigold flowers (*Calandula officinalis*) and many other carotenoid-rich fruits are used as feed additives for laying hens to improve egg yolk quality [6, 7]. Among these feed resources, *Borassus aethiopum* ripe fruits, whose weight varies between 1.3 kg and 1.5 kg, even more, can be considered. The ripe fruit dried pulp that would be eaten by poultry would improve productivity, and eggs' nutritional quality for consumption [8-10]. So, it was hypothesized that increasing *Borassus aethiopum* ripe fruits' dried pulp incorporation levels in laying hen diets would influence egg yolk colouration and total cholesterol content. Thus, the study objectives were to evaluate the effectiveness of *Borassus aethiopum* ripe fruits' dried pulp increasing doses effect on hens' laying rate, eggs' weights, egg yolk weights, egg yolk colouration, and their total cholesterol contents.

2. Materials and Methods

2.1. Study Area

From December 2022 to February 2023, the study was carried out at the graduate school of agriculture production farm, at National Polytechnic Institute Félix Houphouët Boigny (INP-HB) in Yamoussoukro. The climate is characterized by a dry season from November to March, and a rainy season from April to October, marked by two peaks in June and September. Yamoussoukro geographical coordinates are 6°49'13" from the North latitude and 5°16'36" from the West longitude.

2.2. Experiment and Experimental Diets

Seventy-two hens (72) of 37 weeks-old, weighing 1699.79±179.74 g on average, were used. They were weighed to constitute homogeneous groups, selected from a large flock of 180 hens. Thus, 9 groups were made up of 8 hens each. The birds were housed on a woody platform, at 50 cm above the ground. Each cage measured 2m×1m, thus the housing density was 4 laying hens per square meter. So, the sanitary prophylaxis was ameliorated because most droppings were falling on the ground where some wood chips were spread. Moreover, each cage was fully covered with a fishing net. The overall equipment was well aerated.

Also, diets were made with ingredients such as fishmeal, eggshell flour, soybean meal, wheat bran and a concentrated Nutri-A premix (Table 1). Thereafter, some Borassus aethiopum ripe (Ba) fruits' dried pulp powder was incorporated at varying rates by substituting part of the white corn in the test diets. Indeed, the control diets consisted in one white corn-based (60%WC), and two yellow corn-based (60%YC and 55.2%YC). Finally, the tests diets WC+5%Ba; WC+7.5%Ba; WC+10%Ba, WC+12.5%Ba, and WC+15%Ba were formulated by substituting the white corn by Ba ripe fruits' dried pulp, respectively at 5%; 7.5%; 10%; 12.5% and 15%. After the bromatology analysis, the metabolizable energy was computed [11]. The formulated feed amount served to each hen was 120 g to cover its maintenance and production needs. Moreover, drinking water was served ad libitum, and no lighting program was set. So, the hens had only the daylights, and they could rest during the nights.

2.3. Laying Rate Assessment and Eggs' Weights

Each day, from week-39 to week-50, during 12 consecutive weeks, the eggs were collected. Moreover, they were weighed individually, considering their corresponding diet. Knowing the number of the hens in each cage, the laying rate was computed daily by using equation (1). During these 12 consecutive weeks, we collected 2,805 eggs.

$$Laying\ rate\ (\%) = \frac{Number\ of\ eggs\ collected\ per\ day}{Number\ of\ hens\ in\ the\ cage\ per\ day} * 100\% \quad (1)$$

2.4. Egg Yolks Weights and Colours (L* a* b*)

On the last day of each week, the eggs were weighed. Specifically, the eggs' average weights were computed for each diet [12] (2). Thereafter, the absolute interval between each data and the average was computed for each egg. Finally, the 3 eggs showing the smallest absolute intervals' values between the mean (μ), and each egg weight (x_i) were collected (3). Following, these eggs were broken, and their parts, whose were the egg yolk, the egg albumen, and the eggshell were individually weighed. So, for egg constituents, 3 data were generated per diet, per week. So, for each diet 36 data were collected for egg yolks' weights, colour, and total cholesterol contents.

$$Average\ Eggs'weight = \mu = \frac{1}{n}\sum_{i=1}^{n} x_i \quad (2)$$

$$Absolute\ interval = I = |\mu - x_i| \quad (3)$$

Continuing with N'gatta et al. [12] approach, after the eggs' component weights, egg yolks colour measurements were performed on each egg, using a spectrophotometer (Precise colour reader CS-10, model CHN Spec, Beijing, China). Thus, according to the international colour system [13], fresh egg yolk lightness (L*), redness (a*) and yellowness (b*) were read. The device' light beams were standardized to CIE D65. During the manipulations, the egg yolks were placed in a petri dish for L*, a* and b* values readings.

Table 1. *Experimental diets made of yellow corm, white corn and Borassus aethiopum (Ba) dried pulp.*

Diets	60%WC	60%YC	55.2%YC	WC+5%Ba	WC+7.5%Ba	WC+10%Ba	WC+12.5%Ba	WC+15%Ba
White corn (WC)	60	-	-	55	52.5	50	47.5	45
Yellow corn (YC)	-	60	55.2	-	-	-	-	-
Borassus aethiopum (Ba)	-	-	-	5	7.5	10	12.5	15
Soya meal	12	12	13.5	12	12	12	12	12
Nutri-A premix	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Wheat bran	9.00	9.00	10.30	9.00	9.00	9.00	9.00	9.00
Fish meal	12.5	12.5	13.5	12.5	12.5	12.5	12.5	12.5
Egg shell powder	2.5	2.5	3.5	2.5	2.5	2.5	2.5	2.5
Total	100	100	100	100	100	100	100	100
Analysis data								
Dried matter (%)	96.03	96.32	96.94	96.09	96.62	96.71	96.41	96.61
Ash (%)	8.61	8.60	8.50	9.00	9.12	9.40	9.55	9.65
Fat (%)	4.13	4.67	4.55	5.50	5.62	5.72	5.81	5.90
Crude protein (CP%)	15.08	15.20	15.15	16.15	16.17	16.25	16.32	16.35
Computed data								
Tot_Carb (%)	71.53	71.53	69.55	69.09	68.63	68.32	68.10	69.55
ME (kcal/Kg. DM)	3,380.92	3,379.23	3,399.50	3,399.08	3,393.07	3,391.35	3,391.79	3,380.92
Lysine (%)	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32
Methionine (%)	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63
Meth + Cyst. (%)	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9

Tot_Carb (%): Total carbohydrate percentage; Tot_Carb (%DM) = 100 – [CF (%DM) +CP (% DM)+Ash (% DM)] [11]
Metabolizable Energy, ME (kcal/Kg. DM) = [2.73*CP (%DM) + 8.37*Fat (%DM) +3.6*Tot_Carb (%DM)]×10 [11]

2.5. Eggs' Yolks Total Cholesterol Content

On each egg yolk, total cholesterol contents were assessed following Pasin et al. [14] approach. In detail, 1 g of egg yolk was taken into a beaker to which 9 mL of a 2% NaCl solution was added [14]. The beaker containing the mixture was then placed on a magnetic plate with a bar for homogenization for 20 min. After this step, the solution was put into tubes which were centrifuged for 2 min to improve its purity. Then, 10 µL of this solution were collected and put in a tube. Immediately, 1 mL of the reagent (Lot 16704, Barcelona, Spain) was added, then the whole was vortexed. The tube containing the mixture was placed in a dark room to incubate for 10 min before reading the optical density (OD) on a spectrophotometer (Jasco V530, Kyoto, Japan). The standard solution was prepared under the same conditions as the samples. After the samples and the standard OD readings, equations (4) and (5) were used to compute the total cholesterol content in the egg yolk in mg/dL of fresh yolk. Finally, this total cholesterol was timed by 0.1 to get the result in mg/g.

$$Tot_C(mg/dL) = \frac{OD_{\text{sample}}}{OD_{standard}} * 200 \quad (4)$$

$$Tot_C(mg/g) = \frac{OD_{\text{sample}}}{OD_{standard}} * 200 * 0.1 \quad (5)$$

Where Tot_C: total cholesterol, OD: optical density, 200: standard concentration.

2.6. Statistical Analysis

The eggs were recorded from week-39 to week-50, 12 consecutive weeks. During this period, 2805 eggs were weighed. So, the eggs' weights and hens' laying rates were computed during these 12 weeks. But, for eggs' components analysis, only week-50 was retained. So, egg yolks L*, a*, and b* colour evaluation, and the total cholesterol contents were assessed only on week-50. On each egg yolk, the data were generated in triple and analysed with XLSTAT software, version 2014. An analysis of variance (ANOVA) was carried out within a 95% confidence interval (α=5%), and the least square means method was applied to discriminate the means, by the Newman-Keuls (SNK) method.

3. Results and Discussion

3.1. Hens' Laying Percentage

Table 2 presents hens' average laying rate alongside the diet. The highest laying rate was observed with WC+12.5%*Ba* diet with 76.19±2.69%, and the lowest, 60.86±1.90%, was obtained with a pure white corn-based diet, 60%WC. In general, laying rate values fell into 2 groups, which were significantly different ($p<0.001$). The diets WC+12.5%*Ba*, WC+15%*Ba*, WC+2.5%*Ba*, and WC+5%*Ba* performed as well as diets 60%YC and 55.2%YC diets for an average of 70.81±2.43%. Strangely, diets WC+10%*Ba* and WC+7.5%*Ba* were left in the backyard since their results were like those of 60%WC. This last group hens average laying rate was 61.93±1.90%. So, the 8.88% gap was a 12.54% loss from 70.81% to 61.93% ($p<0.001$). The hens' eggs laying rates fell within the range 42.9 to 81.3%, like Houndonougbo et al. [15] results with ISA Brown layers. Again, the current results were like those of Yakubu and Aguda [16]. In fact, at 40, 45 and 50 weeks of age, their hens' eggs laying percentages were 63.55, 72.64 and 74.38%, respectively [16]. Also, these current laying rates of supplemented diets, from 69.35±2.69 with WC+5%*Ba* to 76.19±2.69% with WC+12.5%*Ba* were like 68.8-74.9% obtained with Hy-line layers [17]. Already, Attia et al. [18] demonstrated that, when supplementing laying hens' diets with an unsaturated fatty acids source, the incorporation ratio is a key factor. Of course, Tiho et al. [9] concluded that *Borassus aethiopum* ripe fruits' dried pulp is a good source of unsaturated fatty acid, for 76-78%, when the pulp was dried between 40 and 80°C. Therefore, in a white corn-based diet, *Borassus aethiopum* ripe fruits' dried pulp best incorporation rate could be set between 12.5 and 15%.

Table 2. *Hens' laying percentage according to the diets.*

Diets	μ±σ (%)	Comparisons, p-values
(1) WC+12.5%*Ba*	76.19±2.69[a]	
(2) WC+15%*Ba*	74.70±2.69[a]	(1) vs (2), 0.646[ns]
(3) WC+5%*Ba*	69.35±2.69[ab]	(2) vs (3), 0.223[ns]
(4) 60%YC	68.01±1.90[ab]	(3) vs (4), 0.679[ns]
(5) 55.2%YC	66.96±1.90[ab]	(4) vs (5), 0.748[ns]
(6) WC+10%*Ba*	62.80±1.90[b]	(5) vs (6), 0.198[ns] (2) vs (6), 0.003[**]
(7) WC+7.5%*Ba*	62.14±1.90[b]	(6) vs (7), 0.838[ns] (2) vs (7), 0.002[**]
(8) 60%WC	60.86±1.90[b]	(7) vs (8), 0.694[ns] (2) vs (8), 0.001[**]

μ±σ: mean ± standard error; ns: non-significant; **: significant; n=2,805 eggs, Means within a column, with different superscript significantly differ, by Newman-Keuls (SNK) multiple ranges test at 95% interval of confidence.

3.2. Eggs' Weights

According to the diets, the egg average weights ranged between 57.71±0.30 and 61.63±0.22 g (Table 3). The heaviest eggs were obtained with 55.2%YC diet and those with low weight were recorded on the WC+15%*Ba* diet. Looking at the diets' effects on eggs average weights, there are 4 distinct groups. Effectively, 55.2%YC was the leader with 61.63± 0.22 g. Following, diet WC+7.5%*Ba* output was 60.40±0.24 g. Clearly, showing 1.23 g gap or 2% weight loss, the two diets results were different (p=0.001). Ranking third, diet 60%WC eggs' average weight was 59.18±0.23 g, and this performance represented 1.22 g loss compared to WC+7.5%*Ba* result (p=0.001).

Table 3. *Eggs' weights according to the diets.*

Diets	μ±σ (g)	Comparisons, p-values
(1) 55.2%YC	61.63± 0.22[a]	
(2) WC+7.5%*Ba*	60.40±0.24[b]	(1) vs (2), 0.001[**]
(3) 60%WC	59.18±0.23[c]	(2) vs (3), 0.001[**]
(4) 60%YC	59.14±0.23[c]	(3) vs (4), 0.927[ns]
(5) WC+12.5%*Ba*	58.98±0.31[c]	(4) vs (5), 0.670[ns]
(6) WC+10%*Ba*	58.95±0.23[c]	(5) vs (6), 0.933[ns]
(7) WC+5%*Ba*	58.38±0.31[cd]	(6) vs (7), 0.286[ns]
(8) WC+15%*Ba*	57.71±0.30[d]	(7) vs (8), 0.080[ns] (6) vs (8), 0.006[**]

μ±σ: mean ± standard error; ns: non-significant; **: significant; n=2,805 eggs, Means within a column, with different superscript significantly differ, by Newman-Keuls (SNK) multiple ranges test at 95% interval of confidence.

Singularly, 60%WC was the first diet of a large group represented by itself and 60%YC, WC+12.5%*Ba*, WC+10%*Ba*, and WC+5%*Ba*. So, these 6 diets had a 58.86±0.27 g average egg weight. After these 3 groups performances, the worst outcome was delivered by WC+15%*Ba*, with 57.71±0.30 g. Likewise, Tiho et al. [19] concluded that the diet structure had an important effect on poultry performance. In fact, a higher mash proportion tended to reduce broilers' growing performance [19]. So, the poor performance of diet WC+15%*Ba* may be related to its mash increasing rate. Of course, the corn rate decreased from 60% to 45% with 60%WC and WC+15%*Ba*, when *Ba* ripe fruits' dried pulp proportion went from 0 to 15%. Elsewhere, the recorded eggs' weights correspond to standard eggs size announced by Mantsanga et al. [20]. In fact, 57.71±0.30 and 61.63±0.22 g eggs' weights were included in 53-63 g class, which is a medium class in European's regulations [21]. Moreover, herein results were higher than 50-60 g announced by Houndonougbo et al. [15]. Again, these results were heavier than 57.5 g obtained by Diomandé et al. [22].

Importantly, the hens fed on 55.2%YC performed better than those fed on 60%YC. An 8% decrease in yellow corn incorporation in the diets, within the good reference diets, led to an 4.21% increase in egg average weight. Interestingly, this egg weight average moved from 59.14±0.23 with 60%YC group to 61.63±0.22 for 55.2%YC. Better, the hens' laying percentages of these 2 groups were not significantly different (p=0.748; Table 2). Although WC+7.5%*Ba* diet eggs were heavier than those of WC+12%*Ba* diet, by delivering 60.40±0.24 g while WC+12.5%*Ba* had 58.98±0.31 g; WC+7.5%*Ba* cannot be preferred to WC+12.5%*Ba*. Singularly, hens fed on WC+12.5%*Ba* had 76.19±2.69% laying percentage while those fed on WC+7.5%*Ba* performed 62.14±1.90% (p=0.000).

3.3. Eggs' Yolk and Albumen Weights (g) According to the Diets

According to Huang and Ahn [23], proteins and lipids are the two major egg yolk components. Specifically, egg yolk protein is mainly composed of livetins (38%, α-, β- and γ -forms), lipovitellins (36%, α- and β-forms), LDL (17%), and phosvitin (8-9%). A part LDL cholesterol, these proteins are major functional components. So, eggs are seen like healthy product. But, due to controversy discussions on egg yolk total cholesterol content, egg yolk consumptions are balancing years after years [23]. Truly, egg yolk can be separated into two fractions, whose are the granules (22%) and plasma (78%) by centrifugation [23]. Because plasma itself accounts for 85% of LDLs and 15% of livetin [23], it seems safer to consume egg albumen than egg yolk. Facing this scientifically supported arguments, many persons are avoiding consuming egg yolk. With this knowledge in mind, more and more scientific works tend to enrich egg yolk with ω-3, ω-6, and ω-9 rich natural carotenoid sources, because the laying-hens stock in the egg yolk the dietary cholesterol they get through the feed. Alternatively, many ways are used to increase egg yolk consumption through the food industry processing. For example, in the cake industry, the eggs foaming properties are used to come up with delicious and soft cakes like sponge cake [24]. These new technologies may give new opportunities to egg yolk utilizations. By the way, Chen et al. [25] demonstrated that egg products can be used to perfume other broiler meat.

Egg yolk weights ranged from 14.31±0.20g for

WC+12.5%*Ba* diet to 15.39±0.14g for 60%WC diet (Table 4). So, 60%WC had a higher yolk weight value than the other diets. Comparison of yolks' weights by ANOVA indicated a significant difference at the 5% level between 60%WC and 3 other diets containing *Borassus* aethiopum dried pulp, WC+10%*Ba* (p=0.024); WC+12.5%*Ba* (p=0.000); WC+15%*Ba* (p=0.013). Controls based on yellow corn diets (60%YC and 55.2%YC) have no significant difference at the 5% level (p=0.964). Herein yolks' average weights were within 14.43g and 18.97g interval obtained from laying hens fed on *Dioscorea dumetorum* chip [26].

Looking carefully, following the diets WC+5%*Ba*, WC+10%*Ba*, and WC+15%*Ba*, it appeared that the yolk weights decreased alongside an increasing *Borassus aethiopum* fruits' dried pulp incorporation rates, for 14.84±0.20, 14.65±0.14 and 14.59±0.20 g, respectively. From WC+5%*Ba* to WC+15%*Ba*, there was 1.69% loss on yolk weight. This tendency has been reported by Tiho et al. [8] when they incorporated 10% and 20% *Borassus aethiopum* ripe fruits' dried pulp in laying hens' diets. Mostly important, many works argued that laying hens not only can transfer pigments from feed ingredients into the yolk [8, 12]. But when the diets are more and more rich in pigments for the egg yolk colouration, there is a regression effect on yolks' weights [8, 12].

Table 4. *Eggs' yolk and albumen weights (g).*

Diets	Egg yolk		Egg albumen	
	μ±σ (g)	Comparisons and p-values	μ±σ (g)	Comparisons and p-values
(1) 60%WC	15.39±0.14^{a}		37.65±0.27^{b}	
(2) 60%YC	15.14±0.14^{ab}	(1) vs (2), 0.289^{ns}	37.10±0.27^{bc}	(1) vs (2), 0.441^{ns}
(3) 55.2%YC	15.13±0.14^{ab}	(2) vs (3), 0.964^{ns}	39.40±0.27^{a}	(2) vs (3), <0.0001***
(4) WC+7.5%*Ba*	14.92±0.14^{abc}	(3) vs (4), 0.368^{ns}	39.45±0.27^{a}	(3) vs (4), 0.919^{ns}
(5) WC+5%*Ba*	14.84±0.20^{abc}	(4) vs (5), 0.431^{ns}	37.05±0.38^{bc}	(4) vs (5), <0.0001***
(6) WC+10%*Ba*	14.65±0.14^{bc}	(5) vs (6), 0.435^{ns} (1) vs (6), 0.024**	36.22±0.27^{c}	(5) vs (6), 0.177^{ns} (1) vs (6), 0.018** (3) vs (6), <0.0001***
(7) WC+15%*Ba*	14.59±0.20^{bc}	(6) vs (7), 0.774^{ns} (1) vs (7), 0.013**	36.37±0.38^{c}	(6) vs (7), 0.734^{ns} (1) vs (7), 0.035**
(8) WC+12.5%*Ba*	14.31±0.20^{c}	(7) vs (8), 0.249^{ns} (3) vs (8), 0.008** (1) vs (8), 0.000**	37.23±0.38^{bc}	(7) vs (8), 0.220^{ns} (1) vs (8), 0.343^{ns} (4) vs (8), <0.0001***

μ±σ: mean ± standard error; ns: non-significant; **: significant; ***: Highly significant; n=36 per diet (3 per week for 12 weeks) (N=288 eggs, for 8 diets); Means within a column, with different superscript significantly differ, by Newman-Keuls (SNK) multiple ranges test at 95% interval of confidence.

3.4. Eggs' Yolk Colours Yellowness (b) and Lightness (L*)*

Egg yolk colours viewed through its yellowness (b*) and lightness (L*) show the carotenoids availability in the diets (Table 5, Figure 1). Above all, visual egg yolk colour appreciation is difficult when the scores rank around 7, 8, 9 and 10 (Figure 1). Clearly, adding some *Borassus aethiopum* ripe fruits' dried pulp powder in a white corn-based diet, substantially improved the yolk colour. In 60%WC diet, some carotenoids were available through the wheat bran, so, the yolks are not perfectly white. Nonetheless, this carotenoid source could not sufficiently colour the egg yolks and make them acceptable for consumers. Meanwhile, adding 5% of *Borassus aethiopum* ripe fruits' dried pulp allowed a great change, from score 2 to 7, on Roche Yolk Fan scale. Continually, by increasing the carotenoids sources incorporation rate in a white corn-based diet, the egg yolk colours have been greatly improved.

Particularly, for the diets WC+10%*Ba*, WC+12.5%*Ba*, and WC+15%*Ba*, the visual observations, and assortments were difficult. In fact, in addition to these 3 precedent supplemented diets, WC+5%*Ba* egg yolks were also acceptable for common visitors. Facing these confusing consumers' observations, a spectrophotometer was used to come up with reasonable differences (Table 5).

The spectrophotometer revealed 4 groups for egg yolk yellowness (b*), and 2 groups egg yolk lightness (L*) tendances. The diets 55.2%YC and 60%YC egg yolks yellowness were similar, with 147.11±3.27 (b*) average (p=0.070). The dense coloured egg yolks, with high b* values, had the lowest L* values. Because of *Borassus aethiopum* ripe fruits' dried pulp important fat content, the egg yolks from supplemented diets are shiny [9]. Thought the eggs' yolks from WC+5%Ba, WC+7.5%Ba, WC+10%Ba, WC+12.5%Ba, and WC+15%Ba had good carotenoid stocks, the important fat content in the dried pulp induced high L* values, because they were shiny. Thus, supplemented diets lightness values were like that of 60%WC (0.422≤p≤0.988).

3.5. Egg Yolk Total Cholesterol Content

A part WC+15%*Ba* diet egg yolk total cholesterol content, all egg yolks from white corn-based diets supplemented with *Borassus aethiopum* ripe fruits' dried pulp results were like that of 55.2%YC (Table 6). Because the egg yolk is an appropriate well to stock excess of cholesterol [4, 6, 8, 12], WC+15%*Ba*, 60%YC and 60%WC induced high total cholesterol stocks. At this point, it may be concluded that total cholesterol content is not only related to natural carotenoid contents in the diet.

***Table 5.** Yellowness (b*) and Lightness (L*) according to the diets.*

Diets	Yellowness		Lightness	
	µ±σ (b*)	Comparisons, p-values	µ±σ (L*)	Comparisons, p-values
(1) 55.2%YC	153.94±3.27^{a}		78.54±0.37^{b}	
(2) 60%YC	140.28±3.27^{a}	(1) vs (2), 0.070^{ns}	77.76±0.37^{b}	(1) vs (2), 0.405^{ns}
(3) WC+5%*Ba*	92.53±4.22^{b}	(2) vs (3), <0.0001***	80.20±0.48^{ab}	(2) vs (3), 0.422^{ns}
(4) WC+12.5%*Ba*	90.17±5.17^{b}	(3) vs (4), 0.326^{ns} (2) vs (4), <0.0001***	81.21±0.58^{a}	(3) vs (4), 0.405^{ns} (2) vs (3), 0.005**
(5) WC+10%*Ba*	88.28±3.27^{b}	(4) vs (5), 0.790^{ns} (2) vs (5), <0.0001***	81.46±0.37^{a}	(4) vs (5), 0.959^{ns} (2) vs (3), <0.0001***
(6) WC+15%Ba	81.36±5.17^{bc}	(5) vs (6), 0.337^{ns} (2) vs (6), <0.0001***	81.44±0.58^{a}	(5) vs (6), <0.988^{ns} (2) vs (6), <0.0001***
(7) WC+7.5%*Ba*	66.48±4.22^{cd}	(3) vs (4), 0.051^{ns} (2) vs (7), <0.0001***	82.25±0.48^{a}	(3) vs (4), 0.634^{ns} (2) vs (4), <0.0001***
(8) 60%WC	57.67±3.27^{d}	(7) vs (8), 0.0226^{ns} (2) vs (8), <0.0001*** (6) vs (8), 0.011**	83.79±0.37^{a}	(7) vs (8), 0.425^{ns} (2) vs (8), <0.0001***

µ±σ: mean ± standard error; ns: non-significant; **: significant; ***: Highly significant; n=36 per diet (3 per week for 12 weeks) (N=288 eggs, for 8 diets); Means within a column, with different superscript significantly differ, by Newman-Keuls (SNK) multiple ranges test at 95% interval of confidence.

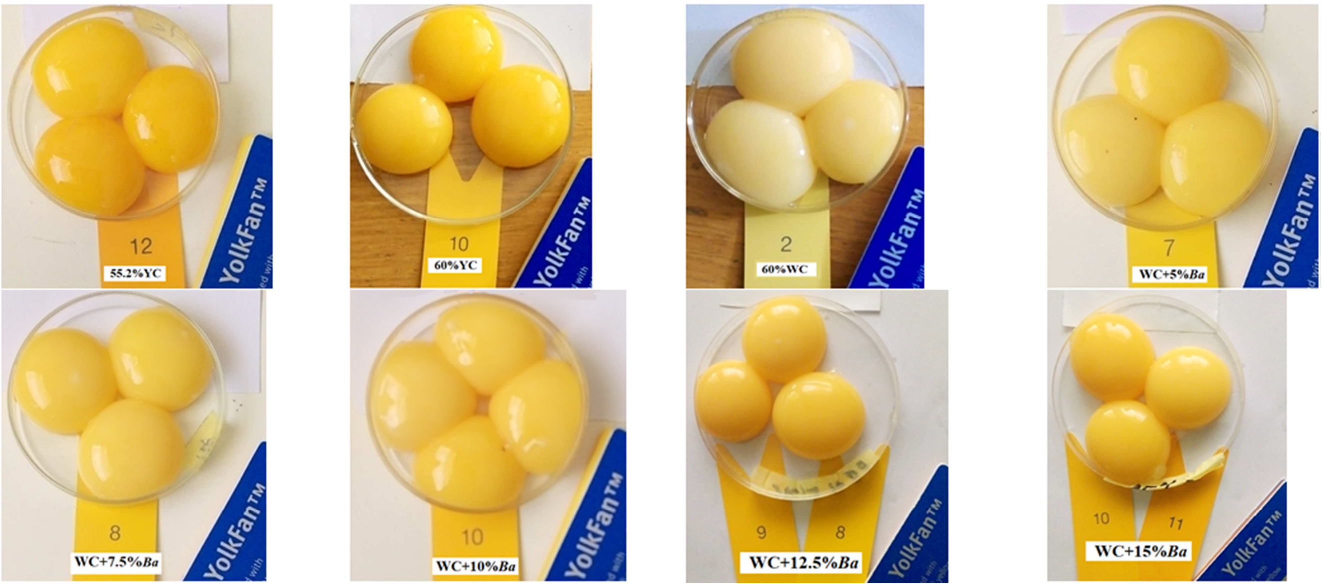

***Figure 1.** Visual egg yolk colour appreciations with Roche Yolk Fan according to the diets.*

***Table 6.** Egg yolk total cholesterol content according to the diets.*

Diets	µ±σ (mg/g)	Comparisons, p-values
(1) WC+15%*Ba*	57.51±4.75^{a}	
(2) 60%YC	47.60±4.75^{ab}	(1) vs (2), 0.162^{ns}
(3) 60%WC	44.70±4.47^{ab}	(2) vs (3), 0.672^{ns}
(4) WC+7.5%*Ba*	37.30±4.47^{b}	(3) vs (4), 0.289^{ns} (1) vs (4), 0.041**
(5) WC+12.5%*Ba*	34.71±3.19^{b}	(4) vs (5), 0.706^{ns} (1) vs (5), 0.030**
(6) WC+10%*Ba*	31.63±3.17^{b}	(5) vs (6), 0.653^{ns} (1) vs (6), 0.018**
(7) 55.2%YC	30.90±1.47^{b}	(6) vs (7), 0.914^{ns} (1) vs (7), 0.019**
(8) WC+5%*Ba*	30.39±1.47^{b}	(7) vs (8), 0.347^{ns} (1) vs (8), 0.018**

µ±σ: mean ± standard error; ns: non-significant; **: significant; n=36 per diet (3 per week for 12 weeks) (N=288 eggs, for 8 diets); Means within a column, with different superscript significantly differ, by Newman-Keuls (SNK) multiple ranges test at 95% interval of confidence.

Of course, 60%WC diet egg yolk less yellow colour (Figure 1, Table 5) contained more total cholesterol (57.51 mg/g) than WC+10%*Ba* (31.63 mg/g; -25.88 mg/g), and WC+12.5%*Ba* (34.71 mg/g; -22.8 mg/g). The top 3 diets, WC+15%*Ba*, 60%YC, and 60%WC diets eggs' yolks total cholesterols average was 49.93±4.65 mg/g. Jahanian and Rasouli [27] concluded that substituting an oil source by another may lead to an important change in total cholesterol content in egg yolks. For example, when they substituted soybean oil by palm oil granulated fat powder at 25%, 50% and 75% rates, the total cholesterol values increased from 9.65% (100% soybean oil) to 10.21%, 10.74%, and 11.73%, respectively [27]. But it should be noted that palm oil has equal saturated and unsaturated fatty acid percentages.

In contrary, when Nanjappan et al. [28] replaced soybean meal by some linseed meal, an important source of ω-3, the egg yolks total cholesterol contents importantly decreased. In the case, when they incorporated 1.3% linseed meal, the egg yolk total cholesterol decreased by 27%. Because *Borassus* *aethiopum* dried pulp which is very rich in ω-3, ω-6, and ω-9 [9], its incorporation may have a good impact on egg yolk nutritional value, thus the consumers' health. The same is true for cholesterol levels of 13.7 to 21.9 mg obtained by Benakmoum et al. [29] compared to levels in egg yolk. This difference in contents can be explained by variations in the levels of incorporation. It may be that this plant is a richer source of antioxidant compounds such as phenolics and flavonoids compared to *Ba* [30].

4. Conclusion

In brief, replacing white corn by the *Borassus aethiopum* (*Ba*) ripe fruits' dried pulp increased the mash rate. So that the egg weight decreased while the *Ba* incorporation rate was increased. A good approach could be to replace some mash instead off the grains. For example, the white corn rate could be kept constant, and *Ba* ripe fruits' dried pulp would replace the wheat brand. Also, it was observed that 4.8% decrease in yellow corn incorporation percentage in the diets, from 60%YC to 55.2%YC, the eggs average weight was improved by 4.21%, while the hens' laying rate did not change significantly. So, incorporating 55.2% yellow corn in diets was better than putting 60%. Finalizing this work objective, WC+12.5%*Ba* maybe regarded as the best diet. For one thing, this diet laying rate was higher than those of the references diets such as 60%YC and 55.2%YC. In fact, this diet ranked first and increased the laying capacity from 60.86% with 60%WC diet to 76.19%, +15.33%. Moreover, the colours of the egg yolks from WC+12.5%Ba were nicely coloured, for b*=90.17, under 55.2%WC with 153.94 and 60%YC with 140.28. But, with human eyes visual, these yellowness differences were not perceptible. Finally, WC+12.5%*Ba* diet egg yolks' total cholesterol contents were lower than those from 60%YC and 60%WC. The major missing data could be the lack on these egg yolk compositions in terms of LDLs and HDLs contents. So, the fatty acid profile of the egg yolk from white corn-based diet enriched with an important unsaturated fatty acid source like *Borassus aethiopum* should be assessed.

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