Food and Feed Additive of Insects: Economic and Environmental Impacts

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Abstract: *Background*: Food insecurity and malnutrition in children may impose extreme disease conditions, which potentially affect the sustainability of zero hunger and wellness worldwide, leading to variations in nutritional patterns by region. Edible insects are common and are included in diets such as pastries, cookies, pasta, pies, flours, biscuits, candies, bars, chocolates, beverages, alcoholics, and so on.

Methods: The current price of insect-incorporated foods and conventional foods in the grocery stores online were analyzed and compared. The architectural sketch of insect integrated rearing system. Edible insects can be reared to harvest or sourced from the wild, cleaned, steamed, and oven-heated before blending into fine powders for additives. The smooth powder is milled with other food ingredients before they are mixed thoroughly, pounded, baked, and cut into sizes.

Results: The nutritional information of insect food and feed was higher than conventional products. Prices of all the conventional commodities were higher except for insect beverages ($14.83≈11,274 nairas) and bars ($22.30≈16,945 naira) ($P<0.05$). Marketable insect feed products are lacking, probably due to a lack of entrepreneurial intervention in this line of production.

Conclusions: Considering the environment, insects have much more advantages. Foods of insects are quite cheap and encouraged in Asia-pacific than in the African region. The environmental, economic, and nutritional values of insects are equally an advantage over other animals. Modeling the price of edible insect foods is paramount to large-scale production. Concerted efforts and legislation are therefore required to promote this innovation in developing and under-developing nations.

Keywords: Additive, Economics, Edible insects, Environment, Food, Feed.

1. INTRODUCTION

The prevailing issues surrounding the search for sustainable feedstock, food security, maintaining balanced nutrition in children, especially in the African region, and economics and environmental implications are the central core of this study. Insects are healthy, nutritive, and environment-friendly feed resources for their chances of improving livelihood and sociality. Individuals, other than children, of other ages, such as the elderly and pregnant women, are not left out in their cravings for quality foods. The projection by UNICEF [1] showed that in 2022 over a quarter amounting to over 20% of children under the age of five, which exceeds one in a cluster of five children, are malnourished, causing growth disorders and exposure to infections. Based on this, the inclusion of insects in food and feed supplementation has become important to combat food insecurity and improve malnourishment and malnutrition. Disgust factor has been a major setback to the incorporation of insects in local and national diets. A study by [2] acknowledged that only two studies revealed the importance of edible insect-nourished foods, such as cooked foods and snacks, in improving nutrition in children. This study is essential in promoting the inclusion of edible insects in familiar diets following their debate as viable additives in the conferences on “Insect to Feed the World" held in 2014, "the World edible insect day celebrations" of 2015, and "The future of animal products in the human diet" organized by the United Nations Food and Agricultural Organization [3]. These debates prompted so many questions begging for answers, such as whether insects are nutritious delicacies, how individual insects would be prepared to compensate for the desirable protein quotient, whether insects can be reared to compensate for quantity supply, whether pathogenic contaminations can be transferred during preparation, insect chitin digestion, and why they should major as an alternative protein source. These questions have been answered, thus establishing insects as an important substance for inclusion in food

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E-ISSN: 1929-4247/23

and feeds. The main consideration of insects as an additive is on the basis that some are nutritionally acceptable due to high-calorie content (89-1272 kcal/100g) linked to high lipid in larvae species (13-57%), high protein values in adult species (11-77%), crude fiber (8-27%), minerals (8-77 mg per 100 g), and vitamins (0.1 to 8.9mg per 100g) [4]. The risk of adopting insects as a potential additive has been addressed by [5]. EFSA [5] reported that care should be taken in consuming insects reared on inappropriate diets, such as organic wastes and decaying wastes of animals, as bacteria superinfection may arise, and that only trusted vendors should sell insects to retailers when they are mass-produced. However, insects raised on inappropriate diets can be utilized as feed for animals, while those raised on pure-breed meals can be reserved for food inclusions. Humans in almost all parts of the earth have tasted insects either directly or indirectly, and the clamor for their addition to food and feed is of global concern [6]. In order to divert the attention of human disgust factors and encourage the informed choice of acceptability, insect inclusion into familiar food has therefore been the focus [7]. Since immemorial, insects have been consumed whole, which is implicated in more than 2000 species, most of which have been reported in Asian, African, and some Latin American countries [8]. The practice of eating insects has been reported in Africa [9], Asia [10,11], Latin America [12], and Australia [13]. Another moral justification for insect inclusion in diets is that they have a wide range of consumption, and the checklist of insects consumed worldwide has been confirmed [3]. Another notable setback to successfully including edible insects in food is the hurdle of harvesting from the wild every time [14]. The barrier can be conquered by rearing either traditionally in mini-rearing facilities or modernized facilities. The feed resources for insect culture, thermal gradients for survival, degree day requirements, life cycle assessment, biochemical tests, and possibilities of microbiological contaminations are important factors that have been considered [7, 15].

Food additives could be natural and synthetic substances added to food to preserve or enhance its freshness, biosafety, flavor, physical appearance, and texture [16]. Edible insects have been categorically included with other synthetically or naturally originating feed resources such as plants, animals, minerals, or a combination of both origins. Many edible insect products are available in grocery stores, yet, there are no reports on the financial implications of these products or proposed architectural designs for the rearing facilities and preparation of foods for insects. In the history of food additives, the addition of salt and sugar (as additives) into familiar food as well as Sulfur (II) oxide in wine preservation has been a long-term tradition, which in one way is not only geared towards food preservation but also improving the nutritional content and perception of foods of insect origin. In addition, food and feed additives are important to enhance the quality of the quantity supplied, efficient growth performance, and healthiness through enhanced digestibility, and improve taste and aroma to guarantee the products' shelf-life. The study of [17] highlighted the importance of producing edible insect foods from recommended methods such as fat extraction, enzyme actions, and considering the heat gradient of processing. No study has been reported on the economic implication. However, the preparation strategies and environmental impacts have been highlighted. The inclusion of insects into animal feed is of less concern as what an animal is fed upon is not questioned as such. The habit of indirectly eating insects is common because some people eat insect-infested foods as well as fish and poultry birds reared with whole insect meals. The study of [18] confirmed that producing marketable insect-incorporated feed for animal products would not raise consumer acceptance concerns. Consumer acceptance of livestock-fed insect meals is of the essence to define the focus of commercialization of insect inclusion in animal feed.

Insect inclusion in food and feed is an innovation in studies to further get more consumers to accept them. This study, therefore, compared the price of edible insects and conventional foods in grocery stores online, the nutritional status of the foods and feed, and the environmental implications of rearing insects and livestock. More importantly, this study proposed an integrated system for the breeding of insects using poultry byproducts. Further economic impact studies should focus on modeling the cost as well as designing studies to break the economic barriers of edible insect foods to fulfill their acceptance. More so, nutritional labels of food and feeds are often taken for granted by consumers, especially in the African regions, and this has a way of decreasing the consumer choice of valid products. The provision for nutritional labels of foods should be enforced to justify children's trials of novel food products and tastes. Food and feed additive are justifiable by determining the biochemical content, which is made visible on labels to inform consumers about the retained nutrients and stability of the products [19-21]. The formation of an expert food

ethics committee by the National Agency for Food and Drugs Administration and Control (NAFDAC) and the Food and Agricultural Organization (FAO) ensures that all food and feed additives pass through safety and quality test. This ensures that only those who pass the test may be globally available for purchase. Several reviews on insects have neglected the importance of comparing the price and nutritional labels of food and feed of insects with familiar products. This triggered the design of this study.

1.1. Preparation, Nutritional Composition, and Benefits to Man

Utilizing substances derived from insects, such as protein, lipids, and chitin, or blending insects into powder is one way to reap the nutritional and sustainable benefits of eating insects. If edible insects are processed and blindly incorporated into familiar food forms, they are more likely to be accepted and consumed. Foremost, insect foods and feed can be prepared by simply harvesting insects from the wild and incorporating them directly or by rearing them in facilities to increase their number before application. Common techniques such as lipid extraction, enzymatic proteolysis, commercial thermal processing (such as blanching and pasteurization), low-temperature processing (such as chilling and freezing), dehydration, and fermentation technology can be employed in refining insect ingredients. Each method has benefits and drawbacks that should be carefully weighed since not all edible insects or insect flours can be processed using the same techniques or under the same conditions.

From Figure **1**, insects are gathered, washed of every contamination, cleaned, and steamed. They are furtherly oven heated before blending into powders for food and feed application. Using insect flour as a model for producing various forms of innovative insect foods, they can be normally made by roasting or dehydrating whole insects, then grounded into a fine powdery form. However, chitin-protein interactions can impact the functional properties (such as emulsification, foaming, solubility, and so on) of the protein present in these flours, thus, restricting their suitable use in the formulation of food products. Enzymatic proteolysis of a protein's peptide bonds, heat treatments, solvent extractions, or alkali/acidic processes that yield peptides of various lengths and free amino acids are strategies for creating insect protein powders that will enable the separation of chitin [17]. [22] presented a standard review of the fundamental procedures used to produce protein powders, including defatting, protein solubilization and recovery, purification, and drying. This standard review also addressed procedures for producing quantities of high-quality food/feed oil, and insect oil extraction is essential to make subsequent protein isolation easier. It has been reported that insect oil can be extracted by simple mechanical press and supercritical-CO_2 extraction [23]. Insect ingredients are milled with food and feed materials before thoroughly mixed and pounded. The product of this process is cut into desired sizes before they are baked and presented for consumption. This method was adapted with modification from the study of [7].

Given that a substantial section of the global population experiences food insecurity, edible insect inclusion in food would benefit man directly and indirectly. It would benefit man directly as regards its consideration as the most intriguing protein source for the future. Indirectly, by maintaining zero pollution of the environment due to livestock production. Including insects in food and feed will help fight insecurity and improve malnutrition, especially in children from underdeveloped and developing nations [24]. This will ensure that the sustainable development goal of zero hunger is tackled. More so, including or fortifying food and feed with insects can improve the nutritional quality of the available commodity for life sustenance. Likewise, animal performance, health, and digestibility can be improved by adopting insects incorporated feed.

Insect inclusion in familiar foods such as burgers, biscuits, and flour revealed that insects incorporated commodities are higher in calories and macro and micronutrients (Table **1**). A study by [15], which included house cricket (*Acheta domesticus*) in biscuits, showed that higher inclusion above 5g was acceptable by consumers but affected the product's attractiveness. Consumers preferred biscuits with insect inclusion at the rate of ≤5g. Apart from nutritional considerations, the taste and aroma can inform the continuous choice of specific food and sometimes the consumption of insect-formulated feed by animals. The study of [25] reiterated that physical and sensory qualities, as well as the availability of nutritional information, are prerequisites to consumer choice of edible insect incorporations. Likewise, it depends on extraction, fortification, industrial production, and incorporation of familiar products by regions. More so, insect inclusions function as preservatives of food and feed and maintain food's hydrogen ion balance. Insect inclusion in food and feed will save the cost of acquiring pricey food and feed ingredients. Including insects will help realize a

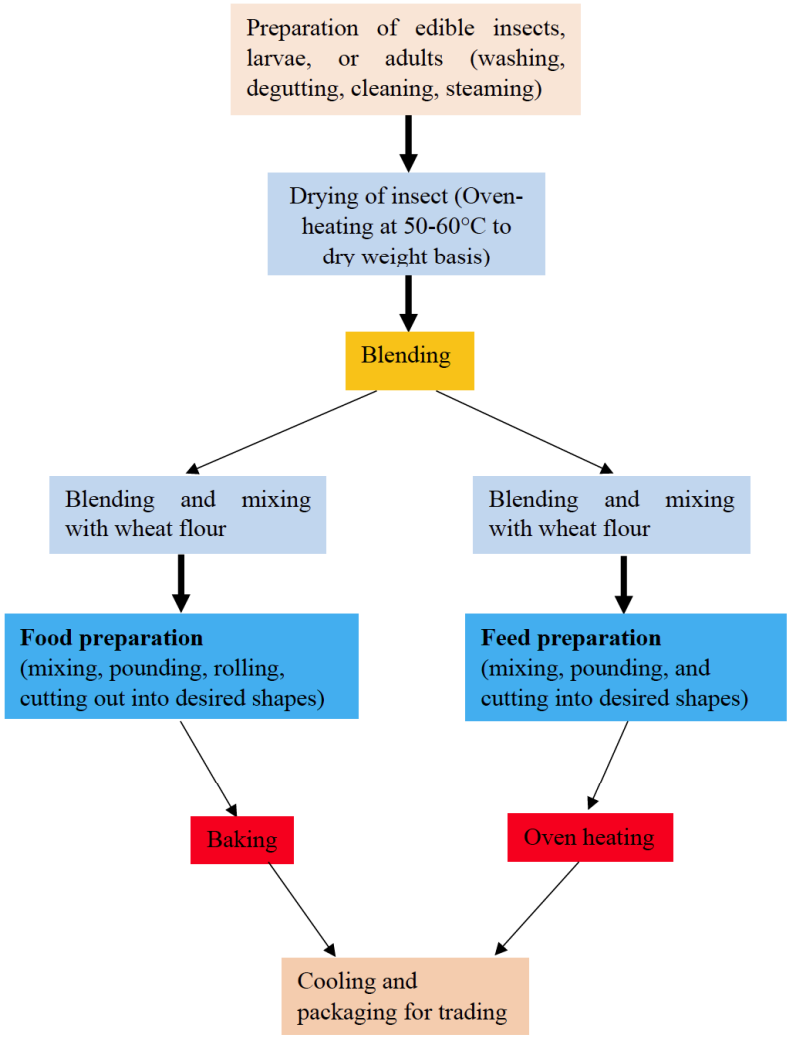

Figure 1: Preparation process for food and feed. (Source: Adapted with modification from [7].

sustainable environment devoid of pollution, reduce space, and maximize insect productivity. Apart from the nutritional advantages of insect foods, edible insects present bioactive chemicals which provide consumers with a wide range of health advantages capable of changing the physiological or cellular functions of consumers [26]. The biologically active compounds include antioxidant, cardioprotective, antibacterial, antifungal, anti-inflammatory, and anticancer properties [27-28]. Extracts of fatty acids in insect cuticles have been reported to protect species from fungus infections significantly, hence reducing contamination from whole insects [29]. It has also been discovered that peptides with anti-inflammatory activity can be found in edible insects [27]. In anticipation of the benefits man can derive from insects, peptides extracted from silkworm pupae may be utilized therapeutically to treat stomach cancer [30]. Insect proteins are equally not excluded in their medical applications, especially for treating kwashiorkor in malnourished children. For instance, when a smoothie is made from blends of edible insects and added with other ingredients, and given to a child suffering from nutrient deficiency, positive results are expected, as reported by Tao and Li [31].

The average nutritional composition of food in grocery stores globally is shown in Table **1**. The nutritional information of commodities is presented in macronutrients and micronutrients. Insect products have higher calories, proteins, and fats than conventional products. Conventional products are higher in carbohydrates and contain cholesterol. The fiber content in wheat flour is higher than in insects. It could be that the seed coat of wheat is tougher than chitin in insects when formulated in flour. The Fibre content of insect burgers and biscuits is higher than that of conventional products. There is paucity in the micronutrient report of most insect products. For instance, there is no report for insect flour and some other insect commodities.

Table 1: Average Nutritional Composition of Food in Grocery Stores Globally

Nutrients	Burger	Insect burger	Biscuit	Insect biscuit	Wheat flour	Insect flour
Calories (KJ)	280.5	429.25	274	1333.05	360.80	457
Macronutrients						
Carbohydrates (%)	46.5	21.89	53.0	28.15	72.7	5.98
Protein (%)	26.0	37.72	8.4	23.84	11.8	73.7
Fat (%)	16.6	19.65	24.1	31.27	1.74	19.8
Fibre (%)	1.71	10.05	2.1	8.10	1.49	0.54
Cholesterol (%)	0.08	ND	7.59	ND	ND	ND
Micronutrients						
Sodium (%)	0.69	0.98	0.85	0.013	0.003	ND
Potassium (%)	0.39	0.65	0.28	0.018	0.13	ND
Sugar (%)	8.05	5.90	3.5	ND	ND	ND
Iron (%)	0.16	0.32	0.003	0.021	0.003	ND
Cobalamin (%)	0.23	ND	0.11	ND	ND	ND
Vitamin B6 (%)	0.10	ND	0.00	ND	0.0002	ND
Magnesium (%)	0.05	ND	0.04	0.018	0.06	ND
Calcium (%)	0.10	0.24	0.31	0.022	0.02	ND
Vitamin A (%)	ND	0.47	ND	ND	ND	ND
Salt (%)	ND	0.74	ND	ND	ND	ND
Vitamin C (%)	ND	ND	0.14	ND	0.006	ND
Phosphorus (%)	ND	ND	ND	0.03	0.11	ND
Zinc (%)	ND	ND	ND	0.006	ND	ND
Copper (%)	ND	ND	ND	0.0025	0.0003	ND
Thiamin B1 (%)	ND	ND	ND	ND	0.0003	ND
Riboflavin (%)	ND	ND	ND	ND	0.0001	ND
Niacin B3 (%)	ND	ND	ND	ND	0.0012	ND
Ash (%)	ND	ND	ND	ND	0.81	ND
Moisture (%)	ND	ND	ND	5.67		ND

Note: nutritional composition is based on 100g serving weight; ND means not determined. **Sources:** Insect foods in grocery stores online, [7], [15], [37].

The average mean values of the nutritional composition of conventional and insect-formulated feed are shown in Table **2**. A commercial diet had more calories than insect feed. Cockroaches have higher carbohydrates than other insects but lower proteins. Varying degrees of nutritional composition have been shown in studies [21, 32-36]. Insects are, in all, best in contributing to the macronutrients. Not much has been holistically reported for micronutrients in feed.

2. MATERIALS AND METHODS

In this review, the nutritional content of some food incorporated with insects and commercialized foods, the strategies for preparing insect foods, the online grocery store prices, and the environmental impact were considered for analysis. The study also focused on comparing the economic impacts of food from edible insect sources with those without edible insects to make an inference.

2.1. Search for Literature and Selection

This was done using Google search, PubMed-NCBI, Science Direct, FAO, WHO, UNICEF, and Cochrane Library from 2010 to 2023 to find important information using keywords such as 'edible insects as Additive,' ‘Economic impact of insect food,' ‘Edible insects,' 'nutritional composition of edible insects,' 'preparation,' 'importance of insects to humanity,'

Table 2: Average Mean Values of the Nutritional Composition of Conventional and Insect-Formulated Feed

Nutrients	Conventional Meal	Cockroach meal	Housefly meal	Palm weevil meal	Black soldier fly meal
Energy (KJ)	2950	1482.12	2890	733.1	ND
Carbohydrates (%)	ND	65.17	24.3	11.7	ND
Protein (%)	22.0	11.89	47.1	31.2	44.91
Fat (%)	4.5	12.24	25.3	45.2	29.67
Fibre (%)	3.5	10.13	7.5	2.1	8.03
Ash (%)	-	4.51	6.3	4.7	7.31
Moisture (%)	-	8.25	ND	8.2	5.21
Nitrogen (free extract)	ND	7.51	ND	ND	7.31
Sodium (%)	ND	1.13	ND	ND	ND
Potassium (%)	ND	0.49	ND	ND	ND
Iron (%)	ND	0.39	ND	ND	ND
Magnesium (%)	ND	0.38	ND	ND	ND
Calcium (%)	ND	0.43	1.7	0.3	ND
Phosphorus (%)	ND	0.92	0.6	4.9	ND
Zinc (%)	ND	0.047	ND	ND	ND
Copper (%)	ND	0.014	ND	ND	ND

ND means not determined. **Sources:** [19, 24-25, 32-34].

'edible insect foods,' 'Environmental impact of edible insects,' 'edible insect Feed' and 'price of edible insect foods in the grocery stores. 'The price of different commodities such as biscuits, burgers, chocolate bars, bread, beverages, flour, pasta, and spreads, both insect incorporated and conventional, was searched out. A literature search was filtered and restricted to foods with or without edible insects. Potential studies were scrutinized to select relevant articles and were uploaded into Ryyan [38] for information screening and selection.

Studies reporting the nutritional profile of edible insects and edible insect foods, the nutritional profile of conventional foods, preparation strategies for edible insect foods, economic and environmental impacts, as well as prices of all edible insects and conventional commodities, were included. However, there was no restriction on the year of publication, insect inclusion rate, design and duration of the study, and insect types.

2.2. Study Selection and Analysis

One hundred and fourteen (84) studies were retrieved. Eighteen (18) reports were selected for full assessment after the titles and abstracts were screened. Ten (10) were selected for nutritional profile and preparation, and none reported economic impacts. To compensate for this shortfall, prices of commodities, conventional and the majority of insect food products, were searched out in dollars from the various online market outlets such as 'Amazon' and other online stores displaying insect products and converted to naira using the current dollar to naira rate (755). The prices of insect and conventional commodities were subject to the Analysis of Variance (ANOVA) test to ascertain significant differences within commodities.

3. RESULTS

3.1. Economic Implication

The comparison of the dollar price equivalent in naira between conventional and insect food products in the global market is shown in Table **3**. The prices of all the conventional commodities were higher except for insect beverages and bars. Insect beverages cost about 11,300 nairas. The differences between the mean prices of insect products and conventional products were significant for flours, beverages, spreads, and chips and crackers ($P<0.05$). No insect-incorporated bread was seen in the grocery market. The price differences between conventional and edible insect-incorporated pasta, burger, and bars were insignificant. The median price of conventional flour was higher than other commodities (Figure **2**).

A price comparison between conventional and insect feed products in the global market is shown in

Table 3: Price Comparison between Conventional and Insect Food Products in the Global Market (Dollar Equivalent in Naira)

Products	Conventional products	Insect products	F-ANOVA	P-value
	Mean ± SE (N)	Mean ± SE (N)		
Flours	30,501.8 ± 3,697.3 (10,000 - 58,000)	10,925 ± 2,999.6 (4,180 – 24,320)	11.36*	0.0026
Bread	680 ± 248.5 (240 – 1,100)	-	-	-
Pasta	9,759.52±1,167.23 (600 – 19,500)	6,393.13 ± 1,487.49 (2,660 – 26,600)	3.27	0.079
Beverages	9,433.22 ± 2,047.9 (1,385-38,000)	11,273.87 ± 2,308.5 (4,332-16,712.4)	9.05*	0.0043
Spreads	12,603.91 ± 2,006.6 (1,950-32,500)	5,874.8 ± 1,625.9 (1,953.2 – 9,728)	29.17*	<0.0001
Chips and crackers	7,560 ± 1,963.7 (280 – 21,500)	6,306.9 ± 1,134.64 (3,800 – 11,400)	4.39*	0.047
Burger	3,500 ± 500 (2,000 – 5,000)	3,735.5 ± 1,074.1 (550.25 – 6192.25)	0.11	0.751
Bars	6588.89 ± 1410.93 (1,200 - 18,000)	16945.41 ± 2516.06 (2712.5 – 37620)	2.62	0.12

Note: mean values are in naira, SE- standard error of prices, and the values in parentheses are the price range of commodities.

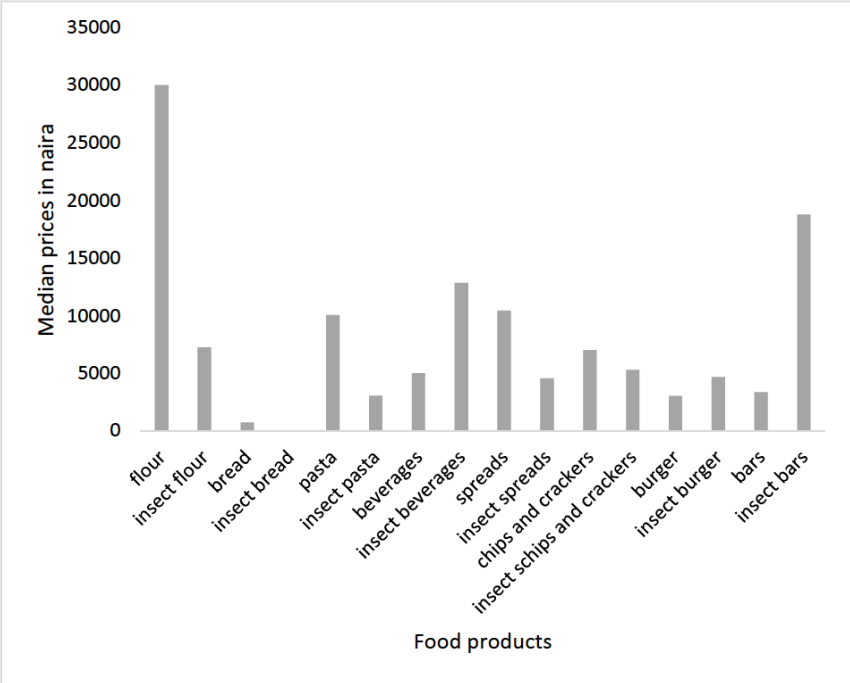

Figure 2: Median price comparison of conventional and insect food commodities in the global market (price in naira equivalent).

Table **4**. Bird feed, especially those for layers, was pricier compared to others. Fish feed was equally pricy. The difference between the prices was significant ($P<0.05$). Insect-incorporated feed was not encountered in the grocery stores, and this made it difficult to present any price for analysis.

3.2. Environmental Impacts

The impact of adopting insects has been outlined from the environment. Firstly, it related to the requirements for rearing insects in both mechanized and mini-breeding facilities and the requirements for

Table 4: Price Comparison between Conventional and Insect Feed Products in the Global Market (Dollar Equivalent in Naira)

Feed	Conventional feed	Insect feed	F-ANOVA	P-value
	Mean ± SE (N)	Mean ± SE (N)		
Grower	6,987.5 ± 882.3 (1,850 - 10,200)	NA	3.71*	0.024
Layer	19,925.3 ± 5,205.3 (6,650 – 38,750)	NA		
Broiler starter	9,628.9 ± 1,528.7 (7,250 – 21,750)	NA		
Broiler finisher	8,053 ± 282.9 (7,200-8,975)	NA		
Fish feed	17,691.3 ± 3,422.6 (2,500-72,000)	NA	-	-

Note: mean values are in naira, SE- standard error of prices, and the values in parentheses are the price range of commodities.

harvesting. Harvesting of insects from the wild in either larval or adult form can serve as an avenue to mass produce in mini-facilities before transferring to the mechanized facility, as shown in Figure **3**. Similarly, the requirement for rearing insects is very low compared to livestock production. For instance, less water in liters, land, feed, and pollution released to the environment is low compared to other animal rearing.

3.3. Architectural Design for Insect Rearing Facility

The proposed architectural plan for the insect production facility is shown in Figure **4**. The rearing area is further explained in Figure **5**. Figure **5** shows an integrated facility for insect rearing. This design can adopt any dimension using a standard building dimension as a guide. A step out of the rearing area is the storeroom and processing room. The mini-rearing of insects can adopt the well-dimensioned design in Figure **6**.

4. DISCUSSION

The prices of the products are major determinants for the successful acceptance of edible insect incorporations in the global market. Price model studies that forecast the economic future of insect incorporations and conventional products in grocery stores are lacking. This makes it almost difficult to compare this study with another edible insect price analysis study, thus making it a novel price study. However, the price models of agricultural products are

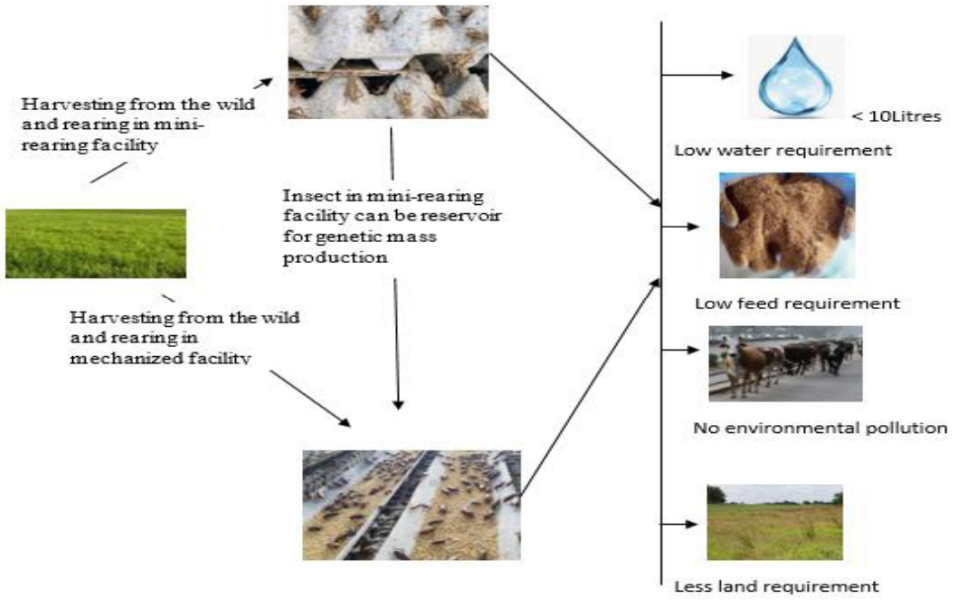

Figure 3: Environmental implications of adopting insects as food and feed.

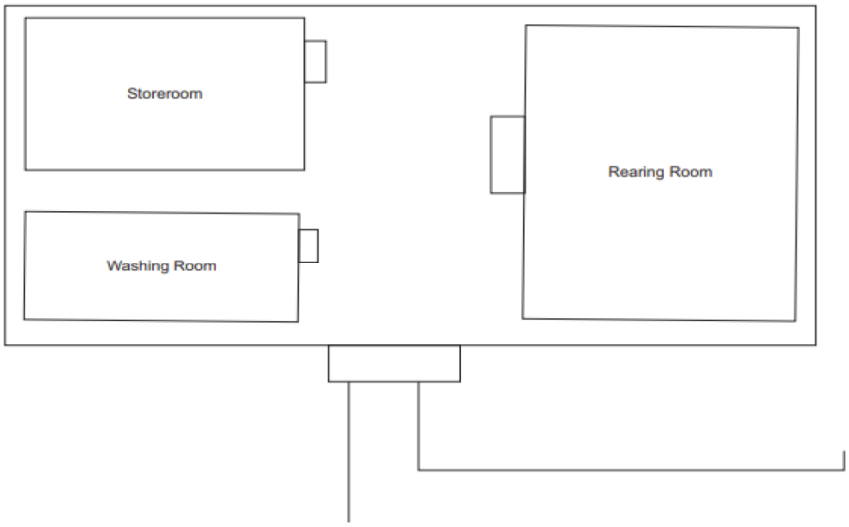

Figure 4: Proposed architectural plan for an insect production facility.

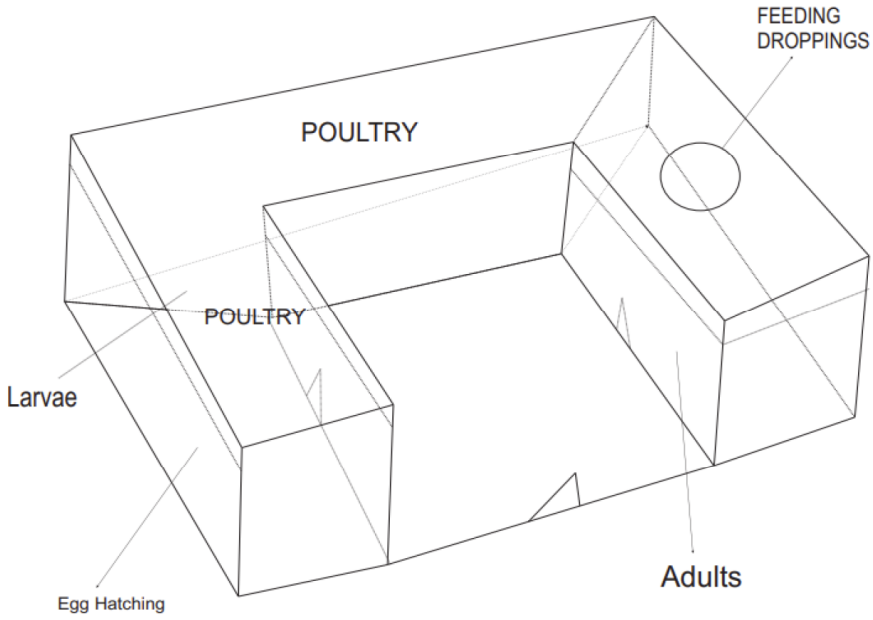

Figure 5: Proposed building skeleton for insect rearing for feed production.

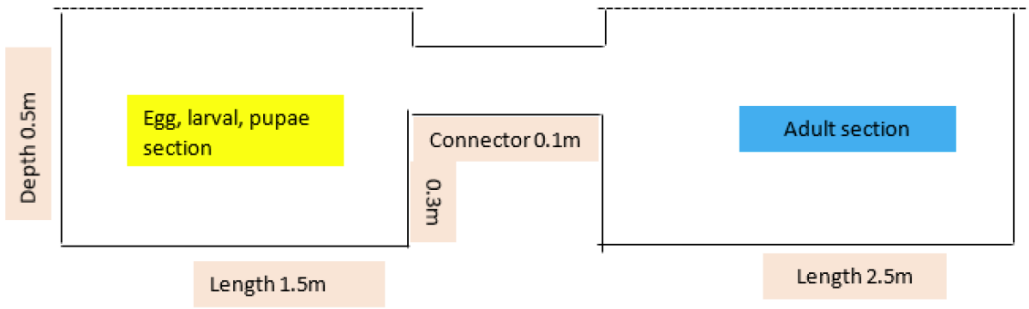

Figure 6: Proposed rearing mini-facility for edible insects in plastic containers.

available in studies [39-40]. A study by [41] highlighted the importance of price as a precursor to consumer-seeking behavior of insect products amidst the quality of the products and the nutritional information. Flours were expressed in a 50kg bag of product, beverages in packs of 24, bread in loaves, pastas, spreads, and bars

in cartons, and burgers per dough. In this current study, the prices of all the conventional commodities were higher except for insect beverages and bars. This is probably due to the fact that edible insect commodities are more accepted and consumed compared to insect-incorporated products that are faced with challenges of human disgust. The price of insect beverages was equally high, and this could be ascribed to the tedious extraction method of whole insects. The first approach to getting consumers to embrace insect food products is to address the over-price tagging by reconciling trends from price models. There are no insect feed products in the grocery stores online. This is probably due to lacking entrepreneurial intervention in this line of production. The price searched per year on the internet was homogenous, and this made it difficult to model the price of commodities in this study. Further study on price modeling should reach out to the management of each grocery store for a detailed list of insect commodities in order to understand and model the price trend.

Insect harvesting and farming can provide entrepreneurial opportunities in developed and developing countries and also provide income through the selling of insect products. Insects have a low risk of transmitting diseases from animals to humans, such as bird flu and cattle diseases [42]. Limited land is required to rear insects compared to a large portion of land for livestock production. Insects help reduce environmental contamination and require less water, as there are no grazing and pollution of crops and the environment compared to cattle rearing. Insects can feed on waste products of food and animal. Limited availability and distribution of edible insects lead to the high cost of edible insects. Edible insects are available in most parts of the world, and this makes it easier to adopt locally known species. The requirement for rearing insects is quite lower compared to livestock production. Less land is required by insects to be mass-produced either in mini-rearing facilities or mechanized facilities [43]. For instance, a 10-meter square concrete well, not more than 1.5 meters deep, is appropriate to start up a mini cricket farm, partitioned into larvae and adult sections. Similarly, about 1 hectare of land is equally appropriate to start up a mechanized insect farm. Much more to this, insect farms can be integrated into livestock farming to clear waste generated from the environment. Less than 10 liters of water is required since some insects rely on metabolic water. Insect-formulated feeds can be adopted in the rearing of insects like other livestock.

There is no defined architectural design put in place to guide the general public who are willing to build edible insect-rearing facilities for large-scale production. The mass breeding of insects is, in one way, to better the environment in terms of diverting attention from waste generated by livestock production. For instance, 600-meter squared land and above is adequate to kick start a small insect farm, which is comprised of an insect rearing area, a washing and processing building, as well as the production and store room building. The store and processing buildings can adopt regular house dimensions while that of the rearing area is further dimensioned. Most insects are holometabolous, having four life stages, including egg, larvae, pupae, and adults, and as such, the rearing area can be compartmentalized following this pattern in a duplex design. The insect rearing area is situated on the first floor, while the livestock production, for instance, poultry, is situated above the structure. The facility is automated in terms of feeding the poultry birds and discharging poultry droppings into the larval section of the insect-rearing area. The poultry section above the larval section is perforated to allow easy passage of poultry droppings. The poultry section above the egg hatching section equates to the egg hatching section of the poultry, and it is not perforated because no waste is produced above, and the egg hatching section of insects does not require waste. An electric humidifier is important in the egg hatching section to record the environmental factor required for the effective hatching of eggs. Rectangular wood placed in layers or paper crates for eggs placed in three or four layers is required for ovipositioning. The larval section for insect rearing is normally smeared with waste from the poultry, which is wetted by an automated shower pipe descended. The pupae cum adult section does not require poultry above, but a hole is made above to allow for serving food and water automatically to emerging insects. In a clear description of the duplex design, you approach the squared house as proposed in Figure **5**; an open space with a center table is presented for sorting and cleaning. The structure inside is walled with clear glass to enable easy monitoring of insect activities without opening doors. The egg-hatching, larvae, pupae, and adult section of the insect-rearing area has a door that is equally made of glass. The dimension could adopt that of a regular building. For low and middle-income countries that cannot adopt this proposed plan, two containers, either circular or rectangular, can be connected with a pipe and used for the mini-rearing of insects. This study is limited to the comparison

between the economic impact of edible insect foods with conventional foods. It is equally limited to the environmental impacts of rearing edible insects in mini- and mechanized rearing facilities, as well as the architectural design of facilities that can be adopted for sustainable rearing of edible insects.

4. IMPLICATIONS AND OUTLOOK

This review has demonstrated that insect inclusion in varieties of familiar products for human consumption can add up to reduce the issues of food insecurity in many developing and underdeveloped worlds. The first is to consider rearing edible insects either in mini-affordable facilities or adopting the architectural design proposed in this study. Proper preparation is equally adequate to monitor the contamination of food and feed. Besides insect adoption as whole snack packs, local consumption and their inclusion in animal feed have been clamoring for in order to increase the number of innovative insect and commercial products in grocery stores. Production and commercialization of insect foods are capable of improving livelihood and the environment. Although, the price of commodities is a determinant for continuous patronage. It was observed that edible insect-formulated food products in grocery stores are quite cheaper compared to conventional products. The bulk of these products are cheaper and consumed more in the Asia-pacific continent when compared to the African region. Environmental, economic, and nutritional values of feed and foods of insect inclusion are by far encouraging.

Considering the fact that prices of conventional products are not likely to improve, especially with the problem of securing quality food ingredient facings in different countries yet unresolved, there is a need to adopt edible insects, a Food and Agriculture Organization (FAO) projected protein alternative, to familiar food and feeds in various innovative forms. There is an equal need to build upon the architectural design to encourage sustainable insect rearing. An outlook on the implication of insects on the environment shows that mass rearing and adopting them as alternative proteins could reduce environmental contamination that comes from livestock rearing and reduce excessive water usage in livestock farming, as well as land required. Insect mass production can be improved if certain terms and conditions such as increased market, consumer acceptance, economic scale-up, standard assessment, shelf-life, well-developed co-operative and funding models, and clear and comprehensive legal framework at national and international levels are considered to pave the way for investment, production, and trading.

ACKNOWLEDGEMENT

Not applicable.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not Applicable.

CONSENT FOR PUBLICATION

The authors have declared the publication of this manuscript in your journal. Please contact any of us via email when necessary.

AVAILABILITY OF DATA AND MATERIAL

All the data are analyzed and presented in the article.

COMPETING INTERESTS

The authors declare no competing interest.

FUNDING

Not Applicable.

AUTHORS' CONTRIBUTIONS

CC and VN conceived and designed the study. OG collected the field data. VN analyzed the data. All authors interpreted the analyzed data and wrote and reviewed the manuscript. All authors equally read and approved the final manuscript.

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Received on 10-04-2023 Accepted on 06-06-2023 Published on 27-09-2023

https://doi.org/10.6000/1929-4247.2023.12.03.5