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CONSUMPTION OF EDIBLE-INSECTS: THE CHALLENGES AND THE PROSPECTS

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ABSTRACT

Alternative sources of proteins are necessary to tackle the foreseeing challenge of protein scarcity. Insects were among the foods consumed by early man and they are still vital components in the diets of Asia, Africa, and Latin America. Social barriers are limiting their global acceptance, their consumption is intimately attached to location and culture, and their nutritional values are not known to many. Their consumption is associated with taboos and pessimisms, and are seen as something filthy, not something decent to be consumed. The aim of this review was to provide an overview on the challenges and prospect of edible-insects, and provide highlights on their global position in human nutrition. Literature used was gathered through an online search on Google Scholar and Science Direct databases. Disgust, food neophobia, lack of awareness, unavailability, and personality traits are the major barriers to edible-insect acceptance among consumers. Accepting edible-insects as food depends greatly on location, eating habit, prior experience, age, gender, and religion of a consumer. Entomophagy advocate should intensify their efforts and attract more consumers in the West and other parts of the globe. Research collaborations between applied and social sciences are necessary to win the affection of new consumers and convinced their psych and emotion during the first introduction. Creating awareness on the nutritional, health, and environmental benefits of using insects as a novel protein, processing to completely mask insect presence, and producing products with a close resemblance with meat will certainly promote global insect consumption.

Keywords: entomophagy, alternative protein, consumer perception, insect consumption, unconventional protein.

INTRODUCTION

Entomophagy is a global practice, except in developed countries, mainly Europe and North America (Megido *et al.*, 2014; Testa *et al.*, 2016). Over 2 billion people from over 3000 ethical groups in 130 countries (Ramos-Elorduy, 2009), mostly in Asia, Africa, and South America (Rumpold & Schlüter, 2015; Poelaert *et al.*, 2018), consumed from over 2000 identified insect species (Niassy and Ekesi, 2016; Tang *et al.*, 2019). The edible insects account for only 0.2% of over one million insect species described by science (Akhtar and Isman, 2018; Cartay *et al.*, 2020). Indigenous edible insects are readily available in Asia, Africa, and South America (Gahukar, 2011). Africans consume approximately 500 species (Kelemu *et al.*, 2015) while in India alone about 255 species are considered edible (Chakravorty, 2014). Commonly consumed insects are grasshoppers, termites, large moth caterpillars (Chung, 2008), beetles, bees, wasps, ants, locusts, crickets, cicadas,

leafhoppers, planthoppers, true bugs, dragonflies, and flies (van Huis *et al.*, 2013). The biodiversity in the insect species leads to great variation in chemical composition and microbiology of insects (Fernandez-Cassi *et al.*, 2019).

About 4 billion people in the world rejected insects as food (Ruby, Rozin & Chan, 2015) and they may continue to be rejected in many parts of the World (Williams *et al.*, 2016). Legal barriers, safety concern and lack of consumer acceptance are among the leading obstacles in promoting entomophagy (Rumpold & Schlüter, 2015). Interest in consuming new foods and environmental advantages of entomophagy will continue to promote insect consumption in the future (Sogari, 2015). Understanding the environmental impacts of insects and factors affecting the safety and quality of their proteins will play important roles in eliminating barriers to their universal acceptance (Payne *et al.*, 2016). Information regarding insect acceptability by other societies, their nutritional qualities, and their low environmental impacts can make consumers change their perception of entomophagy (Hunts *et al.*, 2020).

The world population is expected to reach 9.7 billion by 2050 (Tomberlin *et al.*, 2015; Gallo and Federico, 2018). Therefore, alternative protein sources are necessary to provide the accelerated world population with the required amounts of protein (Megido *et al.*, 2014; Tang *et al.*, 2019). Also, to provide developing nations that are currently suffering from food insecurity and malnutrition with sufficient protein and other essential nutrients (Ramos-Elorduy, 2009; Gahukar, 2011).

BARRIERS TO EDIBLE-INSECTS ACCEPTANCE

Rejection

Many people are ignorant about the nutritional qualities of insects and choose not to pay attention to their nutritional benefits (Jacob *et al.*, 2013). Concerns for using insects as food are also related to their safety, animal right, and consumers' right (Pali-Schöll *et al.*, 2019). Insects can be edible and people may choose not to routinely consumed them (House, 2018) because their consumption in some parts of the world is taboo with strong negative emotion and is normally associated with the poor economic class (Rao, 2016).

Entomophagy is reducing in many societies because is considered by some to be an old dietary style, dirty and unhealthy (Akullo *et al.*, 2017). In Africa, rejection is due to poor awareness and negative thoughts associated with insects in some societies (Niassy *et al.*, 2016). Edible insects are known and consumed more by elderly persons than the new generation in Botswana (Obopile & Seeletso, 2013). Modern upbringing style and changes in culture and religious beliefs also contributed to the decline in entomophagy (Chung, 2008). This is usually common in westernized societies (Yen, 2015a), many young people in these societies have negative views about entomophagy (Chung *et al.*, 2002). Insects such as cockroaches, and alike, that are known to be dwelling in dirty places are rejected by new consumers (Ruby, Rozin & Chan, 2015), and they may continue to be rejected due to their unclean habitant, disgust and safety concern.

Rejection by the West

Eating insects is a taboo among the majority of people in Western countries (Sidali *et al.*, 2019), many avoid the idea of eating insects for several reasons (Ali, 2016).

Except for the Czech Republic where insects are process and market (Bednárová *et al.*, 2013), the Western world rejected insects as food predominantly due to cultural reasons (Sogari, 2015). Disgust is the most common reason for rejecting insects among Americans (Ruby, Rozin & Chan, 2015), this is derived by fear of diseases and contamination (Jensen & Lieberoth, 2019). Western people are not familiar with insects as food and some believed that insects are filthy and potentially harmful (Barton, Richardson & McSweeney, 2020). Most of the Western people are regarding insect as a mere pest, not something decent to be considered as food (Glover & Sexton, 2015), therefore, it will be difficult to predict whether insect will be fully accepted as food in the region (Sogari, 2015).

Peculiarity disgust is the most important predictor of edible-insects acceptance, it is superior to environmental and health consciousness (Powell, Jones & Consedine, 2019). Food neophobia and food technology neophobia also contribute to insect rejection in the West (Lammers, Ullmann & Fiebelkorn, 2019). The alleged poor sensory attribute lamented by some Western consumers was the reason for their rejection (Tucker, 2014; Cunha and Ribeiro, 2019). The high cost and unavailability of insects may affect their acceptance (Barton, Richardson & McSweeney, 2020), also lack of interest in trying novel foods by some persons (La Barbera *et al.*, 2020).

Shelomi (2015) opined that entomophagy was rejected by Western people due to the wrong strategies adopted during the first introduction, entomophagy advocates and researchers focused on education and trialability to promote the acceptance of the edible insects, forgotten that changes in value are supply-driven, and there were no follow-up studies that will justify any rejection. Also, ethical issues were given less attention to promoting entomophagy (Waltner-Toews & Houle, 2017). In the current approach, justifications were mostly given based on the nutritional, economic, and environmental benefits of entomophagy. This is putting new consumers in a dilemma, the psychology of the consumers' needs to be changed first since disgust is deeply associated with the individual psyche (Deroy, Reade & Spence, 2015). Shelomi (2015) also argued that using scientific evidence alone will not ensure total adoption of entomophagy by the Western population, according to him entomophagy will only be accepted by Western when attention given to production and marketing strategies were changed to focused more on supply-side innovations. This may be true; as Western consumers keep on rejecting insects despite the long-term campaign regarding their environmental, nutritional, sensory, food safety, and environmental benefits (van Huis, 2015). Sidali *et al.* (2019) opined that adopting rural tropical culture can improve insect acceptance in the West. Also, Issues related to emotion and psychology must be addressed for entomophagy to be accepted by the Western countries (van Huis, 2015).

Disregarding insects as food by Western countries leads to avoiding insects in food production research in the region (van Huis *et al.*, 2013). Entomophagy is still a strange field of study in Europe, this accounts for it is slow development and less commitment to marketing and business

analyses (Pippinato *et al.*, 2020). Solutions to the present problems in entomophagy required multidisciplinary collaboration and cooperation between technical and social sciences (van Huis, 2017). Efforts should be double on public awareness of the importance of using insects as food since exposure to entomophagy is among the leading factor that influences willingness to accept insects as food (Woolf *et al.*, 2019). Better solutions can be postulated when the reasons behind the rejection were fully understood (Santeramo *et al.*, 2018). More researches are needed in the areas of safety, mass production, improved technology for harvest and postharvest products development, acceptance, and marketing (Rumpold and Schlüter, 2013; Liu and Zhao, 2019; Schlüter and Rumpold, 2019). These can improve acceptance and lower rejections caused by eating habit, cultural norms and safety worries.

Safety Concern

Insects can be a vector of disease, can sting and bite, can also accumulate pesticides, and passed it to the food chain (Rao, 2016). They harbor a wide range of both pathogenic and spoilage microorganisms (Grabowski & Klein, 2017). Their safety concerns are related to microbial contaminants, allergens, and chemical contaminants such as toxins and heavy metals (Cappelli *et al.*, 2020). Edible insects were rejected by many because of the claimed pathogenicity and allergenicity (Patel, Suleria & Rauf, 2019). Consuming raw insects can be dangerous (Grabowski & Klein, 2017) as many species produced for food and feed can cause disease from the several microorganisms they harbor (Eilenberg *et al.*, 2015). Insects are associated with some risks even when grown under controlled conditions, the risk depends on the species, rearing, and processing conditions (Mézes & Erdélyi, 2020). There is hazy information regarding edible-insects safety (Alrifai and Marcone, 2019; Murefu *et al.*, 2019). Some insect species that are traditionally considered safe may turn unhealthy when subjected to laboratory scrutiny, some species can contain allergens and others can feed on contaminated plants (Mézes & Erdélyi, 2020). Safety regarding pesticide residues, mycotoxins, and human pathogens must be considered (Rumpold & Schlüter, 2015) as insects are regarded as unhygienic and disease vectors by Western people (Lensvelt & Steenbekkers, 2014). Researches should be intensified in the area of safety to protect consumers from any possible health risks associated with insects (Fernandez-Cassi *et al.*, 2019). The nutrients quality, bioavailability, and digestibility need to be assessed for all the edible species (Rumpold & Schlüter, 2015). Safety measures including control of hazardous chemicals, allergens, pesticide residues, pathogens, all forms of toxins, etc., must be pondered during farming, harvesting, processing, and distribution of insects and insect products (Liceaga, 2019). Substantial research needs to be conducted in the area of safety including allergy reactions, anti-nutritional factors, and all forms of contaminants (Testa *et al.*, 2016). Cappelli *et al.* (2020a) come up with strategies that will ensure the safety of edible-insect during processing. Consuming raw insects can be dangerous (Grabowski & Klein, 2017) as

many species produced for food and feed can cause disease from the several microorganisms they harbor (Eilenberg *et al.*, 2015).

Microbiological concern

Present understanding of insects shows that insect pathogens do not harm vertebrates (Eilenberg *et al.*, 2015), therefore, there is a low risk for transmission of zoonotic diseases such as bird flu and mad cow disease by insects (Rao, 2016). Unlike in the vertebrate animals used as a source of protein, insect pathogenic viruses occurring in a farmed insect cannot be transmitted to humans, therefore, farmed insects are not considered to be biological vectors (Finke *et al.*, 2015). Insects contain a wide range of microorganisms, González-Escobar *et al.* (2018) reported 299 and 285 genera of microorganisms in the larva and adult escamolera ants respectively, included are the following species: *Pseudomonas, Bradyrhizobium, Flavobacterium, Burkholderia, Methylobacterium, Corynebacterium, Brevundimonas, Arsenophonus, Sphingomonas, Rhizobium*, and *Sphingobium*. Several pathogenic microorganisms including *Acinetobacter, Bacillus, Buttiauxella, Campylobacter, Clostridium, Staphylococcus, Pseudomonas*, and Neisseria were identified by Ssepuuya *et al.* (2019b) in grasshopper. Clostridium perfringens spores, Enterobacteriaceae, lactic acid bacteria, yeasts, and molds were found in processed cricket, locusts, and mealworm larvae (Garofalo *et al.*, 2017). In general, microbial population and diversity are significantly affected by growing habitat, trading location, swarming period, and plucking methods (Ssepuuya *et al.*, 2019).

Consumption of raw insects can be dangerous as they may harbor pathogenic microorganisms (Garofalo *et al.*, 2019) such as Salmonella, Campylobacter, and Escherichia coli (Finke *et al.*, 2015). Higher total aerobic mesophilic bacterial and Enterobacteriaceae counts were reported by Grabowski and Klein (2017) in a variety of raw insect samples collected from pet shops and private breeders. House cricket was reported to have higher aerobic bacterial counts and spore-forming bacteria after thermal processing (Fernandez-Cassi *et al.*, 2019). The natural microbiota of insects withstand rearing and processing conditions, bacteria found in insects possess heat resistance and spore-forming potentials (Frigerio *et al.*, 2020), these organisms required special attention during processing and storage. Vacuum cooking and boiling are the most effective methods for destroying microorganisms in insects (Megido *et al.*, 2018). Raheem *et al.* (2019) recommended the application of strict critical control points along the processing chain to prevent cross-contamination. The microbiological quality of edible insects can be improved by improving the rearing and harvesting conditions (Grabowski & Klein, 2017), also by starving them until they empty their stomach before harvesting (Megido *et al.*, 2014).

Chemical contaminants and allergens

Limited data on the heavy metals content and other dangerous chemicals are the leading challenges regarding insect safety (Fernandez-Cassi *et al.*, 2019). Accumulation of chemical contaminants such as heavy

metals, mycotoxins, and veterinary drug residuals in insects depends on their food and occurs more in insects with a longer life cycle (Finke *et al.*, 2015). Hazardous chemicals such as allergens, heavy metals, anti-nutrients, pesticides, etc. are the potential threat (Raheem *et al.*, 2019). Chemical hazards, toxicology, allergy, and other safety issues must be investigated to ascertain the wholesomeness of edible insects (Kelemu *et al.*, 2015). Issues to be considered include microbial safety, toxicity, and inorganic contaminants (van Huis *et al.*, 2013). Consumption of wild-harvested insects can be dangerous as they are often treated with insecticides (Van Huis, 2020). Organic contaminants, Zn, and Cu in edible insects are similar to that in conventional proteins, while As, Co, Cr, Pb, Sn are found in lesser amounts (Poma *et al.*, 2017). The levels of pesticides, veterinary drugs, and mycotoxins in mealworm, grasshopper, house cricket and black soldier fly obtained from pet stores and research centers in Belgium were below the permitted maximum residue limits for other edible foods (De Paepe *et al.*, 2019). Insects such as the black soldier fly can bio-accumulate non-essential elements such as barium, bismuth, and gallium in addition to essential elements (Proc *et al.*, 2020). Köhler *et al.* (2019) reported a low level of arsenic, cadmium, lead, and mercury in Bombay locust, scarab beetle, house cricket, and mulberry silkworm. Tannin and phytic acids were reported by Chakravorty *et al.* (2016) in Oecophylla smaragdina and Odontotermes sp.

Research on insect allergy is still at the infancy level and current EU regulation on edible insects does not force producers to include insects in the list of allergenic substances (Garino *et al.*, 2020). Caution must be taken to avert allergic response in sensitive people (Ayensu *et al.*, 2019), new allergic reactions are expected to emerge as insect consumption is continuously encouraging and insect foods are introduced to more people (Fernandez-Cassi *et al.*, 2019). The phylogenetic relationships of insect with crustaceans and house dust mites prompted the need for assessing edible insect safety, many studies revealed the occurrence of cross-reactivity between tropomyosin and arginine kinase in crustaceans (Ribeiro, Cunha & Sousa-pinto, 2019). These allergens were well-known in arthropods, also found in insects (Rumpold & Schlüter, 2015). Mealworm-based products can cause an allergic reaction to persons that are allergic to crustacean (Garino *et al.*, 2020). Francis *et al.* (2019) reported cross-reaction in mealworm and cricket arginine kinases, the researchers also concluded that cross-reaction with/between arginine kinases from other insect species is also possible.

Availability

Inaccessibility creates a barrier to the acceptance of novel foods (Tuorila & Hartmann, 2020). The availability of insects is the primary determining factor for their consumption, the insect species consumed by humans are the most abundant naturally (Raubenheimer & Rothman, 2013). Seasonality is among the major challenge that hinders insect consumption, many species are only available for some months because their life depends on a particular seasonal plant (Jacob *et al.*, 2013). Insects are overexploited in some parts of the world and many species are on the verge of been exhausted. The population of an edible caterpillar is seriously declining in South Africa, this may be associated with over-harvesting and climate change (Langley *et al.*, 2019).

Making insects more available through commercialization will reduce disgust and encourage acceptance (Sidali *et al.*, 2019). Large scale production of insects is important to provide significant quantities and prevent overexploitation of species (Yen, 2015b).

Harvesting insects at their exponential growth rate prevent overexploitation of species (Ramos-Elorduy, 2009). The use of modern technology in insect harvesting can increase collection efficiency but may put more pressure on the natural source (Yen, 2015a). Depending on the natural source of insects will not ensure a continuous supply as many species are known to be seasonal (Tang *et al.*, 2019). A sustainable supply of insects will only be achieved when their potentials are considered and attention similar to that given to the production of other sources of protein is given to their production (Jacob *et al.*, 2013).

Affordability

Affordability is among the major limitations in promoting insect consumption, overcoming this will increase the demand for insect foods (Ruby, Rozin & Chan, 2015). Insects proteins are more expansive than conventional proteins in Western countries (Pippinato *et al.*, 2020), and in some cities of Central Africa (Odongo *et al.*, 2018). In the United States, cricket powder is more expensive than conventional protein (Morales-Ramos, Rojas & Dossey, 2018), and some edible insects can cost twice the price of beef in Nigeria (Jacob *et al.*, 2013). In many cases, insects are not available year-round, therefore, they can be expensive even in places with abundant wild species. In South-eastern Nigeria high cost of harvesting and shortage during the dry season are the major barrier to entomophagy (Ebenebe *et al.*, 2017). Some processing methods also propel the price of insect products, for example, extraction of insect protein is very expansive; more profitable processing methods are required to make insect proteins more affordable (van Huis *et al.*, 2013). Another challenge is the production of insect products with amazing sensory properties that will cost less than conventional protein (Gjerris, Gamborg & Röcklinsberg, 2016). Pleasant sensory attributes can be derived from insects' protein when they are subjected to appropriate and adequate processing conditions.

Legislation constrains

Insects are considered as an impurity with specific permissible limits in the food regulation guidelines of many countries, legislation that will guide insect utilization as food and food ingredients need to be developed (Mariod, 2020). Legislations on edible insects are not enough (Gahukar, 2016), authorities need to be convinced that using insects as either food or feed is safe for both humans and animals (van Huis, 2017). Lack of well-defined legislation on edible insects is a serious burden to entomophagy (Mariod, 2020), also a misinterpretation of existing law by authorities as reported by Arppe *et al.* (2020) in Finland. Presently there are no specific regulations for breeding and marketing of edible insects in many countries (Mézes & Erdélyi, 2020). Lack of clear legislation and norms also hinders the industrial development and farming of insects in developed nations (van Huis *et al.*, 2013). Many Insect producers do not report information related to traceability, veterinary drugs, farming, storage, and transportation conditions (Fernandez-Cassi *et al.*, 2019). It will be important to display the results for risk assessment for the attention of the consumers (Mariod, 2020). Ulrich *et al.* (2017) developed a procedure for determining insect ingredients in processed food using Matrix-Assisted Laser Desorption Ionization-Time Of Flight Mass Spectrometry (MALDI-TOF MS). This will help in checking adulteration and contaminations.

Entomophagy is receiving less attention in the West because is considered as a new culinary art that many are not ready to accept (Lotta, 2019). Edible insects were captured in the new EU novel food regulation

but there are still controversies regarding insect farming, slaughter, and processing regulation (Lotta, 2019). Marketing is only allowed when the insect or it is product is duly authorized by the food regulatory body, a protocol that entails safety assessment (Goumperis, 2019). Clear legislations are required to guide insect farmers and to control insect application in food (Liceaga, 2019), they are also needed in the area of feedstuff, hygiene, the permissible limit of undesirable substances, microbiological criteria, and guideline for import (Goumperis, 2019). The approval statement for the use of insects as food in the US is not clear, details were not provided on whether insects are to be used as additives or their use shall be generally recognized as safe (GRAS) (Lotta, 2019). Inadequate communication, lack of mutual vision, and inter-firm linkages among stakeholders are affecting the realization of unanimous policy (Marberg, van Kranenburg & Korzilius, 2017).

Another important legislation challenge is on insect welfare during production and slaughter (Goumperis, 2019). There is a need for research in the areas of insect welfare, health, farming system, and humane killing method, it is necessary to include insects into the scope of animal protection law (Pali-Schöll *et al.*, 2019). It's important to determine whether insects are sentient or not because there is no established scientific evidence that proves the emotional consciousness of insects (Pali-Schöll *et al.*, 2019). Using organic waste as feed for edible insects also requires a legal framework (Mariod, 2020), as this is among the factors that strengthen the rejection of insects as food by regulatory organizations in the Western world (Hartmann & Bearth, 2019).

Over-Reliance on Wild Species and its Consequences to the Environment

More than 90 % of edible insects are sourced through wild gathering (Yen, 2015a). There is a discrepancy between insect conservation and entomophagy, indiscriminate harvesting of insects can be a threat to some insect species and the environment (Yen, 2009). Care must be taken as some potential solutions to food security problems are incompatible with the solutions of other problems (Dicke, 2018). Anthropogenic activities and climate changes are affecting the availability and distribution of insects and presently many species are in danger (van Huis *et al.*, 2013). Edible insect species in tropical countries are on the verge of extinction (van Huis & Oonincx, 2017). Harvesting edible insect randomly can have ecological and environmental implications by reducing insect population and altering ecological interaction between insects and plants (Choo, 2008). Ecologists considered entomophagy as a barbaric act that destroys a natural relationship in the ecosystem that allows other animal and plant species to prosper (Rao, 2016).

Enlightenment on sustainable practice on wild insect collection and habitat preservation are essential in maintaining ecological balance (Nadeau *et al.*, 2015). Economical rearing, harvesting, and processing techniques are necessary to prevent population depletion and ecological imbalance (Kelemu *et al.*, 2015). Domestication of insects and sustainable harvesting practices will reduce the dangers associated with over-reliance on the wild source (van Huis, 2017). The development of entomophagy requires upscaling the entire production chain to include technologies for mass rearing, harvesting, processing, and packaging, also extensive studies on socio-economic and marketing patterns (Kelemu *et al.*, 2015).

Tendencies for Incessant Rejection

Westerners continue to reject edible-insects despite their enormous role in the

global consumption of animal proteins (Shockley & Dossey, 2014). Their acceptance will have a great impact on global entomophagy recognition (Alexander *et al.*, 2019). There is a high disposition that the Western world will continue to reject entomophagy as recent findings by many researchers expressed persistent resistance to entomophagy by Western people, therefore, a lot of work needs to be done by entomophagy advocates in Western countries to influence the majority of the population. Lombardi *et al.* (2019b) reported that neophobia is still a trending hurdle to insect acceptance in Italy. They also have little awareness of the environmental impacts associated with conventional protein production, and only a few are willing to consume meat alternatives (Hartmann & Siegrist, 2017). Even persons that are familiar with entomophagy and possess high environmental consciousness continue to reject edible insect in Germany (Orsi, Voege & Stranieri, 2019). The high level of consciousness on food choice commonly observed by many in the Western world increases their disgust and lower their willingness to accept insects as food (Chan, 2019), most consumers insisting on knowing the ingredients used in the production of any strange food (Cicatiello *et al.*, 2020).

The results of online surveys recently conducted by researchers continue to show a negative attitude toward entomophagy among Western people, these include the work of Jensen and Lieberoth (2019) conducted among Danish undergraduate students and that of Orsi *et al.* (2019) conducted among Germans. Similarly, German children and adolescence prefer to consume culture meat bugger than insect bugger (Dupont & Fiebelkorn, 2020). A survey conducted by Hwang and Choe (2020) in South Korea shown that the overall image of edible insect restaurants is negative due to taboo, consumers are also cautious about the insect quality and alleged that edible-insects can cause health problems. The results of an interview conducted by Myers and Pettigrew (2018) with 77 elderly Western Australians, aged 60 years and above, showed a low level of awareness on nutritional and environmental benefits of using insects as food, and most of the interviewees believe that entomophagy is incompatible with their cultures and values. Videbæk and Grunert (2020) reported multidimensional regression results indicating ambivalence attitude among Danish consumers, the individual difference concerning disgust may lead to this kind of uncertainty (Powell, Jones & Consedine, 2019).

Another challenge that will continue to deter the acceptance of entomophagy in the West is the unavailability of insects in these countries, Gómez-Luciano *et al.* (2019) reported that consumers in UK, Spain, Brazil, and the Dominican Republic are more willing to accept plant proteins as an alternative to meat than insect proteins because plant proteins are more readily available. The type of insect used as food is also of concern to many consumers, online survey conducted in Germany by Lammers *et al.* (2019) showed that 41.9 % of the respondents are willing to consume insect burger but only 15.9 % of the survey respondents are willing to consume burger containing buffalo worm used as the principal ingredient.

PROMOTING INSECT CONSUMPTION : THE CURRENT PRACTICES

Elimination of Sociocultural and Psychological Barriers

Disgust, food neophobia, lack of awareness, unavailability, and personality traits are the major barriers to edible-insect acceptance among consumers. Entomophagy depends greatly on location, eating habits, prior experience, and age, gender, and religion of a consumer. Payne *et al.* (2016)

and Terrien (2017) opined that acceptance of insects as new food will suffer serious impediments due to social and psychological barriers that are in many cases intimately attached to the location, culture, believes, and eating habits. Introducing novel food may require a solid understanding of the values and believes related to the culture of the targeted population (Bisconsin-Júnior *et al.*, 2020). Consumers must be informed about the nutritional benefits of using insects as food (Gahukar, 2016) and insect must be seen as a source of protein and not feculent (Terrien, 2017). Introducing insect food into different cultural settings may require different approaches, people with different cultural backgrounds have a different perception of using insects as food (Bisconsin-Júnior *et al.*, 2020). Facilitating edible insect acceptance is a complex and difficult task, it requires understanding the psychology and behavior of the new consumers (Dermody & Chatterjee, 2016). Promoting entomophagy after adopting western foods requires a broad record of insects consumed in the past (Ebenebe *et al.*, 2017). There is a need to overcome these obstacles by convincing new consumers particularly Western people, with the evidence that will conquer their reluctance on using insects as food (New, 2013). To fast track this, the benefit of using insects must be observable to consumers (Terrien, 2017). Deroy *et al.* (2015) opined that a place must be created for insects in the circle of nutrition, they should not be portrayed as a conventional protein substitute.

Insects' appearance, their sensory attributes, and the availability of information regarding their safety and origin are among the key factors determining their acceptance (Mishyna, Chen & Benjamin, 2020). Recommendation by other consumers and shopping locations also affect willingness to consume insects (Alemu *et al.*, 2017). A substantial milestone was recorded in the last five years, and capacities were exponentially developed in the areas of rearing, processing, awareness, and marketing of edible insects globally (van Huis, 2020). The tremendous effort by the Association of African Insect Scientists in securing research funding and convincing policymakers to accept insects as an alternative source of protein promote insect consumption in Sub-Sahara Africa (Niassy *et al.*, 2018)

The nutritional benefit of insects cannot be realized if people chose not to consume them (Stull *et al.*, 2018). Lombardi *et al.* (2019b) reported that the perception of consumers can be change by explaining the benefit of using insects as food. Insect consumption is presently promoted through scientific comics, diffusing rural dietary cultures to an urban setting, and the use of attractive marketing including strategic packaging ideas (Payne *et al.*, 2016). Another means for promoting entomophagy is by the bottom-up approach in ingredients substitution, and by preparing insect meals in more delicious and attractive manners (Ruby, Rozin & Chan, 2015). Incorporation of insects into other products increases convenience and reduced psychological barriers to insect acceptance (Telfser & Temmes, 2015). The use of modern food technologies and standards can enhance insect consumption through the provision of insect products that are safe and attractive (Jacob *et al.*, 2013). Ethical concerns are important in promoting entomophagy, (Gjerris, Gamborg & Röcklinsberg, 2016) identified five critical ethical areas that are relevant while promoting entomophagy viz. environmental influence, human and animal health, human inclinations, social satisfaction, animal welfare, and animal ethics issues

The potential of social influences in promoting insect acceptance was reported by Berger *et al.* (2019). Entomophagy advocates are using sustainability aspects of edible

insects in convincing European entrepreneurs to start edible insect's business (Telfser & Temmes, 2015). Consumer education and public enlightenment about entomophagy can influence the attitude of new consumers (Lensvelt & Steenbekkers, 2014), these include active communication and outreach programs that smartly combined information, education, and exposure (Telfser & Temmes, 2015), also changing the attitude of consumers through motivations (Tuccillo, Marino & Torri, 2020). In addition to the sociocultural practice, price and quality, benefits, risks, naturalness, trust, attitude and culture, and fit with consumer needs also reported to affects insects acceptance (Lensvelt & Steenbekkers, 2014).

Strategies and Methods for Improving Sensory Qualities

Fear and negative attitude toward insect consumption can be minimized by allowing consumers to compare insect protein with conventional protein in a sensory session (Megido *et al.*, 2014; Barton *et al.*, 2020). Researches involve tasting sessions provide positive results than online surveys which are mostly characterized by strong rejection (Gere *et al.*, 2018). Revealing product information can influence consumer perception during a sensory session (Pambo *et al.*, 2018), therefore, a combination of semantic manipulation and practical sensory evaluation will play an important role in introducing edible insects to new consumers (Ali, 2016). The first eating experience is critical to acceptance, positive perception during the first trial will motivate consumer's willingness in accepting insects (Hartmann & Bearth, 2019). Improving sensory characteristics of insect based-food will minimize the negative perception of the overall liking of the insect products (Cunha & Ribeiro, 2019). Introducing insect-based foods during childhood will reduce disgust by ensuring early familiarisation (Tuorila & Hartmann, 2020).

Products without visible insects or visible parts, such as legs or wings are more acceptable (Gere *et al.*, 2018). Used of insect flour in the production of insect-based food is a noble approach that can mask the insect (Zocca *et al.*, 2018). Entomophagy can be promoted by incorporating insects into familiar products (Lensvelt and Steenbekkers, 2014; Van Huis, 2015; Liceaga, 2019), because many people are very uncomfortable with the natural appearance of the insects (Tang *et al.*, 2019; Jensen and Lieberoth, 2019; Tuccillo *et al.*, 2020). The possibility of integrating edible insects into the meal of Western Europe was reported by (Megido *et al.*, 2014). Recent findings reported an increase in the acceptance of insect protein incorporated into familiar foods (Pambo *et al.*, 2018; Liceaga, 2019). Foods produced from processed insects with no visible components (Pippinato *et al.*, 2020) and unaltered sensory (appearance, aroma, flavor, texture) characteristics (Liceaga, 2019) are more acceptable. Cicatiello *et al.* (2020) studied the acceptability of different insect products using sensory panel, the results of their research revealed that chocolate bar prepared with insect powder was more acceptable than other foods with visible insects. Defatting of insects can improve their acceptability, Ribeiro *et al.* (2019b) reported improved sensory properties and overall acceptance in cereal bar produced from defatted cricket powder.

PROSPECTS OF EDIBLE INSECTS

The Entomophagy Attitude Questionnaire (EAQ) recently developed by La Barbera *et al.* (2020), which was cross-validated and recommended by Verneau *et al.* (2021) will be used as a standard scale for entomophagy perception and willingness studies when fully accepted. Entomophagy is

among the trending topics in food and feed research because of the expanding interest in using insects as both food and feed (Niassy & Ekesi, 2016). In the last two decades, scientists thoroughly investigated and reported reasons for considering insects as food based on their nutritive, health, and economic significance (Ruby, Rozin & Chan, 2015). Edible insects provide protein to many traditional diets and are an important livelihood in many cultures (Choo, 2008).

Researchers are working hard to promote the consumption of edible-insect among European and American consumers. Entomophagy may be accepted by the Western world because scholars and policymakers begin to consider insects as an alternative source of conventional protein (Chan, 2014). More attention was given to entomophagy in the Western countries after the FAO report on edible insects in 2013, since then, acceptance of insects as food is growing both in academia and in commercial spaces (Payne *et al.*, 2019). Entomophagy is gradually becoming popular in the Western world (Pippinato *et al.*, 2020; Poelaert *et al.*, 2018) and the campaign is yielding positive results as a significant increase is observed in the production and marketing data (Pippinato *et al.*, 2020). There is also a substantial increase in the researches trying to reveal the potentials of edible insects as a safe and novel source of protein (Jantzen da Silva Lucas *et al.*, 2020). Many companies showed interest in joining the edible-insects industry and entomophagy was also added to the curriculum of many institutions (Dunkel & Payne, 2016). European Commission is investing vastly in researches to explore the feasibility of using insects as food and feed in the future, policies that will allow insect utilization as food and feed are also underway (Testa *et al.*, 2016). With the enactment of the amended Novel Food regulation in January 2018, the marketing of edible insects is fully regulated by the European Union (Schlüter & Rumpold, 2019).

There is growing interest in insect farming for food in the West (Berenbaum, 2016), and some consumers have shown a positive attitude towards direct and indirect entomophagy (La Barbera *et al.*, 2020). The acceptability of insects by Western people depends on the commitment of the key stakeholders in the food chain. Producers, researchers, food regulatory bodies, entomologists, and processors should provide consumers with supportive information that will assist in convincing the consumers to consider insects as a good and novel source of protein (Hunts *et al.*, 2020). An online survey conducted by Ruby *et al.* (2015) shows that a significant proportion of Americans are willing to accept insects as food. A bright future is foreseeing with the start of the commercial production of insects in the United State (Morales-Ramos, Rojas & Dossey, 2018). The consumption of mealworm and cricket is increasing in Europe as the two insects are now commercially available as a whole and as an ingredient (Francis *et al.*, 2019). Western acceptance of entomophagy is critical to global acceptance of insects as food due to the status of European food laws in global food policy (Telfser & Temmes, 2015). Creating awareness on the health and environmental benefits of using insects as a novel protein source, adequate processing to completely mask insect presence, and smart processing to produce products with a close resemblance with meat will certainly promote global insect consumption.

Katayama *et al.* (2005) and Katayama *et al.* (2008) proposed the use of edible insects in the design of a space agricultural system to be used as a source of protein in space diet. This is because insects can survive in a wide diversity of ecological conditions (Rao, 2016). In addition to protein, insects can also contribute to the production of other

foods in the space, can be used as feed for other animals, and can also serve as pollinators in crop production (Katayama *et al.*, 2008).

Insects are predominantly consumed more in tropical countries because they occur naturally in mass (van Huis, 2015). Insects are favored food in some parts of Latin America, West Africa, and Southeast Asia (Ruby, Rozin & Chan, 2015). They are also an important diet to Australian indigenes, Middle East, and South and Central Americans (Chung, 2008). Insects are consumed more in Thailand, China, Japan, Korea, and Indonesia than in any other nation (Chung, 2008). Thailand's insect industry is well developed with more than 20,000 registered insect farming enterprises (New, 2013).

CONCLUSION AND RECOMMENDATIONS

Conclusion

Edible-insects contributed to the nutrition of many and will remain very relevant to the nutrition of many in the years to come. Insects consumption depends greatly on location, eating habits, prior experience, age, gender, and religious belief. The consumption of edible-insect is gradually declining in some societies; the practice is predominantly left with elderly people. The major barriers to global edible-insect acceptance are sociocultural influences, psychological factors, and religious belief. Edible-insects are rejected by new consumers, predominantly due to cultural reasons, disgust, fear of disease and contamination, food and food technology neophobia, lack of awareness, inaccessibility, personality traits, and alleged poor sensory attributes which in many cases w ecological and environmental as trigger by fear and negative attitude towards entomophagy.

Researchers are working hard in promoting the consumption of edible-insect in Europe and America. Accepting edible-insects by the western world will brighten their global image and recognition due to the position and contribution of Europe and America to the global nutrition policy. Policymakers and researchers in the West are giving more attention to entomophagy in recent years, there is a growing interest in both commercial and academic spaces. The start of commercial production of edible-insects in these regions is an indication of a bright future for both direct and indirect entomophagy. Commercial production will make edible-insects more versatile, large-scale industrial production will prevent overexploitation of species, save the environment and natural ecosystem relationships by preventing ecological imbalance, and significantly reduce the price of edible-insects. To overcome legislation constraints, regulatory authorities need to be convinced that edible-insects are safe and fit for human consumption.

Recommendations

There is a looming danger of protein scarcity in decades to come due to the rapid population growth, unsustainability in animal breeding and unbearable hike in the animal feeds price. The conventional sources of proteins are not reliable and cannot satisfy the world population in years to come, therefore, alternative sources of proteins are necessary to tackle the foreseeing challenges. There is an urgent need for swift action on the promotion of entomophagy to ensure edible-insects acceptance particularly in developing countries with acute food shortages. Many knowledge gaps need to be addressed in promoting and adopting insects as food. Consumers should be educated on the safety of edible insects as many have serious concerns about dangerous microorganisms and toxins in insect products. Insects can provide significant amounts of proteins and other essential nutrients to the accelerated

global population when more attention is given to their production, processing, safety, and marketing. Accepting insects as food will improve the nutritional status of many, particularly in developing countries. Insects can also contribute to the development of many novel food products and also change the nutritional content of many existing foods.

Entomophagy cannot be fully accepted when the promoting strategy relies mainly on educating target consumers on the various benefits of edible-insects using scientific evidence alone, ethical issues need to be given due considerations. The psychology, emotion, and the belief of the consumers need to be understood, this will provide clues on their perception of edible-insects. Another factor to be considered is cultural variations, consumers with a different cultural background will have a different perception. Understanding these will give ideas on how to introduce the edible-insects in the first place since the first bite is always critical to acceptance and continue eating. Introduction to children will ensure early acquaintance and minimize disgust when they grow up. The attitude of consumers can be changed by motivations, innovation in insect business should be consumption-to-production because the consumer is critical to any business, and the power of culture, habit, and heritage is very strong.

Attention should be given to scientific evidence in the occasions of ensuring the safety of edible-insects to the consumers, information on the non-existence of pathogens, allergens, or any other contaminant should be back up with laboratory evidence. Convincing new consumers by explaining the various benefits of insect consumption should be back up with tangible and observable evidence.

Safety must be ensured by taking precautionary measures throughout the production and processing chains. Insect species, breeding ground and its premises, feed, and water should not be a source of any contamination. Processing into delicious, attractive, and irresistible meals with no visible insects, or their parts, and the use of an appropriate and eye-catching packaging system will promote edible-insects' acceptance. This can be achieved through the addition of insects into familiar foods, development of new products, or by imitating commonly consume products

Entomophagy will certainly continue to be rejected by people whose religion believes is against consuming foods from animal origin, this will remain the toughest hurdle to be overcome in promoting entomophagy.

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