What Governs Selection and Acceptance of Edible Insect Species?

Sampat Ghosh, Chuleui Jung, and V. Benno Meyer-Rochow

Abstract Entomophagous habits have undoubtedly accompanied the evolution of humankind from its beginnings. With few exceptions, insects are generally non-toxic, nutritious, abundant and easy to collect. About 2000 species of insects are known to be consumed by different ethnic groups. We explored on what basis insect species might be selected as desirable by human consumers and why in many parts of the world eating insects has become obsolete and even turned into a matter of disgust. Traditions obviously play a role and superstition and taboos will have been major factors. However, climatic and ecological characteristics that influence the locally available food insect spectrum and looks, taste, and feel of an insect are further features that come into play. Not to be neglected either are economic considerations, e.g. the time and cost involved in harvesting, purchasing and preparing food insects, be it by drying, cooking, frying, spicing them up with rare or expensive ingredients, etc. Finally, motivation can be a powerful regulator too and whether or not to ingest an insect can depend on whether the act of consumption occurs out of curiosity or a nutritional need, as a special treat or part of a ritual, treatment of a disorder or directive. In this contribution, we examine the various reasons, e.g. based on tradition, nutrition, ecology and economy, for selection, acceptance or rejection of certain species of insects in different regions and cultures.

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A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_20

1 Introduction

From a scientific point of view, food can be defined as a substance that provides nutrition in order to maintain life and growth for any life form. To facilitate our understanding of food utilization within the complex structures of food webs, consumers of food, i.e. animals, are assigned on the basis of their preferred foods to different categories like herbivores, carnivores, omnivores, detritivores, etc. Often the introduction of sub-groups like, to list but a few, frugivores (fruit eaters), fungivores (feeding on fungus), insectivores (feeding on insects), piscivores (fish eaters), etc. is deemed necessary and the use of the suffix "–phagy" as in xylophagy (feeding primarily on wood), oophagy (feeding on eggs), saprophagy (living on decayed organic matter), coprophagy (feeding on faeces or dung), necrophagy (feeding on dead or decaying animal flesh), and of course entomophagy (consuming insects) is equally common.

Humans, *Homo sapiens,* are generally considered to be omnivores, i.e. unspecialized feeders, being able to make use of almost any food category available to them, but having gone through a variety of dietetic shifts during their evolutionary history (Fig. 1). And yet, a closer inspection of human food practices worldwide reveals enormous differences in food preferences and food rejections (Meyer-Rochow 2009), observations which had earlier led Rozin (1984) to state that "the best predictor of the food preference of a particular person would be information about the person's ethnic group".

If what is perfectly acceptable to some is causing outright revulsion in others (rats would be one example: Meyer-Rochow et al. 2015; insects another: Evans et al. 2015; Tan et al. 2015), how can we possibly define what "human food" is? Obviously a vast array of factors influences food choice in human societies (Rozin 2007a) and to shed some light on the reasons that govern the food habits in different human societies and even sections of the population within a community, a holistic approach is required. Observations pertaining to studies in fields as diverse as ethnology, anthropology, psychology, ecology, physiology, genetics, economy, climatology, as well as several more need to be considered.

According to the report on the State of Food Insecurity in the world in 2015 by FAO, 795 million people worldwide are undernourished (FAO 2015a). One estimate showed that during the period of 2012–2014, the global food deficit was 67.6 billion kcal/day, an average of 84 kcal/day/undernourished person (FAO 2014a). In the year 2050, the world's population is expected to be 9 billion. The search is on for alternative sustainable food sources to feed the world's increasing human population in future years and the FAO (2014b) calculated that a global food production increase by 70% was needed in order "to feed the world in 2050". As a consequence of the rapid population growth, increasingly more land has been converted to agricultural uses, some of which like raising ruminant livestock, now having come under considerable criticism. In general, animal proteins are of higher nutritional value than plant proteins, because animal proteins contain larger amounts of essential amino acids needed for human development

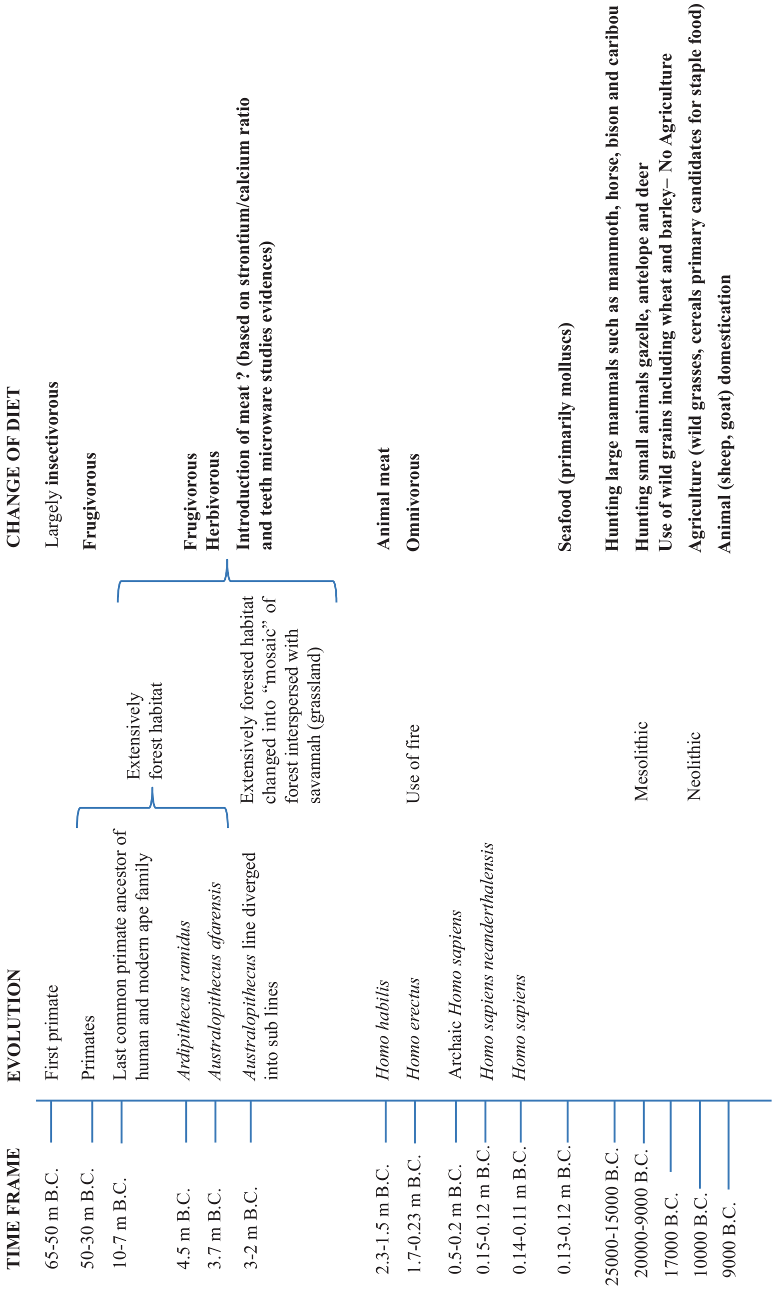

Fig. 1 Dietetic shift along with the evolutionary pathway

and there is a sharply increasing trend in the consumption rate of meat and dairy products worldwide. People in mainly western nations generally have higher protein consumption rates than those of developing nations and this stems mostly from the greater proportion of meat in their diet (Pimental et al. 1975; IEG Independent Expert Group 2016).

At present in developing countries with still rising populations, consumption of meat has been growing at 5–6% and that of milk and dairy products by 3.4–3.8% per annum (FAO 2015b). Meat-based food systems require more energy, land and water resources than the lacto-ovo-vegetarian diet system and in the long run the latter is more sustainable (Pimental and Pimental 2003). It has been pointed out that in order to slow down further global warming, deforestation, soil erosion and shortages of water availability, it is paramount to drastically reduce ruminant meat consumption (Koneswaran and Nierenberg 2008; Scholtz et al. 2013; Thornton 2010; Hedenus et al. 2014). However, to achieve that goal we believe it would be useful to explore and compare the food habits of different traditionally living groups of people and to understand their reasons for selecting particular food items out of the spectrum of food items available to them. An examination of the nutritional potential and sustainability of the specific food categories consumed by traditionally living communities would be desirable.

1.1 Insects as a Food Item

In this context we are giving priority to insects as almost 2 billion people worldwide consume these invertebrates as part of their diet and they possess a huge potential as farmed minilivestock (Paoletti 2005; Van Huis et al. 2013). Most persons, who have habitually eaten insects or who have started eating them recently do so, because they enjoy their taste (Megido et al. 2013; Deroy et al. 2015; House 2016). Moreover, the nutritional value of insects is no longer in doubt and they therefore appear to possess all the features one wishes an alternative food resource to have, as these and other analyses have demonstrated: Meyer-Rochow (1976), Ramos-Elorduy de Conconi et al. (1984), Ye et al. (2001), Yang et al. (2006), Finke (2002), Bukkens (1997, 2005), Malaisse (2005), Ghaly and Alkoaik (2010), Yhoung-Aree (2010), Fontaneto et al. (2011), Chakravorty et al. (2011a, 2014, 2016), Rumpold and Schlüter (2013), Ghosh et al. (2016, 2017).

One major problem, however, lies in the acceptability of insects in sections of people who did not traditionally consume them (Deroy et al. 2015). Since even amongst communities, whose members regularly consume insects, great differences exist between those that regard certain insects as tasty and edible, worthy of collecting and others that would reject these very species, considering them unfit for human consumption but accepting species avoided by the former community, we felt that finding answers to what governed the selection of an insect as an acceptable

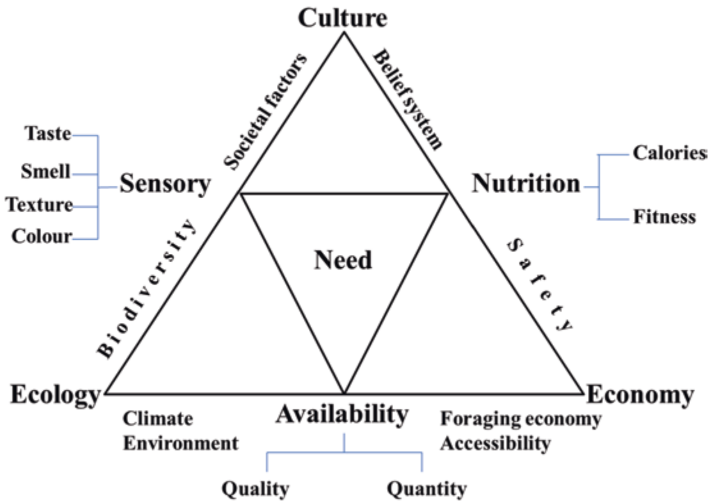

Fig. 2 Factors influencing food choice mechanism

food could also help us finding ways to popularize insects as human food and enlighten people of non-entomophagous societies about the merits of at least some food insects.

2 What to Select and What Not to Select

Since time immemorial, people have relied on the surrounding ecosystems as sources of their food, the most important prerequisite for life and health. What governed them then and still governs them now to distinguish between different food items, making them to accept some and reject others, remains a subject of scientific inquiry pertaining to both fundamental and applied research (Fig. 2). Vabø and Hansen (2014) distinguish food choices from food preferences and regard food preference as one of several other factors like health, price, convenience, mood, nutrient content familiarity, ethical concerns and sensory appeal that determine food choice. Smell, looks, texture and ultimately taste are considered to be among the most important drivers of both food choice (dietary habits) and food preferences, i.e. the selection of a particular food item out of a repertoire. However, the ease with which a particular type of food can be obtained, supply and demand, tradition, and ethical concerns, religious and other beliefs, etc., may further influence the choice (Lensvelt and Steenbekkers 2014). All of this is likely to apply to most of the various food sources, including, of course, insects.

Since selectivity is not only exhibited by humans, but also animals, clues on what governs selectivity are likely to be extractable from comparisons with animals and how and on what basis they carry out their food selections (Evans et al. 2015). Obviously anatomical and physiological characteristics of a species impose limitations on the food an organism might consider in its choices. A sheep might dearly want to reach and eat the fresh leaves of a tree, but it cannot climb. A cat would happily feast on an antelope, but it's not a lion and it lacks the size and strength of the latter to even consider prey as big as an antelope. A cat would also rather starve than to feed on leaves or grass, because its digestive system would be unable to handle the vegetarian diet and even within the guild of herbivorous ungulate species, food selection highly depends on how their digestive system can deal with high cellulose diets (Hanley 1982). Similar limitations would exist for invertebrate species so that one can categorically conclude that ecological and physiological constraints in combination with competition and natural selection are powerful factors in food selectivity. What these examples teach us further is that a food item not only has to be available, it also must be obtainable and the digestive system of the individual ingesting the food has to be able to handle it, i.e., seeing to it that the body can receive nutrients from it.

Monkeys are evolutionarily much closer to humans than cats and ungulates and like us are rather choosy, selecting their food items carefully. Spending time looking for food can be energetically demanding, which is why Emlen (1966) postulated that food selection is largely based on maximizing energy yield in relation to foraging time. Westoby (1974), however, felt that the primary foraging objective should be to optimize the nutrient mix within the available food spectrum. With regard to insects support for this notion comes from a study by Abrol (2007), in which plant cultivars with higher calorific rewards had the competitive edge over others in attracting foraging pollinator populations and therefore enjoyed better pollination successes. Milton (1979), studying howler monkeys and their food selection, found that these simians selected young leaves and preferred those with a high protein to fibre ratio. Frugivorous Bolivian spider monkeys on the other hand eat mostly figs and Felton et al. (2009) reported that their analyses of the chosen figs showed that the monkeys' food intake was "governed by protein-dominated macronutrient balancing".

This apparent preference of protein-rich items in howler and spider monkeys is somewhat surprising as primates are not known to possess specific protein taste receptors and therefore must have used other senses to distinguish protein-rich from protein-poor food. In fact Righini et al. (2015), also observing howler monkeys and their food choices for one year in the field concluded that with the exception of the time from October to January when the monkeys selectively collected fruits high in lipid content, no strong correlation with particular nutrients was apparent.

2.1 Focusing on Humans

What about humans then? Humans are believed to have evolved from frugivorous primates and although the diet of early hominins did not only consist of fruit, but very likely contained appreciable amounts of seeds and starch-rich underground plant items (Luca et al. 2010), an innate fondness of sweetness can be expected to have been present (Andrews and Martin 1991; Dudley 2000). Sweet fruit often contain insects and as the study by Bravo and Zunino (1998) with howler monkeys has shown, the latter do ingest, although not preferentially, some fig fruit with insect larvae. Many neotropical primates are known not just to eat fruits and leaves, but actively hunt insects, foremost and for all Orthoptera (Nickle and Heymann (1996), but old world monkeys, too, have been recorded as early as 1902 (baboons: pages 345, 382–383 in Marshall 1902) and 1921 (*Cercopithecus* sp.: Carpenter 1921) to appreciate many kinds of insects, but to avoid aposematically coloured ones (Carpenter 1921).

It does not seem far-fetched to assume that insect eating habits in humans followed a rather similar path to that sketched above for the monkeys, which is why Meyer-Rochow (2005) had suggested humans first ate insects together with picking sweet fruit. Other insects not associated with fruits, but collected because of their abundance, ease of access and, especially with regard to lipid-rich species, taste would also have mattered. To decide which species to take would have depended, apart from the season and availability of a species, on the collector's skill and equipment (if any was necessary) and personal preferences based on the palatability of the insect prey. Novelty-seeking, i.e. neophilia, may also have played a role (Miller 1997).

Reim (1962), reviewing entomophagous practices amongst Australian Aborigines, noticed that the latter showed a strong preference for fatty grubs and in contrast to tribal people of Papua New Guinea, just north of Australia, showed little interest in grasshoppers and locusts. Reim (1962) felt that the rest of the diet, especially that of desert inhabiting Aborigines, lacked sufficient amounts of lipids and concluded that that was the reason why they went for fat containing insects but also, it needs to be said, the highly esteemed honeypot ants and stingless honeybees, their brood and their products honey and wax reserved for the menfolk. In order to locate the bees and their prized "honeybag", as the locals call a bee's nest, an experienced trapper would listen to trees to find out if they were occupied by bees, poke sticks into a tree's holes and smell them to find out if there was some honey on them, and examine nearby spider webs for bee remains (Meyer-Rochow 1975a). It is obvious that the right tools and know-how are valuable assets in the procurement of specific species, something that also the studies of Laotian cricket and grasshopper collectors (Meyer-Rochow et al. 2008) and Japanese zazamushi collectors (Césard et al. 2015) show.

2.2 History and Ecology

Historically the consumption of insects was once widespread (Bergier 1941; Bodenheimer 1951), but the roots of human entomophagy, as we have just explained, are likely to go much deeper with roots in our primate ancestry (Fig. 1). Although this chapter has no intention to discuss the palaeo-anthropology of human origin or the anthropology of food and eating (Mintz and DuBois 2002), it is generally accepted that modern humans have evolved in Africa in a setting of tropical biodiversity, which would have included a great variety of insects as well as fruits. Thus, availability of both these food items and the occurrence of them together would have facilitated their joint uptake and acceptance by our human ancestors.

Early hominids then migrated to different geographical regions, some reaching temperate climes, where the lack of edible plant material, fruits (and associated insects) demanded of them to widen their food spectrum and include more and more animals as food. Humans benefitted from the degree of freedom that their genetically programmed taste preferences and their digestive system allowed them to have and it was this genetic scope that permitted them to expand their food experiences and food spectrum in ecologically different environments and habitats. Although our human ancestors' innate preference for sweet food items did not disappear, the attitude towards insects could have shifted from seeing them as a valued food item to regarding them more and more as vermin and to focus their food choice on larger and more fat-containing insect and animal species. More research is required to substantiate this hypothesis, because despite the harsh climate inhabitants of the high Arctic are known to have consumed a variety of insects and maggot-containing dishes (Freuchen 1961) and even during Roman times fat stag beetle and other timber boring larvae, collectively termed "cossus", were still relished (Holt 1885) while recipes of cockchafer soup were circulating in Germany as recent as 200 years ago.

Obviously an increasing awareness of insects as vectors of diseases, an association of insects with dirt and death, with witchcraft and poverty is likely to have led to a greater alienation and more widespread fear and disgust of insects as food especially in western societies, although -and this is often overlooked- locusts are singled out as kosher in the Bible (Leviticus Chpt. 11:21), and thus had to be regarded as acceptable food by Jews, Christians and Muslims alike. To what extent the consumption of maggot-containing cheese (e.g., known as "casu marzu" in Sardinia) or mite cheese (known as "Milbenkäse" in Germany) is rooted in ancient entomophagous habits and represents remnants of a once more widespread consumption of arthropods in Europe is debatable, just like the behaviour of some children in Finland is to kill and suck out bumblebees on account of their sweetish taste. How such habits developed and became a tradition is unknown, but a positive experience must have been involved. To cite another example, a section of North East Indians prefer to eat maggot-containing soybean and consider that a delicacy. However, an indisputable fact, true for the northern as well as the southern hemisphere, is that the decline in insect variety from climatic zones favourable to insects to those unfavourable to them, is paralleled by a decline in species deemed consumable and worth collecting.

2.3 Culture

Cultural experience plays a significant role in determining the acceptability and preference of food. There are many examples of the acceptance of one insect species food by one tribe or a population of one region but considered non-edible by neighbouring tribes. *Zonocerus* spp. (grasshopper) are considered edible in the Republic of South Africa, Cameroon and Nigeria, but considered poisonous elsewhere (Schabel 2010; Van Huis et al. 2013); *Phymateus viridipes* is edible in Zambian region but not elsewhere (Malaisse 1997) and even in areas of close geographic proximity as in Arunachal Pradesh, India, some scarab beetles are considered edible by one tribal community, but rejected by another ethnic group nearby (Chakravorty et al. 2011b, 2013). Many insects are known to sequester a wide range of phytochemicals of differential toxicity and perhaps this would be one of the reasons to taboo some insects by certain ethnic communities. However, the processing or modes of preparation of these insects are remarkable and reflect a rich traditional knowledge base. In Cameroon and Nigeria *Zonocerus variegatus* (variegated grasshopper) are prepared in a specific way by heating the insect in tepid water and changing the water before cooking (Barreteau 1999; Morris 2004). In a rather similar way soybean is prepared to remove anti-nutritional compounds like, for example, trypsin inhibitor.

Koivisto-Hursti (1999) has documented that with regard to food choice, children follow their parents and that this is the main way food habits become stabilized in the community. Once established, food traditions are often extremely persistent, hard to break (Meyer-Rochow 1998) and an integral part of a culture (Rozin 2007b). The "learning experience" (= getting used to a novel food) has been highlighted by Nestle et al. (1998) and Ventura and Worobey (2013) as an important factor in the development and persistence of food preferences from generation to generation. However, it ought to be mentioned here that food preferences can change as people get older and begin to suffer from dental problems and illnesses that render the consumption of certain foods, once relished, undesirable (cf., Koehler and Leonhaeuser 2008).

This cultural influence dominated the selection of preferred species and how they should be prepared, e.g., raw, pickled, roasted, fried, steamed, boiled in tests conducted by Tan et al. (2015) on probands from Thailand and the Netherlands, who had and had not eaten insects before. Individual rather than cultural experience determined "whether judgements were made based on memories of past eating experiences or based on the visual properties and item associations" (Tan et al. 2015). It can be argued that acceptance by one and rejection by another group, removes pressure on the resource and makes good sense in the perspective of ecological sustainability. Such "division of acceptability" may, however, not have been consciously planned or designed to safeguard the availability of the species in question, but may have evolved to underscore the cultural separateness, the distinctiveness of neighbouring cultural groups as unique entities. Thus, acceptability of some species of insects then became a tradition, a symbol, decoupled, for instance, from utilitarian motifs like nutrition and availability.

Gender-based taboos in order to unite and distinguish one sector of the community from another are also not exactly rare. Women of the Baganda tribe of Uganda, for example, are prohibited by custom from consuming long horned grasshoppers (katydids) commonly known as 'nsenene'. Women and children, however, are the main collectors of these insects and the women cook them for their husbands. It is a common tradition amongst the Baganda to offer 'nsenene' to their male guests (S, Ghosh, unpublished). Amongst a variety of northeastern Indian tribes, women are advised not to get touched by certain species of cicada (Chakravorty et al. 2011b). In both cases, consumption of the insects in question by women of reproductive age is presumed to affect a baby's development, an assumption for which no scientific evidence exists.

That taboos imposed by religious and other beliefs (or authorities of any sort) on whole communities or subsections of the population often influence what is and what is not acceptable as food during certain times of the year has been discussed in more detail by Meyer-Rochow (2009) and is undoubtedly applicable to many more insects than grasshoppers and cicadas. However, what complicates the matter is that frequently it does not come into the mind of people (who consume what the scientist would identify as "an insect") that they have actually been ingesting insects regularly. When questioned as to whether they would eat insects at all, they would then often reply that they never did and never would, even if in fact they had just swallowed some. Although their response could be influenced by who poses the question to them and whether they are shy, it is a fact, observed by other researchers as well, that their attitude to see edible insects not as insects, but as an ordinary kind of food is widespread, and thus, in their minds, represent something quite different from "true" insects, which they would not dream of consuming (Evans et al. 2015).

3 Sensory Characteristics

3.1 Taste

In the context of a discussion on food selection governed by sensory characteristics taste has to receive primary attention. Interestingly, the word disgust has its root in "dis" (= opposite, negating 'the acceptable') and "gust" (= gut, digestive system, also part of the words 'gastronomy', 'gaster', 'gastric', etc.), which shows the importance of food intake and attitude. Taste, as the final control, determines whether a food item will be allowed to enter the body, the "gut", or not. There is good evidence to believe that all humankind possess the same kinds of taste receptors (Tuorila 2007), but this does not necessarily mean that substances taste the same way to everyone as the well-known case of PTC (phenyl-thio-carbamide) tasters and non-tasters demonstrates (one third of Europeans are non-tasters, the remainder are tasters: Lawless and Heymann 2010).

Our liking of sweet and dislike of bitter tastes are considered innate human traits, thought to be the result of a biological coding for 'safe' versus 'dangerous' foods. Sequestered plant toxins if stored in an insect will cause the insect to be judged unpalatable (Berenbaum 1993). Taste receptors for sugary substances occupy a prominent position on the human tongue and children the world over can be pacified with sweets. In Carina of northern Italy, children traditionally eat ingluvies of the moth *Zygaena*, which have a sweetish taste (Zagrobelny et al. 2009). This moth species is potentially toxic, because it contains cyanogenic glucosides, which release toxic hydrogen cyanide upon degradation (Zagrobelny et al. 2009). Benzoquinones and hydrogen cyanide are also released by millipedes like *Tymbodesmus falcaus, Sphenodesmus sheribongensis* and an unidentified spirostrepsid species, which are accepted as food by the Bobo people of Burkina Faso in spite of the unpleasant chemicals they contain (Enghoff et al. 2014).

Another characteristic of the food item that is involved in the decision of whether or not to accept and swallow it would be its texture, for which, as with taste, contact receptors in the mouth (or the fingers as well) are required. Odour and looks of a food item can be gauged from the distance by olfactory and visual receptors and are characteristics that facilitate long range detection of and attraction to the food item in question, especially if the consumer has learned to associate these characteristics with an earlier positive taste experience.

Obviously, taste preferences are to some extent culturally conditionable and this has already been underscored with some of the examples given above. The genetically laid down wide bracket of taste tolerance in humans and a digestive system able to accommodate a great variety of food stuffs, therefore, have to be seen as responsible for human beings to extend the range of nutritious substances they select from the environment. Size, shape, smell and visual appearance, and especially a food item's colour, are other sensory properties that further influence the selection and preference of foods, including insects, but which need to be discussed separate from taste.

3.2 Odour

The first cranial nerve in humans (and other vertebrates) is the olfactory nerve and a human's sense of smell is vastly more sensitive than that of taste. The smell of a food item is therefore not only important as a means to detect it from a distance even when it cannot be seen; it also provides a human with the possibility to pre-assess a food item with regard to its acceptability as edible or not, especially in combination with a learned response from an earlier experience. Although putrid and foul smells of vomit, faeces and decaying corpses are universally abhorred, some smells like those of fish, roasts, cheese, cabbage, and fermented foods, etc. are appreciated by some, but avoided by others and, once again, show our human's ability to expand tolerance limits in connection with adapted customs.

Stink bugs are a case in point: pungent and bad-smelling, these pentatomid bugs are nevertheless a favourite food item for many insect-eating people in parts of Asia (Chakravorty et al. 2011a) and Africa (Teffo et al. 2007). They demonstrate afresh the range of stimuli that are able to signify acceptability of a food item to some people, but not others.

3.3 Visual Appearances

Animals often either instinctively or through experience appear to know that the coloration of certain flowers, fruits, mushrooms and animals acts as a deterrent or warning and avoid consuming and sometimes even touching such species. More than 90 years ago Carpenter (1921) carried out experiments to examine the reactions of two monkeys towards different insect species, some aposematically coloured and some not. The experiment revealed that the monkeys made no attempt to eat brightly and aposematically coloured insects like, for example, *P. viridipes* (green milkweed locust or African bush grasshopper) and *Zonocerus elegans* (elegant grasshopper), but readily accepted others. Since both of these species were considered non-edible and poisonous by large numbers of people in various parts of Africa, the still unresolved question arises as to whether these humans also knew instinctively to avoid certain species or had observed and copied the behaviour of simians or perhaps had learned from personal experience and taught other members of the community.

Coloration, however, at least for humans and those animals that possess colour vision, does more than indicate whether a food item is dangerous to health or not. It can provide information on the developmental stage, the amount of sugar or fat in a food item and in this way indicate whether the food item is worth the trouble collecting it. Since different developmental insect stages and even genders can be of different shapes and coloration, discriminating highly appreciated stages or individuals from lesser valued ones in this way is facilitated.

3.4 Texture

In a pre-selection process to decide whether an item can possibly be considered edible and accepted as food, a closer inspection and an assessment of its texture are also important steps. Items with a prickly, rough surface receive considerably less attention than items with a smooth and seemingly softer outside. For example, in insects with spiny appendages, the latter are carefully removed before a person proceeds to prepare such insects further for consumption. There is apparently good reason to take such precautionary measures, for Bouvier (1945) observed that in what is now the Democratic Republic of Congo people who consumed grasshoppers and locusts without removing their legs could suffer from constipation or difficulties in swallowing, caused by the large indigestible chitinous spines on the tibiae of these insects. Sometimes surgery was required to remove the obstruction. Rather similar cases were reported by Kuyten (1960) from Eastern Java (Indonesia) following consumption by the locals of large scarab beetles.

4 Plasticity of Sensory Perception

As mentioned earlier, humans all over the world, despite possessing the same gustatory receptors and basic needs of protein, fat, carbohydrates, minerals and vitamins, display huge differences with regard to those food items they consider tasty or at least acceptable. The fundamental reason for this variety in food preferences is the range of freedom in tolerating widely different levels of what is considered sweet, sour, salty and bitter and a digestive system that can handle a wide range of food items (with the exception of cellulose-rich ones like grass and wood). Given prolonged voluntary or forced exposure to what at first might have been a distasteful flavour or disgusting smell, then this initially unpleasant experience can turn not just into acceptance, but can lead to a preference of the otherwise objectionable taste or smell.

Stink bugs belonging to the family Pentatomidae, mentioned earlier, do not seem to be a promising food candidate given their pungent smell. Yet, these bugs are a favourite food item to a large section of ethnic people of North East India, Indochina (Chakravorty et al. 2011a) and parts of Africa (Teffo et al. 2007). Carpenter (1921) observed that "the odour that to us seems so very unpleasant does not appear to be considered a distasteful quality by the monkeys", who relished *Anoplocnemis curvipes* bugs in spite of their smell. Other examples are fermented bamboo shoots or stored soybeans containing maggots, foods -that just like the famous maggot-containing" casu marzu" in parts of Italy- are considered very delicious amongst members of some ethnic groups in the north-eastern part of India, but rejected as inedible by those who are not accustomed to these items (S. Ghosh, unpublished).

4.1 Nutritional Aspect

The concept of what represents a 'healthy nutrition', a 'balanced diet' is something that only rather recently has become to occupy a prominent factor in the choice of food items. Yet, even today traditions exert a powerful influence on what people eat and therefore the value given to uphold dietary tradition often outweighs that which nutrition experts attach to certain food items. In this context disagreements between food experts and confusing changes in the recommendations of what ought to be avoided and what should be eaten do not help to convince people to abandon religious doctrine, traditions and superstition. For a while, meat consumption was propagated as an almost essential way to obtain sufficient protein to stay healthy, but then a vegetarian diet with legumes and milk as suppliers of essential nutrients was recommended as superior. As of late, insects as a protein source are now gaining more and more support from ecologically minded food experts.

Despite two comprehensive reviews on the uses of insects as food amongst the different peoples of the world (Bergier 1941; Bodenheimer 1951) and a shorter summary by Hoffman (1947), the question of "Why not eat insects?", first raised by Holt (1885), was not revived until exactly 90 years later by Meyer-Rochow (1975b), who asked "Can insects help to ease the problem of world food shortage?". Ever since then, the notion that insects can indeed help, has been gaining momentum and nutritional analyses have further strengthened the idea that insects have a role to play as an alternative especially to mammalian meat. Future food security is seen as one of the biggest challenges of the world of today and insects containing high amounts of protein, valuable and easily digestible fats, relatively low carbohydrate content, small but significant amounts of important minerals and essential vitamins are not only abundant and easy to breed in large quantities in farms that occupy a fraction of the land used for ruminant livestock, they are, with few exceptions, also a very healthy food item (Ladron de Guevara et al. 1995; Bukkens 1997; Banjo et al. 2006; Yhoung-Aree 2010; Chakravorty et al. 2014; Kouřimska & Adámková 2016; Sabolová et al. 2016; Ghosh et al. 2017).

Although the adult insects' exoskeleton can be very hard and tough, consisting of an approximately 50:50 ratio of the carbohydrate chitin and protein (Peters 2003), it adds roughage to the food and, according to Goodman (1989) and Lee et al. (2008), is credited with cancer-preventive properties and an ability to strengthen the immune system, respectively. The widely held belief that it is totally indigestible in humans may not actually be correct, because the gastric juice of a sizeable proportion of humans tested by Paoletti et al. (2007) has been found to contain chitinase, which can degrade chitin. The absence of the activity in 20% of the Europeans tested is explained by the research time as a consequence of the virtual absence of chitin-containing food items in the western diet.

Needless to say that any large scale promotion of insects as human food, to name but a few fields, needs to take into consideration possible ecological effects of significant numbers of insects removed from nature (Meyer-Rochow 2010), possible effects like allergies and incompatibilities with medication, transmission of parasites and diseases affecting the human consumer (Dobson and Carper 1996; Inceara and Türkez 2009; Sun-Waterhouse et al. 2016), digestibility, shelf life, storage and preservation of food insects (Gorham 1976, 1979; Belluco et al. 2013), production costs and retail prices (Meyer-Rochow et al. 2008; Halloran et al. 2016). Future uses of farmed insects could also include feeding them to for example poultry, or establishing cultures of insect cell lines and tissues. However, as with the promotion of the direct use of insects as human food, a considerable amount of additional research would be required.

4.2 Ethno-Scientific Perspective

Obviously before humans had acquired the knowledge to make fire, all foods were eaten raw and those that caused unwellness or worse were avoided. Boiling and roasting not only made some foods tastier, they also allowed some foods to be used that were avoided before, because boiling, for instance, would destroy toxins, soften tissues, intensify tastes and promote digestibility. Holt (1885), who has tasted both raw and cooked locusts and found them "raw…pleasant to the taste; cooked they are delicious". To find ways to improve the taste of insects would have led to the discovery of detoxifying methods. In Cameroon and Nigeria the orthopteran *Zonocerus variegates* is prepared for consumption by heating the insects in tepid water and changing the water before cooking (Barreteau 1999; Morris 2004). Another example is the preparation process of the edible tessaratomid stinkbug *Encosternum* (= *Natalicola*) *delegorguei*, whose pungent defensive liquid can cause severe pain and even blindness if accidentally rubbed into the eye. Consumers of this insect in Zimbabwe and South Africa therefore remove the fluid from the insect by squeezing the insect's thorax prior to further processing (Scholtz 1984). Similar manipulations were sometimes, but not always, carried out by people in North-East India, prior to the consumption of the ghondibug *Aspongopus nepalensis* (Chakravorty et al. 2011a). However, not always are harmful substances removed and even today insect-consuming people often prefer to eat some species raw, in spite of their toxic substances as with *Zygaena* (Zagrobelny et al. 2009) and millipedes (Enghoff et al. 2014).

5 Economy

So far we have focused on likely factors involved in choosing specific insects as food and have tried to put forward our ideas to understand the continuation as well as the discontinuation of this practice among different societies to this present day. Our discussion would be incomplete if we ignored the 'economy' issue to understand the present scenario of insects as a food item with a future. Economic aspects are of overwhelming importance in present day affairs, trigging and influencing especially all facets of trade (Müller et al. 2016). Therefore, what we cannot ignore is the association especially by people with western cultural backgrounds between entomophagous habits and regions of relatively low economic status, adverse or extreme climatic conditions, widespread areas of sterile or infertile land, frequent water shortages, alarming nutrient deficiencies and limited health services. Almost certainly such associations nurture feelings of fear and disgust (Rozin et al. 2008; Barrena and Sanchez 2013; Deroy et al. 2015) and serve as psychological barriers (Looy et al. 2014).

Perhaps for reasons like this, insects until very recently have not received much attention as a food resource and scientists advocating them as a resource were not taken seriously, but now insects have begun to be viewed as a sustainable solution in the context of future food security. The more people find insects as food or addition to familiar foods acceptable, the more will dare to at least try them and then, perhaps, accepting them as a food item whereby they would be setting an example for others (cf. tests on familiar and unfamiliar foods by Pliner and Hobden 1992; Pliner and Mann 2004; Martins and Pliner 2005; Siegrist et al. 2013 have shown that food neophobia is negatively correlated with familiarity). Pre-historic humans started using insets as food by collecting their insects from the wild, a practice still common in parts of the world, but now considered as ecologically no longer advisable in view of an expanding food insect demand. We therefore strongly believe that foraging insects from the wild should give way to systematic farming practices with predictable and controllable regular harvests of the edible insect crop.

Beginnings of such thinking can be traced back to the practice of West Australian Aborogines to physically damage the host trees of the cerambycid beetle *Bardistus cibarius*, so that it may breed there and its grubs, known as 'bardy worms', could later be harvested and conserved for future uses by drying and/or roasting (Reim 1962). Another example comes from the manipulation of host trees for the procurement of palm weevils in Papua New Guinea, where the weevil's larvae are considered a delicacy (Mercer 1994) and from Japan where attempts to cultivate edible wasps have been taking place (Payne and Evans 2017). The best examples, however, are apiculture (beekeeping) and sericulture (rearing of silkworms), both of which have long historical associations with human civilizations. Despite this long association with silkworms and honey bees, most of the other insects until recently were not seen to satisfy the conditions of being domesticated. That this attitude has begun to change is demonstrated by the semi-domestication of bumblebees as pollinators and the farming of certain edible insect species, e.g. crickets (Halloran et al. 2016).

Almost certainly with the increasing awareness of the nutritional and environmental benefits of expanding the circle of insect eating humans, the global demand for edible insects will rise, offering opportunities "to make money" and develop businesses in connection with the new trend. So-called cricket bread, for example, sold as 'sirka leipä' in Finland and containing 3 % cricket flour is already available. Thus, there will be an emphasis on some species based on the available knowledge of their nutritive value, their life cycle details and suitability for farming and semi-domestication. Today the commercial sector has already begun to develop methods permitting the large scale production of certain edible insect species like mealworms (*Tenebrio molitor*.), crickets (*Teleogryllus commodus*, *Gryllus bimaculatus*), and so-called 'white grubs' (*Protaetia cinarea*) etc. However, it is self-understood that not all of the 2000 insects currently regarded as edible (Mitsuhashi 2008; Jongema 2015) will receive the same attention in efforts to rear them in insect farms, but at the same time one must not overemphasise one or a handful of species and neglect other possible and promising candidates. One also needs to carefully consider the removal of species from their original geographic habitat locations to other regions for rearing them, since individuals could escape and become established in their new surroundings as invasive and environmentally undesirable newcomers.

6 Conclusion

In summary, we do see a bright future for certain species of insects as a novel and gradually more and more globally acceptable food item, but attempts to popularize insects as food should bear in mind our finding that even traditionally insect consuming cultures vary with regard to the choices they make in accepting species as edible and that there are reasons for these differences. Transdisciplinary research approaches involving biological as well as social sciences and other disciplines are greatly needed in order to achieve an in depth understanding of the various complex interactions that determine acceptance or rejection of a food item (Fig. 2). Attempts to popularize food insects by focusing only on one or two species, e.g., mealworms and crickets, could therefore lead to some difficulties in certain sections of the potential clientele and other species, e.g. grasshoppers must not be forgotten (Paul et al. 2016). Consideration ought to be given to the differences in food choice and food preference criteria outlined in this paper and insect farming enterprises need to be tailored to the expectations of the clientele and in harmony with the geographic location and environment they operate in.

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