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Farming of insects for food and feed in South Korea: tradition and innovation

Insektenzucht für menschliche und tierische Nahrung in Südkorea: Tradition und Innovation

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Summary

Edible silkworm pupae, known in Korea as "beondaegi" and seen as a valuable byproduct of the silk industry have been part of the local food spectrum for centuries. Edible crickets on the other hand, represented in Korea primarily by the species *Gryllus bimaculatus* and *Teleogryllus emma* as our research has shown, are relative newcomers and have been under cultivation in Korea for no longer than about 20 years. Silkworm pupae on account of their widely appreciated nutritional qualities can be obtained fresh at local vendors or in canned form from most supermarkets. Recently when Viagra-like effects of silkworm extracts were demonstrated in male rats, uses of silkworm pupae as material for the pharmaceutical industry have been added to their role as a human food item. Edible crickets, however, find their greatest acceptance as feed for domestic animals like pigs and poultry as well as increasingly farmed fish. The amount of cricket flour as a protein-rich additive to conventional flour types in the baking industry is expected to rise as is the number of farmed crickets and people employed in the cricket farm sector, generally. The total amount of crickets produced currently in Korea is dwarfed by the amount of 10 tons of silkworm pupae annually, of which 2 tons are specifically reared for the purpose of food and feed. To produce approximately 35,000 "beondaegi" 1 ton of mulberry leaf fodder is required, but 200,000 crickets can be reared on the equivalent of 100 kg wheat bran plus 80 kg of corn.

Keywords: entomophagy, silkworms, *Bombyx mori*, crickets, *Gryllus bimaculatus, Teleogryllus emma, Acheta domesticus,* mini-livestock, nutrients, Viagra-like effects, beondaegi

Zusammenfassung

Essbare Seidenraupenpuppen sind in Korea seit Jahrhunderten unter der Bezeichnung „beondaegi" als wertvolles Beiprodukt der Seidenindustrie bekannt. Essbare Grillen andererseits, in Korea repräsentiert durch die Arten *Gryllus bimaculatus* und *Teleogryllus emma*, sind Neuankömmlinge und nicht länger als ca. 20 Jahre in Kultur, wie unsere Arbeit zeigt. Wegen ihrer geschätzten Nahrhaftigkeit werden Seidenraupenpuppen sowohl von Straßenhändlern als auch Supermärkten frisch oder in Dosen angeboten. Seitdem bekannt wurde, dass Seidenraupenextrakte Viagra-ähnliche Effekte in Rattenmännchen auslösen, kommen zur Rolle der Essbarkeit die einer pharmazeutischen Nutzung hinzu. Essbare Grillen finden ihre größte Akzeptanz als Futter von Schweinen, Geflügel und mehr und mehr auch Fischen. Die Produktion eiweißreichen Mehls auf Grillenbasis, das in der Backindustrie herkömmlichem Mehl beigefügt werden kann, wird wohl steigen, ebenso wie die Zahl der Beschäftigten in der Grillenhaltung allgemein. Die Gesamtjahresproduktion an Grillen ist jedoch winzig im Vergleich zu den zehn Tonnen jährlich produzierter Seidenraupenpuppen, von denen zwei Tonnen ausschließlich der Nahrung für Menschen oder als Futter für Tiere dienen. Um ca. 35.000 essbare Seidenraupenpuppen zu erzeugen, braucht man etwa eine Tonne Maulbeerblätter, aber 200.000 Grillen können mit 100 kg Weizenkleie plus 80 kg Mais produziert werden.

Schlüsselwörter: Entomophagie, Seidenraupen, *Bombyx mori,* Grillen, *Gryllus bimaculatus, Teleogryllus emma, Acheta domesticus*, Kleintierhaltung, Nährstoffe, Viagra-ähnliche Wirkung, beondaegi

Introduction

"Why would anyone want to farm insects" is a question we have often had to face from members of the general public. When we replied that honeybees are "farmed insects" and provide us with honey and help us in our orchards with pollination, that silk owes its origin to insects which have been domesticated to an extent that they would perish outside of cultivation and that the red dye known as cochineal used for lipstick and other kinds of coloration also stems from an insect (cf. Borror et al. 1989), the usual response was: "Well yes, but …".

To be honest, the number of insects under culture, often for hundreds if not thousands of years, is certainly not large and an examination is indeed justified as to why this is so and why only quite recently the breeding of insects as a form of mini-livestock has become a matter of scientific and commercial interest. Prior to 1975 several reports existed, which provided information on where in the world and by whom insects were consumed as food (Bequaert 1921, Bergier 1941, Bodenheimer 1951, Holt 1885) and it seems that even in Europe 2000 years ago wealthy folk relished lucanid and other grubs (Holt 1885). Reports such as these contained species lists, descriptions of how some food insects were prepared for human consumption and some references on the insects' nutritional value, but they did not link insect consumption with global food security issues. The first paper in which it was suggested that insects could help to ease the problem of global food shortages was a two-page commentary by Meyer-Rochow (1975) in the journal 'Search' of the Australian and New Zealand Association for the Advancement of Science (ANZAAS).

Pointing out in that paper that some countries had a long history of using insects as human food, the author suggested that these countries maintain their tradition and not give up entomophagy in order to please western attitudes or appear "more civilized". Insects that were killed by insecticides and other means often represented a higher nutritional value than the plants that people tried to protect. It simply seemed to make more sense using the insects as food or feed rather than destroying them and polluting the environment with chemicals risking potentially harmful side-effects. An obvious consequence of this suggestion was to examine how insects could be used and ultimately farmed (Van Huis et al. 2013). But there is more to it, for insects can serve as efficient bioconverters of organic matter; they can produce pharmacologically active substances (Meyer-Rochow 2017) and, under culture, display high feed to protein ratios, but require less water and less space than conventional food animals (Oonincx et al. 2015). Moreover, the life cycle of many insect species is short, fecundity is high and their often polyphagous nature allows a variety of feed stuffs, including wastes to be given to them (Halloran et al. 2016, 2017). To use insects as many people of non-western cultural backgrounds had practiced for times immemorial made sense; to fight and destroy them as practiced by people belonging to societies of western cultural backgrounds did not (Meyer-Rochow 2010).

It is now known that at least 2,000 species of insects worldwide find acceptance as human food, but of these not many more than just a handful are commercially bred, while perhaps a few additional dozen are considered potential farming candidates, with some having already undergone exploratory farming and others being earmarked for future tests. Some of the latter, to name but the most important ones, include the saturniid caterpillars of *Gonimbrasia belina* (known as the mopane worm), *Lobobunaea* sp., *Pseudobunaea* sp., *Samia cynthia*, and *Cirina forda*; furthermore crickets and grasshoppers like *Brachytrupes orientalis, Gryllus assimilis, Scapsipedus marginatus, Gryllodes sigilatus, Ruspolia differens*; beetles and their grubs like those of various dynastine, e.g. *Allomyrina dichotoma* and other scarab species, cetoniids like *Cetonia aurata* and *Protaetia brevitarsus*, further curculionids like *Rhynchophorus* spp., ceramabycids like *Ergates faber* and *Bardistus cibarius* as well as tenebrionids like *Zophobas morio* and some large water beetles. Hemiptera are represented by *Encosternum delegorguei*, the gondibug *Aspongopus nepalensis* and giant waterbugs of the genera *Lethocerus* and *Belostoma* while for Blattidae the Madagascar Hissing cockroach *Gromphadorhina portentosa*, the Cinerea cockroach *Nauphoeta cinerea* as well as *Blatta (Shelfordella) lateralis* need to be mentioned and for social insects the wasp *Vespula flaviceps*, the weaver ant *Oecophylla smaragdina* and the termite *Macrotermes bellicosus* come to mind. These species, which were commented on by various researchers at the recent International Conference "Insects to Feed the World" in Wuhan/China (15-18 May 2018), are outnumbered by those that are still obtained entirely from the wild often in large numbers like, for example, the rice grasshopper *Oxya yezoensis* in East Asia, various water bugs, e.g. backswimmers in Mexico, numerous beetles and their larvae, dragonfly nymphs and many other aquatic insects in various parts of the world.

Insects nowadays bred commercially fall into five camps: 1. those with a long history of domestication like honeybees and silkworms; 2. those used primarily for educational, scientific (e.g. *Drosophila melanogaster*) and medicinal purposes like some cockroaches (especially in China) as well as some flies whose maggots are being used in debridement; 3. those that are fed to domestic and pet animals as well as to farmed fish and shrimps like, for example, the yellow mealworm *Tenebrio (T.) molitor* and the Black Soldier fly *Hermetia illucens,* but also *Drosophila melanogaster* and locusts; 4. those used as human food or as a nutritious supplements and ingredients in the form of insect flours, e.g. a variety of cricket species dominated by the house cricket *Acheta domesticus* and the field cricket *Gryllus bimaculatus,* but also mealworms like *T. molitor* and pupae of the silkworm moth *Bombyx mori*; 5. those not primarily used as food or feed, but reared to deal with the removal and recycling of organic wastes in bioconversion programs like various species of flies and their maggots, e.g. *Musca* spp., *Lucilia* spp., *Chrysomya megacephala, Calliphora erythrocephala*, etc.

Currently perhaps the most popular industrially bred insect species worldwide are the Black Soldier fly (*H. illucens*) and the mealworm beetle (*T. molitor*), i.e. insects, whose larvae, pupae and sometimes even adults are finding widespread use as feed, but in case of the mealworm also as human food. Crickets as farmed insects are relative "newcomers" in this field, although especially for Thailand a considerable amount of expertise in rearing these orthopteran insects has accrued over the last few decades.

In Korea (both North and South) the two most commonly appreciated insects as human food are rice grasshoppers like *Oxya yezoensis* and silkworm larvae

FIGURE 1: *Illustrations in connection with the production of edible silkworms. (source: Sampat Ghosh)*
A: *Canned beondaegi silkworm pupae available for sale at a typical South Korean supermarket.*
B: *An individual bowl (there are several brands available at different prices).*
C: *Fresh beondaegi silkworms on offer at a traditional market in South Korea.*
D: *Nutritional information in Hangul on the can of beondaegi edible silkworm pupae.*
E: *Beondaegi silkworm pupae served as a side dish in a restaurant.*
F: *Dried beondaegi silkworm pupae for sale at a traditional market in South Korea.*

and pupae (Kim and Jung 2013). The grasshoppers are obtained from the wild, but this is not the case with regard to the consumption of silkworms, especially their pupal stage. Rearing silkworms in Korea is steeped in history and has a long tradition. The practice probably arrived in Korea via China after silkworms were first used in the region of Assam in North-East India for the production of silk and food as early as 6,000 years ago (Cloudsley-Thompson 1976). However, owing to different climatic and environmental conditions, but also social conditions prevailing in Korean farming communities, rearing practices are likely to have undergone adaptations to the local situation in Korea and would differ from those practiced elsewhere (e.g. North-East India, Chakravorty et al. 2015). It is for this reason that we decided one of the foci of this paper should deal with the traditional silkworm farming in Korea carried out for the purpose of obtaining an edible product known as "beondaegi".

For the second focus we decided to deal with cricket rearing in Korea, because orthopterans like *Gryllus bimaculatus* have only relatively recently found a market in Korea (or are in the process of finding one as with *Acheta domesticus* and *Teleogryllus emma*) as food and feed (Keum et al. 2012) and therefore become a new commodity of commercial interest. The industry of cricket farming in Korea is young (Ghosh et al. 2017) as it is in other Asian and African countries (Halloran et al. 2018) and could not build on traditional expertise as biology and life cycle of the hemimetabolous crickets differ greatly from those of the holometabolous silkworm moth *Bombyx mori*. We felt contrasting traditional food insect practices based on silkworm rearing with the more modern approach used in connection with captive crickets in culture would allow us to see how Koreans have dealt with the challenge of turning industrial scale insect farming into a viable proposition.

Material and Methods

In order to understand the operations of insect farms engaged with silkworm rearing and cricket domestication we contacted 6 breeders and carried out 17 surveys telephonically and we also visited two insect rearing facilities during the months of May and June 2018. The information gathered during these visits and the responses to the surveys provide the basis of our report. Both of the farms visited were medium scaled and located near the city of Andong in Gyeongsangbuk province. The silkworm rearing establishment visited had 20 years of experience for the production of 'beondaegi' while the cricket farm was established only 6 years ago. We prepared a semi-structured questionnaire that was e-mailed to the breeders mentioned above and which contained questions on techniques of breeding (temperature, humidity, sizes and shapes of containers), feed, rearing facilities, amount of production, storage of product, selling price and operational processes, including human resources. The breeders showed and discussed the questionnaire with an unknown number of employees and within 2 weeks provided us with their responses.

Results

Growing of silkworms as food in South Korea

Farming of silkworms in Korea has been practiced for at least 2,000 years and possibly longer, although its beginnings are shrouded in history. Silkworms are the cater-

FIGURE 2: *Illustrations in connection with the production of edible crickets. (source: Sampat Ghosh)*
A: *Interior of a cricket farm with arrangement of three-storied racks for cricket boxes.*
B: *View of the rearing facility with cricket boxes arranged in three tiers.*
C: *Wheat bran and pieces of corn as well as foam material soaked in water are given to the crickets on a daily basis, but the artificial flowers are not exchanged.*
D: *Moist pieces of foam are provided to female crickets to deposit their eggs in.*
E: *Clusters of cricket eggs visible as whitish patches inside the foam.*
F: *Artificial flowers made of plastic and cloth are provided as bedding in the rearing boxes.*

pillars of the bombycid moth *Bombyx mori* and almost certainly the main objective by Koreans for rearing them must have been to obtain the silk that the larvae produce in order to construct their pupal cocoons with. Preserved silk threads in a tomb at Dahori, Changwon, GN, South Korea dated to the first century B.C. is evidence of silk manufacture and thus silkworm rearing in this country (Sim 2004). Sericulture was further developed during the early Three Kingdom Period of the Silla dynasty of Korea (57 BC – 935 AD), resulting in the production of several silk textiles such as gyun, si, joo, sa, neung, gi, joo, sa and even colourful patterned and embroidered silks (Sim 2004). However, even the early breeders must have noticed that especially the pupae are edible and, thus, represented a useful and valuable by-product. Different stages of the silkworm to this day have also played a role as therapeutic agents in traditional Korean medicine (Okamoto and Muramatsu 1922 cited in Meyer-Rochow 2013) in connection with a variety of illnesses and disorders: adult males to treat impotence, premature ejaculation and ulcerations, the faeces of the larvae to treat diabetes, arthritis, numbness of the body, paralysis, and most importantly, larvae infected with the fungus *Beauveria bassiana* to mitigate the effects of stroke, convulsions, tremor, etc. (Pemberton 1999).

In present day South Korea about 6,900 people are engaged in the silkworm industry, including those employed in producing the silkworms' main food, namely mulberry leaves. The total mulberry production area is 2300 ha, but people involved solely to look after the silkworm rearing process are approximately just 2000. Based on an annual production of 10 tons of silkworm pupae, the total silkworm industry in South Korea is currently worth about 70 million US dollars per year, which includes silk, silkworm powder, silkworms as a food item for humans and raw material for pharmaceutical products and growing *Cordyceps* spp. (Hong et al. 2010). As with the silkworm industry in Japan, that of Korea has been in decline, while that of India is rising. Of the total amount of annually produced silkworm pupae, about one fifth (i.e., 2 tons) are earmarked as 'beondaegi' and used as a food item for humans, sold cooked and canned in supermarkets (Fig. 1a), offered in bulk by street vendors and in open markets (Fig. b, c) with content information clearly displayed (Fig. 1d), and served in restaurants as part of the menus available there (Fig. 1e). Fig. 1f provides a close-up of what you would then introduce to your taste receptors!

The market price for a 130 g can of beondaegi, containing between 130 and 135 individual pupae, their weights varying between 0.75 to 1.1 g, is 1000–1500 won (= 0.9–1.3 US$), depending on where in the country and from which shop you purchase the item (own observations). Breeders usually charge 150,000 won per kg of male pupae and 70,000 won per kg of female pupae, but prices vary between different silk cooperatives and, moreover, at least 50% of the edible silkworm pupae are imported from China and sold for 20% or less than the price of the Korean product.

As we were able to ascertain, pupae (and we shall here focus on those used as human food) are produced mainly during the months of June to September. One ton of mulberry leaf fodder is required to produce 50 kg of pupae-cum-cocoons (resulting in approx. 35 kg of beondaegi) and the leaves are generally harvested from the field or are sometimes stored in the refrigerator to be used as feed when the need arises. The silkworms go through 5 larval stages, known as instars and are being given mulberry leaves three times a day. Based on the information supplied by the breeders, the rearing of early instar larvae takes place at an ambient temperature of 27°C ad a humidity of 70–85%, but for late instar larvae the temperature is lowered to 23°C with relative humidity remaining unchanged. Sick and abnormal larvae are immediately removed, so that only healthy individuals proceed to produce a cocoon. For the folk medicinal market some farmers run the production line for fungus-infested larvae by either *Beauveria* sp. or *Cordyceps* sp. There is a demand in the speciality markets including functional foods, traditional medicine and cosmetics.

For the beondaegi production, the process differs from the process of silk production (Ji et al. 2015). For silk production generally pupae close to the end of their pupal phase are collected and killed by heating (gradually increasing the temperature up to 100°C). Completely dry cocoons are stored at room temperature until further processing. To remove the yarn from the cocoons, boiling the latter in water of 100°C to which some soda or some other chemical in order to soften them may be added, is the method of choice. After removing the yarn, the capsule and pupae are left. These pupae are not used as 'beondaegi' (edible silkworm pupae), because sometimes pesticides may have been used during storage. For beondaegi production usually 5 day old pupae are used, which people remove from the cut cocoons (older ones are considered less tasty). Ten day old pupae are used for medicinal purposes (Ji et al. 2015).

The trays in which the silkworms are reared are nowadays mostly of plastic, but used to be of wood (own observations). Their dimensions vary, but generally rectangular shapes, approximately 120 x 90 cm are preferred. The growth of the silkworm from the time it hatches as a tiny blackish and hairy caterpillar of little more than one millimetre in length to a mature 5th instar larva of approximately 5 cm in length is a phenomenal 10,000 fold in weight and requires approximately 20 days, depending on feeding and environmental conditions like temperature and humidity. Cocooning (for which scaffolding or some substrates may be provided) and the change from caterpillar to pupa may take a week, but it can take up to three weeks before the adult moths eclose. The life span of the adults is short and usually lasts no longer than a week during which no food is required, but the environment needs to be warm and humid. Both males and females possess wings, but cannot fly. The males are actively searching females whose pheromone known as bombykol, discovered by Nobelist Butenandt et al. (1961), they detect with their olfactory receptors on their feathery antennae. When the female pheromone is present in the draft of air that the males produce by their rapidly flapping wings to draw air towards their bodies and across their antennae, it leads them to the female to copulate with her. Soon afterwards the females lay 500-600 tiny, spherical white eggs and the life cycle begins anew. The larvae hatch within 10-12 days and adult moths are usually discarded as there is no or little further use for them.

It is noteworthy that male and female pupae differ in appearance, the former being somewhat narrower and possessing a small spot on the ninth abdominal segment. Spectral imaging allows to differentiate the sex without having to cut open the cocoon. With regard to the chemical composition male pupae have been reported to contain more fat than female pupae and are richer in protein (Nakasone and Ito 1967). During late pupal stage female silkworm protein amounts of around 30 kD become reduced in contrast to those of the males (Hou et al. 2010). This explains the higher appreciation and value of male pupae as the cocoons of male pupae yield more silk of a higher quality than those of the female pupae do (Cai et al. 2014, Kiuchi et al. 2014).

The pupae are not only marketed as food for humans in either canned, fresh, roasted or even salted form, but are nowadays also increasingly used in cookies. An important aspect of their modern use is the role they can apparently play as an extract in powdered form to lower blood glucose in humans (Ryu et al. 2013) and as a freeze-dried larval powder of mature silkworms to reduce necrotic and histopathological changes induced by diethylinitrosamine in the liver of experimental mice (Cho et al. 2016). Male silkworm pupa have also been mentioned in connection with Viagra-like effects in human males and scientific studies have demonstrated the effectiveness of male silkworm powder on the erectile dysfunction and testosterone level in rats (Oh et al. 2012; Ryu et al. 2002).

Growing crickets as food in South Korea

As with other food cricket industries in Asian and African countries (Halloran et al. 2018) that of South Korea does not have a long history. Having started not even 20 years ago, as of 2016 there have been 724 insect farms (excluding those rearing silkworm, but including those that breed insect species other than crickets). Compared with the silkworm industry, cricket rearing is a small scale business, but in the process of growing.

The species most commonly farmed worldwide are *Acheta domesticus*, but others like *Gryllus bimaculatus, Brachytrupes orientalis, Teleogryllus commodus* and *Scapsipedus marginatus* have also been under consideration as minilivestock or are already being farmed. In Korea the alien species *Gryllus bimaculatus* is most commonly reared with the local species *Teleogryllus emma* (Keum et al. 2012, Ghosh et al. 2017). Based on a cricket farm (Fig. 2a), located in Gilan (Andong City, GB, South Korea), its monthly production of adult crickets of the Korean species *Teleogryllus emma* (examined by Ghosh et al. 2017) is 120,000. The current selling price of 1000 live crickets, irrespective as to whether they are males or females is 30,000–35,000 won (= 23–27 Euros). Not counting the cost to build the cricket farm's physical structures and initially spending money on re-usable items like shelves (Fig. 2b), plastic trays and containers, artificial flowers made up of plastic and cloth (Fig. 2c), etc. the single most recurring costs on a monthly basis are food for the crickets (200,000 won), foam material for female crickets to lay their eggs in (Fig. 2d), water and electricity as well of course wages to humans involved in looking after the crickets. For the said cricket farm 4 persons are at work.

Rearing chambers are rectangular boxes made up of rope and polythene, measuring approximately 120 x 60 x 60 cm in length, width and height and holding up to 10,000 individual crickets each. As the crickets grow the population densities in the chambers are reduced so that mature insects live in less crowded conditions. The rearing chambers are positioned on three-tier shelves, with every tier containing one chamber covered separately from others by fine insect netting. Altogether there are seven 1.2 m long shelves in the rearing room. As a rule of thumb, for about 200,000 crickets one requires the equivalent of 100 kg of wheat bran and 80 kg of corn (either as pieces or in the form of corn flour), which needs to be bought and transported to the farm. Some farms also provide lettuce, carrots or some other vegetables. However, in order to avoid the risk with insecticide contamination, those types of vegetables chosen, especially cabbage, to feed the crickets with, are carefully examined and monitored with regard to their acceptability. There is, however, no legal requirement for such testing of pesticides or other chemicals.

Developing crickets require sufficient amounts of water and foams can serve as water supply oases, which is why moist foams are introduced to the rearing chambers that contain cricket nymphs. The rearing conditions are kept constant throughout the year and consist of an ambient temperature of 28–30°C and a relative humidity of 60–70%. As there is no seasonal change in this artificial environment, production levels do not fluctuate over the year as with silkworms.

Various kinds of bedding for the crickets are available and generally cardboard or egg cartons are being widely used. However, according to at least one farmer's testimony artificial flowers consisting of plastic and cloth are even better than cardboard beddings. Green foam material, soft and moist, is used for the female crickets to lay their eggs in (Fig. 2e), but whether differently coloured foam materials would work equally well as ovipository materials could not be ascertained by us. The sexes are not separated and reared together.

The time it takes from hatching of the egg to when the adults, known as imagines, first appear after the final moult of the nymphs is about 7 weeks. Pre-oviposition time is the period the females spent from turning into an adult until egg-laying occurs, while post-oviposition is the time from egg-laying until death. Females may mate repeatedly, but lay eggs into the foam provided by the cricket farmer only once. The foams should be wet, i.e. containing sufficient moisture, otherwise crickets would not want to lay their eggs in them (information supplied by breeder). Approximately 650 eggs (the range given to us by the breeder being 128–1683) are produced by a single female. The total number of eggs produced is dependent on environmental factors, especially temperature (Jung and Bae 2007), but also on the weight and physical status of the female, with unmated females usually living a little longer than mated individuals (Bentur et al. 1977). Foam pieces containing eggs, the latter visible as white blotches inside the green foam material, are placed in the rearing chamber, which contains the artificial flowers mentioned above (Fig. 2e, f).

Crickets in South Korea are bred mainly as food for domestic animals, principally poultry and pigs, but aquaculture also sees a growing need for the product (Park and Jung 2012) and is increasingly making use of crickets as fish food on account of the former's favourable protein: fat ratio (according to Kulma et al. 2019 being approximately 20–25 : 4–7 g/100 g fresh weight) and its appreciable mineral content.

Discussion

The Korean silkworm industry, although in decline in face of competition from other countries most notably India and China, is of course on account of its much longer history and importance a far more established sector of the Korean economy than cricket farming is. And yet, in spite of that, changes and new developments are also still part of the silkworm industry. The consumption of edible silkworm pupae may have somewhat decreased, but apparently the import of cheaper edible silkworms from China has not decreased and the interest in silkworms and silkworm pupae as a raw material for the pharmaceutical industry and for medicinal uses has actually increased following reports by Ryu et al. (2002) of male silkworm pupal extracts causing testicular increases of 200%, or those of Oh et al. (2012) of improved erectile responses in rats and Yin et al. (2010) and Chen et al. (2014) of exhibiting hypoglycaemic activity. New genetic research with a focus on underpinning the molecular control of differences between male and female silkworms (Cai et al. 2014, Kiuchi et al. 2014) has revived older work on fatty acid differences between male and female pupae (cf., Nakasone and Ito 1967). Research, moreover, on how to make edible silkworm pupae more palatable has led to the recommendation of novel processing methods of late instar larvae and pupae (Ji et al. 2015).

As silkworm pupae represent approximately 60% of the dry weight of the cocoons and serve as an item of the human food spectrum, interest in this product's nutritive value and chemical composition is understandable and numerous publications are testimony to this. Rao (1994) published a detailed account on the chemical composition of spent silkworm pupae and found them rich in trace elements like phosphorous, calcium, iron, zinc, copper, chromium, manganese and magnesium. Nearly 50% of the dry weight was protein, which rose to 75% in defatted pupae, while 30% were fats of which the majority were unsaturated fatty acids. With the exception of the essential amino acid tryptophan, the pupal protein was considered to be comparable to egg protein. Confirmation of these observations came from Pereira et al. (2003), who analysed *Bombyx mori* chrysalis toast finding it to contain 51.1% protein and 34.4% lipid with essential fatty acids such as linolenic acid and polyunsaturated/saturated and n-6/n-3 ratios of 0.99 and 0.30, respectively. Tomotake et al. (2010), who reported a slightly higher protein content, namely 55.6%, and for the total lipids provided a value of 32.2%, moreover identified a potent alpha-glucosidase inhibitor known as 1-deoxynojirimycin, allowing them to conclude that "silkworm pupae are a new source of high quality protein, lipid, and alpha-glucosidase inhibitor".

Apart from the species *Bombyx mori* other silkworm species exist and have found acceptance as food for humans. Although not reared in Korea the non-mulberry eri silkworms (*Samia ricini* and *Samia cythia*) as well as the muga (*Antheraea assama*) silkworms are consumed and in North-East India are more popular than the mulberry silkworm *Bombyx mori*. Eri silkworm pupae, for example, are the most appreciated as food, followed by muga and *Bombyx mori* silkworm pupae (Mishra et al. 2003). However, irrespective of the species they belong to, their protein to lipid ratios, moisture and ash content are all very similar (Mishra et al. 2003). It is clear that silkworm rearing and silk production have never occurred in isolation and that they have always been a focus of a variety of research activities, in fact considerably more so than the rather recent cricket farming activities in Korea, the latter dwarfing the former in terms of its role in the Korea economy.

As with other countries like, for example, Thailand (Halloran et al. 2016) that have recently embarked on cricket farming, small scale entrepreneurial activities, which cricket farming is a part of, do however have a role to play in the local economy. They offer employment opportunities, can provide new ideas and incentives and may lead to economic diversification and advances (Paulson and Townsend 2004). Research results on methods how to best grow and rear edible crickets in Korea are not always published and, in fact, are sometimes withheld by the growers and guarded as business secrets. On the other hand published findings based on cricket research elsewhere in the world are welcomed and noted with interest by Korean entomologists and, if applicable to the Korean cricket farming situation, are then made available to the Korean cricket grower.

Research on *Acheta domesticus* (the house cricket) and *Gryllus bimaculatus* (the field cricket) by Kenyan entomologists has shown that the nutritional and chitin composition of farmed house crickets depends on their age (Kipkoech et al. 2017) as well as the feed they obtain from the grower during their development (Orinda et al. 2017). Earlier work by Ayieko et al. (2016) had shown that on a dry weight basis industrially reared crickets, typically contained 47% protein, 10% carbohydrates and 25% fat. Minerals identified were sodium, copper, calcium, potassium, iron, phosphorous, manganese and zinc. Vitamins included vitamin A, B1 (thiamine), B2 (riboflavin) and vitamin E. In tests with four different diets (grower's mash, rice bran and blood meal, rice bran and spent grain, rice bran and spent yeast) the highest mean adult weights were obtained with crickets that had been reared on a diet of grower's mash (Orinda et al. 2017). In analyses focusing on age differences, findings indicated that farmed house crickets "would be best harvested between weeks 9 and 11 when the protein and mineral content is optimum" (Kipkoech et al. 2017). That sexual differences in the nutritional value between male and female house crickets exist, with females containing significantly higher amounts of lipids but less protein and chitin than males, has recently been discovered by Kulma et al. (2018).

Although undoubtedly the house cricket *Acheta (A.) domesticus* is the most widely farmed species of cricket in the world right now, other farmed species and potential commercial candidates have also been the subject of research. *Brachytrupes orientalis*, for example, had its chemical composition analysed by Chakravorty et al. (2014) and was found to be considerably richer in crude protein (65.7%) and carbohydrates (15.2%), but poorer in fat (6.3%) than *A. domesticus*. With the exception of methionine (and possibly tryptophan) FAO recommendations of essential amino acids were met, while palmitic (50.3%) ad stearic (32%) fatty acids were dominating lipid components. In Korea, *Gryllus (G.) bimaculatus* has received attention as a subject of cricket farming and another cricket species, *Teleogryllus (T.) emma* has also already been under cultivation (Jung and Bae 2007). Chemical composition of these two species showed that they contained 58.32 and 55.65% protein, respectively. However, fat content differed widely, with *G. bimaculatus* containing only 11.88% and *T. emma* 24.14% fat on the dry weight basis (Ghosh et al. 2017). In both cases unsaturated fatty acids predominated over saturated fatty acids and the two species contained comparable if not higher amounts of minerals particularly of magnesium, iron and zinc than conventional foods of animal origin (Ghosh et al. 2017). When the edible African cricket *Scapsipedus marginatus* was reared on different diets, the shortest development (66 days), highest longevity for males (52.4 days) and females (50.2 days) as well as wet weights for males and females (0.68 and 0.9 g, respectively) were observed in connection with wheat bran meal. The highest fecundity and hatchability were observed when the crickets were fed soya bean meal (1402 ± 25 eggs), but the longest developmental duration (103 days) and lowest survival rates (46%) were recorded in connection with maize meal feed (Magara et al. 2018).

To what extent data such as these are relevant to the Korean cricket breeders (and others in the world) is difficult to ascertain, but that they provide food for thought and encourage breeders to come up with their own tests and innovations is to be expected. That the breeding of crickets, be it for human consumption or feed for domestic animals, has a future despite the fact that apparently no insect species can be regarded healthier than beef or chicken (Payne et al. 2015), is nevertheless equally likely, for all the evidence that there is suggests that the crickets are nutritious, easy to breed and efficient feed to protein bioconverters requiring far less space than conventional food animals. Rigorous health controls in Korea make sure that farmed crickets in Korea meet accepted standards of health and are safe to be consumed by humans and animals.

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Conflict of interest

The authors confirm that no conflicts of interest are associated with this publication and no financial support was received that could have influenced the outcome of the present study.

Ethical approval

The research reported in this paper met all ethical requirements and had the approval of the organizations involved.

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Authors contribution

VBM-R provided the incentive for this investigation, provided ideas and wrote the manuscript; SG put the questionnaire together, evaluated the responses and together with CJ visited breeders and facilities. CJ, moreover, contacted breeders, arranged visits, acted as interpreter, was the recipient of the grant, and held overall responsibility.

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