Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Faculty of Natural Resources and Agricultural Sciences

The house cricket *Acheta domesticus*, a potential source of protein for human consumption

Hussyrs*an Acheta domesticus,* en potentiell källare till protein för mänsklig konsumtion

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Department of Molecular Science

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Abstract

The population of the world is growing and it is expected that it will reach 9.6 billion people by the year 2050. The demand for animal-derived protein is expected to increase which also increases the land and water usage, greenhouse gas emissions (GHGEs) and therefore leads to environmental stress. These factors show that the current way of producing protein is unsustainable. While people in the western world are overconsuming, people in developing countries are not getting the protein and energy they need, which leads to diseases like obesity, kwashiorkor and marasmus. Protein is the most essential component of tissue, especially muscles and in the human body. Animals, as well as plants, are sources for protein in human diet. The house cricket *Acheta domesticus* has with a protein content of 66.6 % dry weight, one of the highest protein contents of edible insects and it is significantly greater than traditional protein sources. Furthermore, all essential amino acid contents are predominantly higher than in traditional protein sources, and are able to meet the daily need of essential amino acids for humans. To integrate the *Acheta domesticus* in human consumption, an increase of promotion and knowledge is needed. Higher acceptability can be given by different processing of insects into powder or flour. Also, familiar snacks (e.g. protein bar, cookies) and culture adapted recipes containing *Acheta domesticus* can promote insects for human consumption. Farming the *Acheta domesticus* can be a lucrative business, even for unemployed people with low education, as it is easy to rear the *Acheta domesticus* and a low capital expenditure is needed. Still, courses have to be given to improve the knowledge about farming *Acheta domesticus*. It can be a challenge to farm on a large scale (but also on a small scale), because of the *Acheta domesticus* densovirus (AdDNV) which can cause high death-rates in *Acheta domesticus* populations. By selecting a more AdDNV tolerant *Acheta domesticus* the chances of getting an outbreak be lowered. Unfortunately, a virus tolerant *Acheta domesticus* has not been found yet. To increase sustainability, optimize rearing and therefore lowering the price per kilogram, many factors like location and energy cost play a big role. By comparing different rearing temperatures, it showed that the *Acheta domesticus* grew faster, but stayed smaller, at 29°C and it grew slower, but gave a higher individual weight in the adult stage, at 27°C. The amino acids and protein content in the haemolymph are the highest in the one-day-old adult. This shows that the rearing temperature of 29°C can be more suitable for the *Acheta domesticus* because the one-day-old adult stage is reached faster. The USA/Canada retail price of the *Acheta domesticus* is with €21,46 higher than the traditional protein sources. Still, by calculating the price to reach 100% Recommended Daily Allowance (RDA) of essential amino acids, the *Acheta domesticus* has a smaller difference in price with €1,02, compared with for example beef which has €0,82 Euro. The challenge is to optimize the farming of the *Acheta domesticus* to lower the kilogram price, which makes it even more competitive with the traditional protein sources.

Keywords: house cricket, Acheta domesticus, protein, amino acids, sustainable diet, future food

Sammanfattning

Världsbefolkningen växer och det förväntas att den kommer att nå 9,6 miljarder år 2050. Efterfrågan på animaliskt framställt protein förväntas att tillta, vilket också ökar mark- och vattenanvändningen, växthusgasutsläppen (GHGE) och därmed leder till miljöbelastning. Dessa faktorer visar att det nuvarande sättet att producera protein är ohållbart. Medan människor i västvärlden överkonsumerar, får människor i utvecklingsländer inte tillräcklig med protein och den energi de behöver, vilket leder till sjukdomar som å ena sida fetma, å andra sidan kwashiorkor och marasm. Protein är den viktigaste delen av muskler och vävnader i människokroppen. Djur och växter, är källor till proteiner i människan. Hussyrsan *Acheta domesticus* har en proteinhalt av 66,6% torrvikt, en av den högsta proteinhalter i ätbara insekter och är signifikant större än traditionella proteinkällor. Dessutom är alla värden från aminosyror övervägande högre än i traditionella proteinkällor och är tillgängliga för att möta det dagliga behovet av essentiella aminosyror för människor. För att integrera *Acheta domesticus* i den mänskliga konsumtionen, behövs det en ökning av marknadsföring och kunskap. Högre acceptans kan ges genom olika behandlingar av insekter i pulver eller mjöl. Kända snacks (t.ex. proteinstång, kakor) och kulturanpassade recept kan också främja insekter vid konsumtion. Att föda upp *Acheta domesticus* kan vara en lukrativ affär, även för arbetslösa personer med låg utbildning, eftersom det är lätt att föda upp *Acheta domesticus* och det krävs ett lågt kapitaltillskott. Men kurser måste ges för att förbättra kunskapen om *Acheta domesticus´* uppfödning. En utmaning kan vara jordbruk i storskaliga (men även i småskaliga) jordbruk på grund av *Acheta domesticus* densovirus (AdDNV) som kan orsaka höga dödstal i *Acheta domesticus* populationer. Genom att välja en mer AdDNV tolerant *Acheta domesticus* kan den sänka chansen att få viruset. Tyvärr har det inte hittats en virustolerant *Acheta domesticus* ännu. För att öka hållbarheten, optimera uppfödningen och därmed sänka kilogrampriset spelar många faktorer som plats- och energikostnader en stor roll. Genom att jämföra olika uppfödningstemperaturer visade det sig att *Acheta domesticus* växte snabbare vid 29°C. Oavsett om *Acheta domesticus* ger en högre individuell vikt i vuxenstadiet vid 27°C är aminosyror och proteinhalten i hemolymfen den högsta för den en-dag-gamla *Acheta domesticus*. Detta visar att uppfödningstemperaturen 29°C kan vara mer lämplig för *Acheta domesticus* och kan ge ett högt innehåll av aminosyror och protein i haemolymf jämfört med en uppfödningstemperatur på 27°C. USA/Kanada-försäljningspriset på Acheta domesticus är 21,46 Euro högre än de traditionella proteinkällorna. Genom att beräkna priset för att nå 100% rekommenderat dagligt tillskott (RDA) av essentiella aminosyror har Acheta domesticus fortfarande ett liknande pris med 1,02 Euro jämfört med till exempel nötkött som har 0,8 Euro. Utmaningen är att optimera uppfödningen av *Acheta domesticus* för att sänka kilogrampriset, vilket gör det ännu mer konkurrenskraftigt med de traditionella proteinkällorna.

Nyckelord: hussyrsa, *Acheta domesticus, protein, aminosyror, hållbar kost, framtidens mat*

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Abbreviations

AA	Amino Acid
AdDNV	*Acheta domesticus* Densovirus
BW	Body Weight
CNEAA	Conditional Non-Essential Amino Acid
EAA	Essential Amino Acid
NEAA	Non-Essential Amino Acid
RDA	Recommended Daily Allowance
UPA	Urban and Peri-Urban Agriculture

1 Introduction

In this work, the house cricket *Acheta Domesticus* (Ortoptera: Gryllidae), will be evaluated. This evaluation focuses on the *Acheta domesticus* as a potential source of protein in human consumption and scientific knowledge about the protein compositions.

The human population is growing and is estimated to reach 9.6 billion people by the year 2050 (United Nations, 2013). The request for animal-derived protein is expected to increase 72% over the next 35 years. (Wu *et al*, 2014). Our current way of producing protein is unsustainable. This can be seen in its emissions of greenhouse gasses (GHGEs), land and water usage, and the rate of which climate change is happening (Conway, 2012; Nijdam et al., 2012). These factors put significant stress on the environment, which is why an alternative form of livestock is needed to provide a source of protein. Further, this work will look into the challenges of introducing insects for human consumption. Because in some parts of the world it is already normal to eat insects (DeFoliart, 2012), but not yet in the western world (Nowak *et al*, 2014).

1.1 A prospective alternative

Insects have been a part of the human diet in tropical countries for hundreds of years and they are often considered to be a delicacy in Africa (DeFoliart, 2012). Worldwide, about 2,000 different insect species and other invertebrates are being consumed by humans (van Huis, 2015). Generally, edible insects are harvested from nature, but farming is getting more common. This leads to insects being used as a mini-livestock through urban and peri-urban agriculture (UPA). UPA can help people to rear the insects within and around cities and follow the trend to get organic and fresh food (FAO, 2009).

Insects for human consumption can make a considerable difference provided that they are commercially mass-produced (van Huis *et al*., 2015). In order to radically increase the production of insects in the future, more research into the safety and allerginicity of insects as human food is required (Testa *et al*., 2016). After that research has been conducted successfully, edible insects will be approved through EU legislation (Finke *et al*., 2015) which will kick start innovation of the automation of rearing and processing technologies (Rumpold and Schlüter, 2013). Then large-scale insect production can be seen.

1.2 Ambition

The knowledge of the nutritional composition in the *Acheta domesticus* is essential, provided that the house crickets will be an option for human consumption. The primary motivator behind this work is to spread knowledge about, and increase awareness in, insects as food, with the end goal of them replacing current forms of agriculture for protein sources. Because the knowledge of the nutritional composition of the *Acheta domesticus* is essential for this, the focal point in this work is to analyse the present knowledge about the nutritional protein and amino acid content of the *Acheta domesticus*.

1.3 Method

This work is a literature study which used books and databases listed at the WUR and SLU library (Scopus and Web of Science). The papers examined for this study are published between 1964 and 2018 and keywords such as: *Acheta domesticus, house cricket, protein, amino acid, sustainable food, future food* were used.

2 Background

2.1 What is protein?

Protein is a nitrogen-containing substance which consist of different amino acids (AA) linked by peptide bonds (Wu, 2016). In humans and animals, protein is the most essential component of muscles and tissues (Reeds, 2000). In the human body, they are utilized to produce hormones, enzymes and haemoglobin. Proteins are essentially AA chains, which are progressively hydrolysed in the human body by the enzymes proteases and peptidases to individual AA, dipeptides and tripeptides (Wu, 2016). Carbon (C), oxygen (O), Nitrogen (N), hydrogen (H) and small amounts of sulphur (S) are the basic units of protein (Institute of Medicine, 2005). The quality is defined for their nutritional value (Wu, 2016), essential AA composition, but also the bioavailability of AA (FAO, 1991). In human diet, the key parameters for quality assessment of protein are the essential amino acids (EAAs) (Akhtar and Isman, 2017). Animals, as well as plants are sources of proteins in the human diet. As a result of deficient and/or an unbalanced EAA content, the nutritive value of plant protein is lower than of animals (Millward *et al*., 2008).

2.1.1 Amino acids

Amino acids are building blocks for proteins and various low-molecular-weight compounds (Kong *et al*., 2012). AA consists of the central α-carbon, linked to a carboxyl group, an amino nitrogen group and a side chain. The α-carbon and the amino group are the linkage between the peptide bonds. The side chain specifies the functional differences and size of each AA. Additional, the side chain group has different charges at physiological pH (nonpolar, uncharged and polar, negatively charged, positively charged), some are hydrophobic and some hydrophilic. These AA chains can be divided in four structural groups: primary-, secondary-, tertiary- and quaternary structures. AAs are important for the health, reproduction, lactation, development, and survival of organism (Wu, 2016). In protein, there are ± 20 different AAs which can be divided in essential amino acids (EAAs) and non-essential amino acids (NEAAs).

2.1.2 Essential and Non-Essential Amino Acids

All AA are mandatory for humans, while the EAA carbon skeleton cannot be synthesized *de novo* by the human body and must be provided through diet. NEAAs are effortlessly synthesized from intracellular carbohydrate molecules and amine groups in the large AA pool in the human body (Hoffer, 2016). Conditionally non-essential amino acids (CNEAA) are non-essential, but become essential when the body is exposed to stress or illness. In table 1, all EAAs, NEAAs and CNEAAs are shown.

Table 1. *Essential, Non-Essential and Conditional Non-Essential Amino Acids for Humans.*

Essential	**Non-essential**	**Conditionally non-essential**
Histidine	Alanine	Arginine
Isoleucine	Aspartic acid	Cysteine
Lysine	Asparagine	Glutamine
Methionine	Glutamic acid	Glycine
Phenylalanine	Serine	Proline
Threonine		Tyrosine
Tryptophan		
Valine		

2.2 Health aspects and recommendation

The requirement of protein for humans differs depending on age, gender, body size, possible environment and physiological activities. For a healthy adult with low physical activity, the recommended daily allowance (RDA) of protein is 0.8 gram per kilogram body weight (BW) per day (Institute of Medicine, 2002). For pregnant and lactating women, children and elderly a higher protein RDA of 1 gram per kilogram BW per day is recommended (Rahi *et al.*, 2015). The protein intake should be 10%-35% of the total caloric intake (Institute of Medicine, 2002).

2.3 Health aspects

Worldwide, 178 million children are malnourished and 20% of all women have a low body mass because of malnutrition (Imdad and Bhutta, 2012). Serious malnutrition leads to kwashiorkor and marasmus, which are acute human diseases, especially for children. These types of diseases are mainly caused by a diet that is lacking in protein or lacking in protein and energy, respectively (FAO, 2013). Kwashiorkor mostly exhibit with changes in hair and skin colour, edema, hepatomegaly, anemia, lethargy, urgent immune deficiency and early death (Müller & Krawinkel, 2005). Marasmus characteristics are a typical triangular face, extended abdomen from muscular hypotonia, primary or secondary amenorrhea or rectal prolapse from loss of perianal fat (Bhan *et al.*, 2003).

In contrast, overconsumption of AA and protein from food and supplements, can also lead to negative effects, especially in people with hepatic or renal dysfunction (Hoffer and Bistrian, 2012). The remnants of protein which could not be used by the body can be a burden for bones, kidneys and can lead to liver disease (Delimaris, 2013).

The most serious public health problem in the western world is obesity. In United States, the amount of obese people has increased from 15 % (1976-80) to 35% (2009-10) in the past 30 years (WHO, 2016). Generally, it is caused by excessive energy intake and a lack of physical activity, but it can also be caused by an unbalance involving hormonal, genetic and metabolic factors (Paddon-Jones *et al.*, 2008). It was shown that increased intake of protein, increased satiety (Westerterp-Plantenga and Lejeune, 2004), simplified fat loss (Layman *et al*., 2005) and aided weight management by controlling total energy intake (Gosby *et al*., 2014). To prevent obesity, satiety is one the most important factors. That is why protein has a big advantage compared to carbohydrates and fat under most conditions because it is more satiating (Eisenstein *et. al*., 2002).

Since the estimation of population aged 60 will be more than doubled by 2050, from 962 million people in 2017 to more than 2.1 billion, new challenges to the healthcare system are needed (UN, 2017). Protein is important for the elderly population. With aging, loss of muscle mass and sarcopenia are leading to functional limitations and difficulties to walk and stair-climbing capacity which are associated with a higher risk of falls and disability (Fielding, 2011). By optimizing the protein and AA intake, it helps to prevent negative nitrogen balance and may also avoid sarcopenia, cardiovascular dysfunction, promote bone health, help maintain energy balance and wound healing (Baum and Wolfe, 2015).

The
field

3 The house cricket *Acheta domesticus*

species, *Acheta domesticus*, is native to Southwestern Asia, but it's nowadays distributed worldwide. The incomplete metamorphoses of the house cricket, which consists of egg, nymph and adult, is shown in figure 1. After hatching, the nymph gains in size and slowly develops into an adult. This takes them a series of 7 to 10 moults. Depending on the time it takes to reach maturity, the moulting of each individual from the same species may be more or fewer times. The nymphs reach their adult stage after 6 to 8 weeks (FAO, 2013) and within 24-72 hours after maturation, mating activities begin. Within 24-48 hours after mating the female crickets lay their eggs in a provided area (Murtaugh and Denlinger, 1985). At an optimal temperature, the eggs will hatch after 11-15 days and begin the cycle as nymphs again (Clifford, 1977).

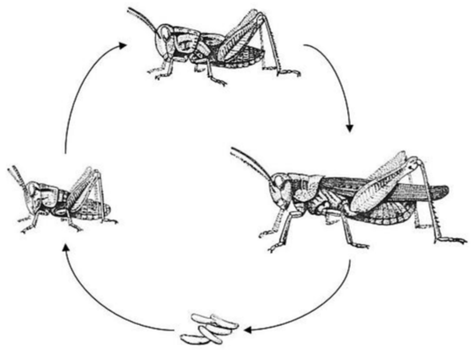

Figure 1. The incomplete metamorphoses (egg, nymph (small and big), adult) of the house cricket *Acheta domesticus.* Adopted from Goforth (2011).

The house cricket contains haemolymph. This is comparable with blood in vertebrates which encloses cellular components, salts, protein, free amino acids, carbohydrates, lipid, water, and more. Unlike the blood of vertebrates, the haemolymph is in direct contact with the tissues and contains the complete internal environment of the house cricket (Wang and Patton, 1968).

Acheta domesticus is dependent on the surrounding environmental temperatures, because the metabolism does not produce enough heat to rise the body temperature (ectotherm) (Rantall *et al*., 2002). Therefore, the temperature has a big impact on the time variation in development.

For example, the growth rate at a rearing temperature of 29°C is faster in the nymph stage and begin of the adult stage compared to a rearing temperature of 27°C (Morales-Ramos, 2018). The relative humidity for the *Acheta domestics* needs to be approximately 50-60% (Booth and Kiddell, 2007).

The house crickets can be reared in unmodified plastic containers filled with egg cartons (Morales-Ramos, 2018) and toilet rolls. Depending on how big the producing farm is, these containers can be in different sizes. Additional, females need a tray filled with topsoil, to lay they eggs. As much as half of the total costs is contributed to feed the house crickets. To cover the nutritional need of *Acheta domesticus* (gut loading), they need to have access to a high-protein chicken feed or specific formulated commercial cricket feed (Gahukar, 2016). To provide the *Acheta domesticus* with water, vitamins and minerals, it is beneficial to give it access to vegetables like carrots. However, house crickets are also able to use certain types of organic waste streams as feed. This could be organic waste (Oonincx *et al.*, 2015), vegetables and cereals (Caparros Megido *et al.*, 2016) and weeds (Miech *et al.*, 2016). Water can be supplied with wet paper towels or by a chicken water feeder. Since the early instars can drown in water, a polyurethane ring in the water tray is necessary. House crickets are animals and therefore welfare is required. They should be free from hunger, thirst, discomfort, pain, injury, diseases, fear, distress and should have the possibility to express normal behaviour (FAWC, 2009).

Harvesting is the end-phase of rearing. All adults are selected, transferred to a bigger container and placed in a freezer. Since the house crickets are ectotherm, sub-zero temperature leads to *torpor*, a naturally occurring state of low-activity until the temperature rises. This state can’t last for longer than 24 hours, otherwise they cannot be revived. Therefore, two days freezing kills and preserves the structure of the house crickets. Moreover, it is a humane and food-safe method and allows a variety of later application (e-g. cooking whole, grinding) (Mott, 2017).

Acheta domesticus has potential for a large-scale rearing for human consumption (van Huis *et al.*, 2013). Nevertheless, the *Acheta domesticus* pet food industry had serious problems with disease outbreaks, especially with *Acheta domesticus* densovirus (AdDNV). The AdDNV is a subfamily of single-stranded DNA virus which infects invertebrate species. An infection causes high death-rates in house cricket populations, predominantly in the last larval stage and in young adults. Moreover, the growth of the *Acheta domesticus* is deferred and individuals become petrified for various days until they die. The densovirus transmits through the body surface or the gut (faeces). Also, studies showed that it can be transmitted through air and therefore between rearing rooms (Szelei *et al.*, 2011). Furthermore, AdDNV can be present in the insulation of a farm and can survive on the epidermis of the house cricket for months (Weissman *et al.*, 2012).

There are differences in the AA content depending on whether the species undergo incomplete metamorphosis or complete metamorphosis. In *Acheta domesticus*, which has an incomplete metamorphosis, the amino acid composition is adequately constant between nymph and adult as well as fed with different diets. While *Acheta domesticus* is primarily known as a potential protein source, it furthermore contains vitamins and minerals, and a high quality of lipids (e.g. omega-3 and omega-6) and fibre (Michaelsen, 2009, Rumpold and Schlüter, 2015).

3.1.1 House crickets as a protein source for human consumption?

Could house crickets be an innovative source for human consumption? This question is confronted with difficulties in cultural acceptance and high farming costs (Dossey *et al*., 2016, Dunkel and Payne, 2016). To be competitive with traditional protein sources, the production cost of house crickets has to decrease (Morales-Ramos, 2018).

3.1.2 Different feed and rearing conditions

Several studies have shown how the rearing conditions can affect the growth rate, protein and AA composition of the *Acheta domesticus* and in which stage the optimal harvesting time is. To optimize the rearing and harvest time for *Acheta domesticus* and, thereby, lowering the cost of feed protein, Morales-Ramos' (2018) study focused on the effects of differing rearing temperatures on the weight and rate of growth of the *Acheta domesticus*. In table 2, the individual weight of the adult *Acheta domesticus* is shown. It shows that the *Acheta domesticus* reaches the adult stage in different weeks, at different temperatures. Compared to the rearing temperature at 27°C, the adult stage was reached one week earlier at the rearing temperature of 29°C. At rearing temperature 27 °C, the highest individual weight was reached in week 10 with an average weight of 355.8±18.6 milligram per house cricket. At the rearing temperature at 29°C, the average weight of the *Acheta domesticus* reached already the highest individual weight in week 7 with 285.8±16.0 milligram per house cricket. See figure 2 for more information.

Table 2. *Individual weight (mean ± standard error of the mean) of adult Acheta domesticus reared at 27°C and 29°C. Adapted from Morales-Ramos (2018).*

Week	**27°C (adult weight mg)**	**29°C (adult weight mg)**
0	-	-
1	-	-
2	-	-
3	-	-
4	-	-
5	-	-
6	-	252.3±13.2
7	280.8±15.4	285.8±16.0
8	322.9±15.1	275.6±20.1
9	352.9±14.7	276.7±21.0
10	355.8±18.6	-

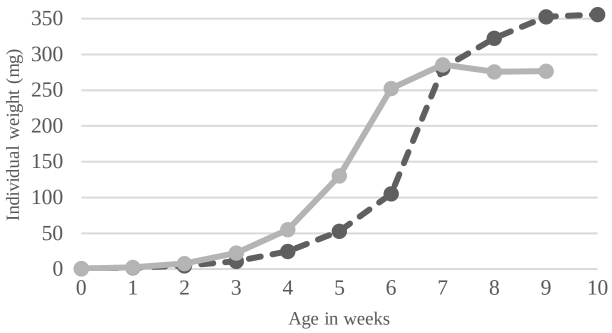

Figure 2. Individual weight at rearing temperature 27°C (line) and 29°C (dash) of *Acheta domesticus* at weekly intervals (age in weeks). Adapted from Morales-Ramos (2018).

Nowoielski and Patton (1964) have done research into optimizing the protein and AA levels at harvesting time. This study showed that age gives a very marked effect on the blood levels (haemolymph) of AA and protein (Figure 3). The free AA values in haemolymph showed a significant difference between sex of *Acheta domesticus*, where the females (drawn line) had 5 milligram higher AA per 100 grams blood than the males (dashed line). The AA concentration in both males and females changed when time passed on. In the two-last larval stages of instar and in the freshly moulted adult, the AA concentration were the highest with ca. 69 milligram (female) and ca. 64 milligram (male). However, this concentration dropped shortly after the final moult.

The highest level of 6% protein was observed in the last two larval stages and in the less than 1-day-old moulted male and female adult. By day fifteen of adult life, the protein level decreased to 4%. No significant differences were found between males and females.

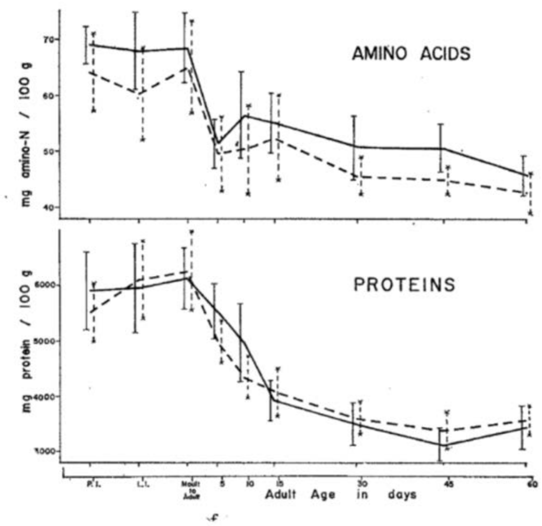

Figure 3. The concentration of total protein and AA in haemplymph of house crickets at different ages (male - dashed line; female - drawn line). The metabolites concentration of late instar larvae and adults expressed as mg per 100 ml of blood. Adopted from Nowosielski and Patton (1964).

3.1.3 Farming price

The retail prices of the house cricket *Acheta domesticus* and traditional protein sources are shown in table 3. In this table, it shows that the retail price of the house cricket from the USA/Canada (€21,36/kg) is 6 times more expensive than those from Thailand (€3,36/kg) and 11 times more expensive than those from Kenia (€1,93/kg). Compared to the traditional protein sources, the crickets from Thailand and Kenia have quite a similar price per kilogram. In table 4 the economic analysis of Morales-Ramos (2018) showed that the yearly cost for rearing at 27°C gives a profit of €12,89 per kilogram compared to the rearing at 29°C which gives a slightly lower profit of €12,02 per kilogram.

Table 3. *Retail price (€/kg) for Acheta domesticus, ground beef, ham, chicken, milk and eggs.*

Protein source	**€/kg**
Acheta domesticus (Thailand)	3.36
Acheta domesticus (Kenia)	1.93
Acheta domesticus (USA/Canada)	21.36
Beef, ground	6.80
Ham	5.56
Chicken, fresh, whole	2.78
Milk, fresh	5.37
Eggs, grade A	3.38

USDA, 2018, Dust and Hanboonsong, 2014

Table 4. *Economic analysis of house crickets reared at 27°C and 29°C. Estimates per gram of hatchlings per cycle.*[1,2]

	27°C	**29°C**
Production cycles per year	5.21	6.77
Production per cycle (g/g H)	171.83	116.55
Production per year (g/g H)	895.96	789.22
Yearly revenue (Euro)	€ 19.10	€ 8.45
Food consumed per cycle (g/g H)	238.46	141.9
Food consumed per year (g/g H)	1,243.41	960.92
Yearly costs (Euro)	€ 6.20	€ 4.80
Yearly profit (Euro)	€ 12.89	€ 12.02

[1]g/g H = grams per gram of hatchlings

[2]Price of feed $ 5.96 and price of live crickets at € 21.36 per kg.

Adapted from Morales-Ramos (2018)

3.1.4 Protein and amino acid content

Species of Orthoptera, including the *Acheta domesticus*, are rich in protein and are globally represented as an alternative protein source (Rumpold & Schlüter, 2015). As is it shown in table 5, with 66.6 % crude protein content in the total body, the *Acheta domesticus* has compared to beef, pork, chicken, salmon, and milk, a significant higher protein concentration.

Table 5. *Protein analysis data for Acheta domesticus and common high protein sources (dry matter).*

Protein sources	**Preparation**	**Protein (%) (Crude Measured as N X 6.25)**
Acheta domesticus	Whole raw, fasted	66.6
Beef	Ground/raw	17.37
Pork	Ground/raw	15.41
Chicken	Ground/raw	17.44
Salmon	Wild/raw	19.84
Milk	Fluid/whole	3.28

USDA National Nutrient Database, 2015

In table 6, the EAA, traditional protein sources and the daily recommendations are shown. Significantly, *Acheta domesticus* has predominantly higher EAA values (g/100g dry weight) than beef, egg and mature soybean seed. Methionine, methionine + cysteine, serine and tryptophan are the few EAAs where beef and egg have a slightly higher amount than the house cricket. However, the cricket has comparatively greater amino acid concentration as the mature soybean seeds and provides the required EAAs for human nutrition according the WHO (2007). The diet has an impact on most nutrients concentration in house crickets, however AA tend to be less sensitive for changes in composition of the feed (Finke an Oonincx, 2017).

Table 6. *EAA content (g/100 g dry weight) of the house cricket Acheta domesticus, traditional protein sources and daily EAA recommendation per adult male (g/ 70 kg).*

Amino acid	***Acheta domesticus***	**Beef**	**Egg**	**Mature soybean seed**	**Recommendation for adult male**
Histidine	2.34	2	1.20	1.07	0.7
Isoleucine	3.64	1.6	2.43	1.76	1.4
Leucine	6.67	4.2	4.15	2.85	2.6
Lysine	5.11	4.5	3.33	2.39	2.1
Methionine	1.46	1.6	1.49	0.48	-
Methionine + cysteine	2.49	2.19	2.56	0.84	1.0
Phenylalanine	3.02	2.4	2.53	1.8	-
Phenylalanine + tyrosine	8.75	4.6	4.49	3.23	1.7
Threonine	3.11	2.5	2.13	1.59	1.0
Tryptophan	0.63	0.25	0.77	0.48	0.3
Valine	4.84	2	2.99	1.77	1.8

Acheta domesticus data: Finke, 2013; Traditional protein source data: USDA National Nutrient Database for Standard Reference (May 2016); daily protein recommendation adults: WHO, 2009

3.2 Human consumption

Cultural facts, emotional aspects (Looy *et at.*, 2014) and individual human diet (House, 2016) play a big role to adapt insect-based foods into our daily diet (Tan *et al*., 2016). For many countries, eating insects is a tradition and needs little commercialization for acceptance. A more critical level of validation is in western countries without a tradition to use insects as food. In these countries, insects are often perceived as dirty, disgusting and dangerous (Looy and Wood, 2006). Also, insects are generally seen as a poor man´s diet (van Huis, 2013). However, studies showed that the consumer acceptance of eating insects has increased over the last five years (Balzan *et al*, 2016, Tan *et al*., 2017). Furthermore, the acknowledgement that insects may serve as an alternative protein-source for human consumption increased (Caparros Megido *et al*., 2016).

The notion of eating whole insects is more absurd. Even if the society wants to consume animal protein, they do not necessarily want to know the origin (Van Huis and Tomberlin, 2017). Therefore, the sensory qualities from the marketing perspective play a big role (Tan *et al.,* 2016). Exquisite taste, attractive packaging and familiar process formats are another strategy to make insects more attractive (Ruby *et al.,* 2015). Also, the acceptance for insect powder or flours may be bigger compared to whole insects. Furthermore, it is attainable to isolate pure protein, fats, chitin, vitamins and minerals (van Huis *et al.*, 2013).

By using the insect powder in familiar products like protein bars, cookies, chips and crackers, insects will be more accepted as food. Also, the name can be an obstacle for many people. Familiar product names or new names should be created to make products containing insect powders more attractive for the consumer. However, insects might cause allergic reaction if people are allergic to crustaceans or house dust mites (Van Broekhoven *et al.*, 2016). Therefore, suitable labelling is still needed. The taste of insects and insect-based food has to be enjoyable. Only when people have had a good experience of eating a certain product, will they consider buying it again. Easy recipes for daily cooking, which include insects and familiar ingredients, are needed to make insects more accepted in our diet (Deroy *et al.*, 2015).

The global regulation for edible insects differs per country, as it is newish for the western food industry (Shockely *et al*., 2017), and a more established form of food in tropical countries. This might lead to issues in marketing and international trade, including farming and production. For example, in Germany and Sweden it is illegal to sell insects as food. The German food law (Lebensmittel- und Bedarfsgegenständegesetz, LMBG) does not allow to sell edible insects until the novel food is established in the regulation (USDA Foreign Agricultural Service, 2009). Further, the Swedish food law (Livsmedelslag) does not want that insects are getting sold on the market because of insufficient research about the health issues. However, the Netherlands is a worldwide leader in using insects for human consumption. With active research and promotion of edible insects the acceptance in the Netherlands is more wide spread compared to other countries.

Also, Switzerland worked on the legislation of insects. Since December 2016, three insect species are legal to sell for food applications. These have to be reared for human consumption and treated by certain food security criteria (e.g high temperatures, freezing). In the United States, the US Food and Drug Administration (FDA) gives no specific rule for edible insects. Therefore, insects which are reared following FDA standards are allowed to be sold on the market.

3.2.1 Processing

The ambition with food processing is to increase the shelf-life and provide product safety at optimum quality. Furthermore, technological processing inactivates pathogens and spoilage microorganisms, which decreases decontamination and allows preservation (Rumpold and Schlüter, 2013). In edible insects, spore-forming bacteria were identified which leads to that they have to be processed and stored properly to provide safety. But it is important that by doing so the properties (e.g. chemical and nutrient composition, digestibility, texture, colour, size, taste) of the insects are not lost (Tscheuschner, 1996). High quality and safe raw material, in addition with cost-effective and sustainable production processes are necessary for development of processing concepts (Rumpold and Schlüter, 2013). It is known, that insects can carry and spread pathogenic and non-pathogenic microorganisms. Moreover, they can be vectors to transmitting zoonosis or cause food spoilage (Rumpold *et al.,* 2017).

By boiling insects, Enterobacteriaceae could not be removed (Vandeweyer *et al.,* 2017). Blanching, subsequent drying or refrigerated storage has to be performed in order to provide a safe product (Vandeweyer *et al.,* 2017). For inactivation or handling of potential spore-forming bacteria in edible insects, similar hygienic measurements as for similar food products, e.g. meat, have to considered (Rumpold *et al.,* 2017).

Drying or freeze-drying is a process which provides product safety and increases the shelf-life. While by drying process the insects are dried by supplying heat, at freeze drying the insect are frozen and vacuum is used to sublime the water straight from solid to gas phase. To assure the safe storage and microbial safety, the water content after drying has to be less than 10% (Rumpold *et al*., 2017).

Another type to processing insects is grinding or milling. By using mechanical forces, insects are cut, crushed and/or grinded into smaller particles. Depending on the raw material properties which has to be ground (hard, soft, elastic, fibrous, pasty, brittle), different grinding equipment can be used. By grinding insects with a high fat content, smearing on the grinding surface can lead to more labour time, because of more difficulties to clean the grinding equipment. Therefore, the fat content of insects has to be taken into account, in order to save labour time. For example, a milling or cooling/freezing step can be done prior the grinding.

Due to the high protein content, protein extraction is also an opportunity to process the A. *domesticus*. It was shown that it is possible to use insect's protein as gelling agents or texturisers in food, as studies showed that they have the properties to form gels (Yi *et al.,* 2013).

However, gelling properties depended on the concentration and on the pH (Yi *et al.,* 2013). A comparison of insect and traditional available gelatine as a stabilizer in ice cream was investigated. An acceptable outcome was found in the characteristics of the ice cream with insect gelatine. No significant differences by general preferences between traditional and insect gelatine were found (Mariod, 2013).

4 Discussion and conclusion

Animal-based protein is essential for humans that want to ensure good nutritional health, growth and recovery in general, and to provide malnourished children with the nutrition they need (Michaelsen *et al.*, 2009). Insects are generally known to be a good source of protein (Akhtar and Isman, 2017) and even small amounts of protein derived from animal sources, including *Acheta domesticus*, can already enhance the value of the diet (Michaelsen *et al.*, 2009). The protein content of the adult *Acheta domesticus*, which is with its 66.6 % crude protein significantly greater than any traditional protein sources (table 5). Moreover, the EAA content (g/100g) is predominantly higher than traditional protein sources (table 6). Compared to traditional protein, the *Acheta domesticus* also has a better proportion of all nine EAA, which form a complete protein for humans. Thus, 100 grams of *Acheta domesticus* dry weight provides a 70-kilogram adult man with more than enough of the daily recommendation of EAA. This recommendation can be fulfilled with as little as 48 grams dry weight of *Acheta domesticus*, while traditional protein sources like beef, egg and soy need 120 grams, 63 grams and 102 grams dry weight to meet this recommendation (appendix, A1).

The retail price of *Acheta domesticus* from USA/Canada is with a price of €21,46 per kilogram much higher than the traditional protein sources, but because of the high protein and amino acid content, the *Acheta domesticus* improves by the price to reach 100% RDA. Thus, *Acheta domesticus* only costs €1,02 to get all EAA for one day for a 70-kilogram man, which does not differ that much from the cost of beef with €0,82 (appendix, A2). To lower the kilogram price and make the *Acheta domesticus* even more competitive with traditional protein, the challenge is to optimize the farming of the *Acheta domesticus.* As it is easy to raise the *Acheta domesticus,* and it needs a low capital expenditure to start and maintain a farm, it could be a lucrative business even for lowly educated people. Still, education, which focuses on the quality enhancement (e.g. *Acheta domesticus* with standard size) and the understanding of the effect of the seasonal temperature variations, is necessary. To ensure the welfare of these animals, the basics of *Acheta domesticus* farming and the dangers of the densovirus needs to be learned. In nature, insects are infested with natural enemies.

A problem in the mass rearing of *Acheta domesticus* (but it can also be a problem in small-scale farming), is the *Acheta domesticus* densovirus (AdDNV).

To reduce the problems with AdDNV and to avoid collapses of whole colonies, a virus tolerant *Acheta domesticus* has to be selected. Unfortunately, this type of house cricket has not been found yet (Szelei., 2011). Therefore, selecting stable and healthy insects is important and a high level of hygiene on the farm is necessary to avoid infection. Another option is to find a replacement for *Acheta domesticus*, which is more resistant to the densovirus. The *Gryllus assimilis* or *Gryllus bimaculatus* can be an option to decrease problems with AdDNV, but other viruses can cause similar problems (Szelei., 2011; Weissman, 2012). Further studies have to be done concerning large-scale farming.

By comparing different rearing temperatures, it showed that the *Acheta domesticus* grew faster at 29°C. Even if the *Acheta domesticus* gives a higher individual weight in the adult stage at 27°C, the amino acids and protein content in the haemolymph is the highest in the one-day-old adult. This shows that rearing at 29°C can be more suitable for the *Acheta domesticus* and can give a high content of amino acids and protein in the haemolymph compared to a rearing at 27°C. Also, the number of cycles per year are higher at 29°C (6.77), compared to the rearing temperature at 27°C (5.21). This will lead to a higher production level. Depending on the location of the production establishment, the energy cost would vary (Morales Ramones, 2018). For example, in cold areas or seasons, the energy to uphold the constant temperature would be high, while it is the same for warm areas, where the temperature has to be cooled down. But, it is difficult to conclude that the rearing at 29°C will be a suitable temperature for mass rearing, since the study is done in small-scale rearing. In order to produce *Acheta domesticus* in a big scale farm, it could differ from this conclusion. Moreover, the study of Morales-Ramos (2018) required constant temperature, which is in developing countries not a standard. It is also important to take into account that small-scale farming for households has to be as simple as possible.

By increasing the amount of protein consumed per calorie in the western world, eating a protein rich diet may help people to lower total caloric consumption while still being satiated, and thus helping people to lose fat and lowering obesity in countries (Westerterp-Plantenga and Lejeine, 2005). Balanced protein intake and an optimal AA composition of the diet for the elderly population, can also help to prevent negative balance and sarcopenia, uphold the energy balance and wound healing (Baum and Wolfe, 2015). The increase of protein and energy intake in developing countries might help to lower the number of people with diseases like kwashiorkor and marasmus.

The attitude towards insects might be the reason why it has not been accepted yet in the western world (FAO, 2013). It is also difficult to increase approval since in each country the global food regulation is different. To get a bigger acceptance, the promotion of edible insects is important. This shows in the Netherlands where since the late 1990s, insects have been commercially promoted and are now more accepted among public population. To achieve this acceptance of edible insects, government funded research is needed to improve knowledge about the health aspects. (Dicke *et al.*, 2014).

Since food safety of edible insects is a problem, the legalization is also a problem (Belluco *et al.*, 2013). Safety is the most important aspect but also quality of the product has to be ensured. This can be reached through controlled processes.

It is important that during the processing and storage of insects, including *Acheta domesticus*, unwanted reactions are avoided (e.g. fat oxidation, browning). Some of the processing methods are already applied in the food industry, but some are not that common yet. Freeze-drying is a relatively expensive process (Ratti, 2001) which is not yet that common in the food industry. Cost efficient and environmentally friendly processing concepts have to be found (Rumpold *et al.*, 2017).

It has been proven that house crickets are an excellent source of protein and have a complete AA content. Further, it was shown that it can be a sustainable protein source for human consumption. However, increase of knowledge and optimization of the production process is needed to lower the price per kilogram, which will make *Acheta domesticus* more competitive with traditional protein sources. Moreover, development of familiar snacks and food (e.g. protein bar, spaghetti), culture adapted recipes containing *Acheta domesticus* and knowledge about consumer preferences is needed to be able to reach a higher acceptance. Finally, all these factors could lead to an excellent alternative for traditional protein sources, but further specific studies are needed.

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Appendix 1

A.1. *Grams of essential amino acids to reach 100% daily recommendation of Acheta domesticus, beef, egg and soy.*

	Acheta domesticus	**Beef**	**Egg**
Histidine	30	35	58
Isoleucine	38	88	58
Leucine	39	62	63
Lysine	41	47	63
Methionine	-	-	-
Methionine + Cysteine	40	46	39
Phenylalanine	-	-	-
Phenylalanine + Tyrosine	19	37	38
Threonine	32	40	47
Tryptophan	48	120	39
Valine	37	90	60

A.2. *Protein price in euro to reach 100% essential amino acids of RDA of Acheta domesticus, beef and egg (dry matter).*

	Acheta domesticus	**Beef**	**Egg**
€/kg	21.36	6.8	3.38
€/100g	2.14	0.68	0.34
€/RDA	1.02	0.82	0.21