Future Foods 4 (2021) 100082

Contents lists available at ScienceDirect

Future Foods

journal homepage: www.elsevier.com/locate/fufo

Introducing mealworm as an ingredient in crisps and pâtés – sensory characterization and consumer liking

K. Wendin[a,b,*], J. Berg[c], K.I. Jönsson[a], P. Andersson[d], K. Birch[a], F. Davidsson[e], J. Gerberich[a], S. Rask[d], M. Langton[f]

[a] Dept of Food and Meal Science, Kristianstad University, 291 88 Kristianstad, Sweden
[b] Dept of Food Science, University of Copenhagen, Rolighedsvej 26, 1958 Frederiksberg C, Denmark
[c] RISE Research Institutes of Sweden, Sven Hultins plats 5, 412 58 Göteborg, Sweden
[d] Solina Sweden AB, Topplocksgatan 5, 212 41 Malmö, Sweden
[e] Geoloc AB, Box 14001, 167 14 Bromma, Sweden
[f] SLU, Swedish University of Agricultural Sciences, Dept of Molecular Sciences, Almas Allé 8, 750 07 Uppsala, Sweden

ARTICLE INFO

Keywords:
Insects
Consumer
Texture
Crisps
Pâté

ABSTRACT

The objective of this study was to evaluate sensory perception and consumers' attitude and liking of products with different textures, crisps and pâtés, with added mealworm ingredient in different amounts. By addition of mealworm (*Tenebrio molitor L.*) in the crisps, the brittleness increased. However, an increase in mealworm also increased the darkness. Adding mealworms to pâté reduced the odour and flavour of vegetable and increased the flavour of cinnamon and pepper as well as the oily texture. There was no significant difference in total liking between 10 and 30% addition of mealworm, nor between 0 and 10% addition, in any of the two products. The crisps received higher liking score than the pâtés. Thus, there is also a much higher probability that a customer would buy insect crisps than insect pâté. Environmental sustainability and sensory properties were shown to be the main reasons for buying foods with added insect ingredients.

1. Introduction

Sustainable food production with low environmental impact has become an important matter. Insects have good nutritional value with, in general, a lesser effect on the environment than conventional animal production. Including insects as a part of our daily diet would provide a potential to increase the sustainability in the food chain (Dobermann, Swift and Field 2017). Insects are cold-blooded and do not use metabolic energy to maintain their body temperature. This makes them able to convert feed energy into food energy more efficiently than livestock species such as cattle, pigs, and poultry (Ramos-Elorduy, 2008). Also, they leave a much smaller ecological footprint than conventional livestock regarding feed, land and water usage, as well as greenhouse gases (Oonincx et al., 2010; Oonincx and de Boer, 2012; Miglietta, Leo, Ruberti, and Massari, 2015; van Huis, 2016; Tabassum-Abbasi, Abbassi, and Abbassi, 2016). From a nutritional perspective, insects are good sources of highly digestible high-quality proteins, fats containing large amounts of unsaturated fatty acids, as well as antioxidant peptides (Zhao, Vázquez-Gutiérrez, Johansson, Landberg, and Langton, 2016; Zielińska, Baraniak, and Karaś, 2017), vitamins, for example B_{12}, and minerals such as zinc, iron, and calcium (Dobermann et al., 2017; Zielińska, Baraniak, Karaś, Rybczyńska, and Jakubczyk, 2015; Finke, 2002).

The production of insects as food for humans is therefore developing in many countries around the world (Payne, Scarborough, Rayner, and Nonaka, 2016). The global insect protein market has been estimated to reach an overall value of 8 billion USD by 2030, and the forecast is that if the supply and demand factors continue to develop favourably, similarly to what has been seen for plant-based food production, this value has a significant potential to increase (Morrison and Patel, 2019).

However, in western countries, insects are generally considered less appealing and have a low acceptance by consumers. It is therefore of importance to process the insects into foods with familiar flavour and texture (Looy, Dunkel, and Wood, 2014; Tan et al., 2015). The key is to overcome the cultural resistance of eating insects (Elhassan, Wendin, Olsson, and Langton, 2019) while acknowledging social norms in the (un)willingness to eat insects. A better understanding of these aspects is necessary in order to reach increased acceptance of eating insects (Jensen and Lieberoth, 2019). Processes need to be developed that turn insects into specific food ingredients, and these ingredients need to be incorporated into culinary, healthy and sustainable food dishes with a focus on insect ingredients (Wendin and Nyberg, 2021).

* Corresponding author.
E-mail address: karin.wendin@hkr.se (K. Wendin).

https://doi.org/10.1016/j.fufo.2021.100082
Received 16 April 2021; Received in revised form 14 September 2021; Accepted 16 September 2021

Table 1
Crisp and **pâté** ingredients given in percent.

CRISPS Ingredient	Crisp 0 (%)	Crisp 10 (%)	Crisp 30 (%)
Dried mealworm flour[1]	0	10	30
Potato flakes[2]	54	47	28
Potato starch (cold swelling)[3]	6	6	4
Salt[4]	1	1	1
Water	39	36	37
PATES			
Ingredient	Pâté 0 (%)	Pâté 10 (%)	Pâté 30 (%)
Dried mealworm flour[1]	0	10	30
Pea protein powder[5]	19	15	6
Carrot[6]	1	1	1
Broth[6]	2	2	2
Sunflower oil[7]	19	18	14
Spices (herbs, cayenne, honey)[6]	1	1	1
Water	58	53	46

1): Swedish small-scale producer, 2) Emsland Group, Germany, 3) AVEBE, Netherlands 4) Akzo Nobel, Sweden, 5) Cosucra, Belgium 6) Solina, Sweden, 7) Swedish Fine Rice and Food, Sweden

In order to gain a deeper understanding of the consumers' perception of foods based on insects, different types of common food products have to be examined. For example, the products should differ in both taste and texture, as well as in the context in which they are consumed. Thus, in this study we chose to include two widely different products, crisps and pâtés, both with same amounts of added mealworm.

The objective was to evaluate the sensory perception and the consumers' attitude and liking of products with different texture, i.e., crisps and pâtés, and with addition of different amounts of mealworm ingredient.

2. Materials and methods

The fresh Yellow Mealworms (*Tenebrio molitor L.*) used in this study were reared privately on a small scale in Sweden, oven dried in 60 °C for 10 h and ground into meal worm flour. The mealworms were mainly fed oats and carrots, and fasted before slaughter which was done by boiling. On dry matter basis the mealworms contained 33.9% fat, 53.6% protein and 7.0% carbohydrates. For further details, see Wendin et al. (2020) or Appendix A.

2.1. Products

Two different types of products with large differences in their texture properties were included in this study: crisps (crispy texture) and pâtés (soft texture). Three varieties of each product type were produced, containing mealworm flour in the amounts of 0%, 10% and 30% by weight, respectively. The amounts of mealworm flour were decided in pre-trials, with the aim of finding suitable amounts of mealworms in both types of products. Thus, a total of six different test products were produced.

The production took place in a pilot plant setting, according to the recipes given in Table 1 and the descriptions below. The macro nutrient contents are given in Table 2.

Crisps

Three types of crisps (Table 1) were produced in a pilot plant. To increase the amount of mealworm, the amount of potato flakes was decreased, and was replaced by mealworm flour.

All ingredients were mixed into a smooth dough. One batch of each dough was produced. The dough was rolled to a thickness of 0.8 mM and formed into circle-shaped crisps with a diameter of 50 mM. The crisps were then fried in oil at 185 °C for 15–20 seconds. The excess oil was drained. After cooling, the crisps were packed in sealed airtight and aroma-tight bags and stored at room temperature until the sensory analysis and consumer test was made, after approximately 10 days.

Pâtés

Three types of pâtés (Table 1) were produced in a pilot plant. To increase the amount of mealworm, the amount of pea powder was decreased, and was replaced by mealworm flour.

The ingredients, except for the oil, were mixed. The oil was then added, and the pâté mix was filled into 200 ml packages and baked in a steam oven at 100 °C in 60 min. One batch of each type of pâté was produced in order to avoid production differences between individual packages. The final products were sterilized. A standard sterilization process was selected for the heat treatment of the final products at 122 °C. The samples were processed in a JBT Retort: AR092-T JBT Mobile Test Unit (Belgium). The packages with the pâté were then packed in airtight and aroma tight bags and kept refrigerated until sensory analysis and consumer test, after approximately one week.

2.2. Sensory analysis

Sensory analysis was performed by a panel consisting of eight trained food expert assessors to investigate appearance, odour, flavour, taste and texture of the included products. Prior to the analysis, the assessors were trained at one occasion for each product. Each training session lasted approximately one hour. The sensory method was a slightly modified version of the Flavour Profile Method®, which is a consensus method developed by Arthur D. Little (Lawless and Heymann, 2010). The method entails that a small group of assessors are instructed to identify and describe the sensory attributes of the included products. Assessors propose and define attributes (Table 3) and then discuss until they reach a consensus regarding which suggested attributes should characterize each sample. During the final assessments, lasting for approximately 45 minutes for each product, the assessors together and in consensus assign each attribute a value on a linear intensity scale running from 0 to 100. The samples were served in a randomised order.

2.3. Consumer Test

99 consumers, aged 18 years or older (inclusion criterion), participated in the test, performed as central location tests (CLT) (Lawless and Heymann, 2010) in Malmö, Lund and Kristianstad, Sweden. The test group included 55% women and 45% men, with an age range from 21 to 66 years, all employed by food companies but not working with insect ingredients. The test measured the degree of liking of the included products using the 9-Point Hedonic Scale, ranging from "dislike extremely" (=1) to "like extremely" (=9). The participants filled out a paper questionnaire, designed in the software Eye Question (The Netherlands), for each test sample. Each sample was assessed with respect to

- Appearance
- Odour
- Taste/Flavour
- Texture
- Overall

The products, pâtés and crisps, were tested in one session in which they were presented monadically in a randomised order.

The product testing was followed by the questions:

- Would you buy food products with insect ingredients? (Y/N)
- Would you buy crisp with insect ingredients? (Y/N)
- Would you buy pâté with insect ingredients? (Y/N)
- For which reasons would you buy food products with insect ingredients? (Choose one or more of the following: Health, Environmental sustainability, Taste, Other, Would not buy at all).

The data were collected by scanning the questionnaires into the software Eye Question (The Netherlands).

The Swedish Ethics Review Act applies to research carried out in Sweden if the research includes the processing of sensitive personal data. This study includes questions about food opinions which, according to

Table 2
Macro nutrients and energy in the study products. The calculated values are based on the macronutrient value of each component.

	Product	Nutrients (g/100 g)			Energy	
		Protein	Fat	Carbohydrate	(kcal/100 g)	(kJ/100 g)
CRISPS*	Crisp 0	4.9	0.2	48.8	216.6	906.9
	Crisp 10	9.7	3.6	43.8	246.4	1031.6
	Crisp 30	18.2	10.3	28.2	278.3	1165.2
PATES*	Pâté 0	2.9	19.7	0.9	192.5	806.0
	Pâté 10	7.7	22.1	1.6	236.1	988.5
	Pâté 30	17.1	24.7	2.9	302.3	1265.7

* Formulations prior to cooking

Table 3
Sensory attributes, abbreviations and definitions.

Sensory Attribute	Abbreviation	Definition
Crisp		
Appearance		
Brownness	A_Brown	Intensity of brown/burned colour
Darkness	A_Dark	Grade of darkness, running from pale to dark
Bubbliness	A_Bubbles	Amount of bubbles
Roughness	A_Rough_Structure	Grade of rough structure, running from smooth to rough
Odour		
Frying oil	O_Frying_Oil	Odour intensity of frying oil
Burned	O_Burned	Burned scents
Mushroom	O_Mushroom	Odour of mushroom, nut and umami-like
Potato	O_Potato	Cooked potato
Taste		
Saltiness	T_Salty	Taste of salt
Bitterness	T_Bitter	Taste of bitter
Flavour		
Mushroom	F_Mushroom	Flavour of mushroom, nut and umami-like
Potato	F_Potato	Cooked potato
Burned	F_Burned	Burned scents
Texture		
Brittleness	Tex_Brittle	Reminding of thin breaking ice
Oiliness	Tex_Oily	Oily and slippery
Meltiness	Tex_Melty	Grade of melting on the tongue
Pâté		
Appearance		
Shininess	A_Shiny	Intensity of brightness and shininess
Roughness	A_Rough	Grade of rough structure, running from smooth to rough
Brownness	A_Yellow_Brown	Brownness on a scale running from yellow to brown
Odour		
Broth	O_Sourlike	Sourlike odour
Vegetable Bouillon	O_Vegetable Bouillon	Odour of vegetarian broth
Taste		
Saltiness	T_Salty	Taste of salt
Flavour		
Broth	F_Vegetable Bouillon	Flavour of vegetarian broth
Pepperiness	F_Pepper	Intensity of white pepper flavour
Cinnamon	F_Cinnamon	Intensity of cinnamon flavour
Texture		
Oiliness	Tex_Oily	Oily and slippery
Crumbliness	Tex_Crumbly	Amount of Crumbles

the Data Protection Ordinance, are not classified as sensitive personal data. According to GDPR, no responses to any of the questionnaires used in this study include information that can be traced to or used to identify any individual. All participants received written and oral information about the hedonic test and the ingredients of the included products, and gave their informed consent to participate.

2.4. Statistics

Data were analysed by calculating frequencies, mean values and standard deviations. Continuous data were further subjected to one-way analysis of variance (ANOVA) with samples as fixed effects (IBM SPSS version 26). Significant differences ($p < 0.05$) between samples were evaluated using the Tukey's Post Hoc pairwise comparison test. Frequency data were subjected to Cochran's q-test.

Finally, principal component analysis (PCA; Panel Check V 1.4.2, Nofima, Norway) was performed to give an overview of the results.

3. Theory

Sensory attributes, i.e., taste, flavour, and texture, are of the greatest importance in food products based on insects (Wendin and Nyberg, 2021). To date, only very few studies have been reported on the taste and flavour of specific insect species. However, from these studies it is clear that most insects and insect ingredients have a mild taste and flavour, which could fit into a wide range of products (Albrektsson, 2017; Wendin, Olsson and Langton, 2019). Texture is an important sensory property, both as a sensation in the mouth, as a factor governing flavour release, and by its impact on acceptance of a

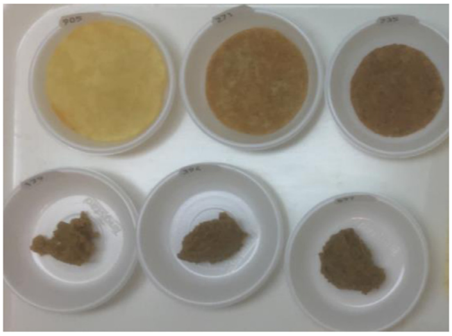

Fig. 1. Crisps (upper row) and pâtés (lower row) with added 0, 10 and 30% mealworm ingredient, respectively.

specific food (Szczesniak, 2002). According to Albrektsson (2017) and Wendin et al (2019) mealworm flavour reminds of nuts and cereals.

To evaluate sensory attributes of a product, sensory analysis should be used. Sensory analysis techniques may be divided into two categories: analytical and hedonic evaluations. The division is based on the purpose of the study.

The analytical evaluation aims towards objective assessments. The assessors in an analytical sensory panel focus on specific aspects and in most analytical methods assess the intensity of each of the attributes according to a scale. They are asked to put personal preferences and opinions aside. The assessors are selected due to their sensory abilities, i.e., by having highly sensitive senses. Standards, such as ISO and ASTM, are available for selection and training of sensory panellists (Lawless and Heymann 2010).

The hedonic evaluation is used to quantify the consumer preference or degree of liking of a product (Lawless and Claassen, 1993). The participants in a consumer test are untrained and represent the consuming population. Consumers often react immediately and perceive the product without considering different attributes in detail (Lawless and Heymann, 2010).

To get reliable results, the recommended number of selected assessors in an analytical panel varies between 8 and 12 persons, based upon the ability to statistically significantly discriminate between products after training (Stone, 2012). The hedonic tests normally require a larger number of participants to reach statistical power (Lawless and Heymann 2010).

4. Results

Two product types, crisp and pâté, were included in this study. The products differed widely in appearance and texture as well as in other sensory properties, see Fig. 1.

4.1. Sensory profiles

The results of the sensory panel evaluation of the two product categories, crisps and pâtés, with three levels of mealworm amounts are shown in Fig. 2.

In the case of crisps, the majority of attributes increased with increasing amount of mealworm addition, except for the flavour of burnt and of potato. The replacement of potato flakes (and potato starch) by mealworm flour increased the appearance attributes to a large amount. The odour attributes O_Burned and O_Mushroom were highly impacted by an increase of the mealworm ingredients. The taste/flavour attributes, except for F_Mushroom and T_Bitterness, were impacted to a smaller extent. Also, the texture attributes Tex_Melty and Tex_Oily changed significantly.

Regarding the pâté formulations, the situation was somewhat different (Fig. 2). Most of the attributes increased with increasing amount of mealworm addition, in this case replacing pea protein, similarly as for crisps. However, for two of the attributes, referring to basic tastes, the difference between the formulations were small (T_Salty, O_Sourlike), and for two others, the order of the formulations was reversed (O_Vegetable_Bouillon, F_Vegetable_Bouillon). The flavour attributes F_Pepper and F_Cinnamon increased largely with addition of mealworm. Also, the texture attributes Tex_Oily and Tex_Crumbly increased with mealworm addition.

4.2. Consumer liking

The consumer liking showed a higher liking for the crisps compared to the pâtés. In all attributes liking was higher for crisps.

Fig. 3 shows the results of the liking tests of the consumer panel. There is a slight tendency for less liking at higher levels of insect flour, most evident for the property Appearance and for Texture (for pâté). Both for crisps and pâtés the liking of appearance decreased significantly with the addition of mealworm, while this was not the case for any of the other attributes. The liking of crisp texture increased by addition of mealworm and this increase was statistically significant between 0% and 30% addition. For pâte, the addition of mealworm decreased the texture liking. The liking of odour and taste decreased slightly with addition of mealworm, although the differences are significant only in some cases. However, the Overall liking numbers for crisp show no significant differences between different levels of insect flour. Note that, in the Overall liking, there is no significant difference between no added mealworms and 10% addition, for any of the two product types.

For the crisp formulations, Fig. 4a shows the correlations between the sensory attributes, the likings, and the different formulations, in a Principal Component (PC) plot. Most of the variation (> 90%) is explained by PC1 alone.

As can be expected, the sensory attributes correlate with the crisp compositions, so that, e.g., the sensory attributes that have high values for Crisp 30 (see also Fig. 2) are relatively close to the Crisp 30 point, along the PC1 axis. Also, the sensory attributes that have high values for Crisp 0 (F_Burned and F_Potato in Fig. 2) are relatively close to the Crisp 0 point, along the PC1 axis.

The Likings points are all close to each other and to the middle point (0 value) of the PC1 axis. This reflects the fact that the corresponding values for each property are very similar for the three compositions (see also Fig. 3).

For the pâté formulations, Fig. 4b shows the correlations between the sensory attributes, the likings, and the different formulations, in a PC plot. Most of the variation (> 95%) is explained by PC1 alone.

As for the crisps, the sensory attributes correlate with the ingredient compositions, so that, e.g., the sensory attributes that have high values for pâté 30 (Fig. 2) are relatively close to the pâté 30 point, along the PC1 axis. Also, in accordance with the crisps, the sensory attributes that have high values for pâté 0 (especially O_Vegetable_Buillon in Fig. 2) are relatively close to the pâté 0 point, along the PC1 axis.

The five Likings points are all close to each other and to the middle point (0 value) of the PC1 axis. This reflects the fact that the corresponding values for each property are very similar for the three compositions (see also Fig. 3).

4.3. Buying products based on insects

There is a large interest of buying products based on insects, see Fig. 5. 85.6% of the respondents would buy these products. However, there is a large difference between the interests for crisps and pâtés, 90.8% and 29.6%, respectively. This difference in interest of buying the different types of products is statistically significant (Cochran's q-test, at the 95% level).

The reasons for buying products based on insects are shown in Fig. 6. The environmental sustainability aspect dominates (78.5%), followed by Tasty (44.9%), Healthy (26.5%), and Others (12.2%). Further, 12.2%

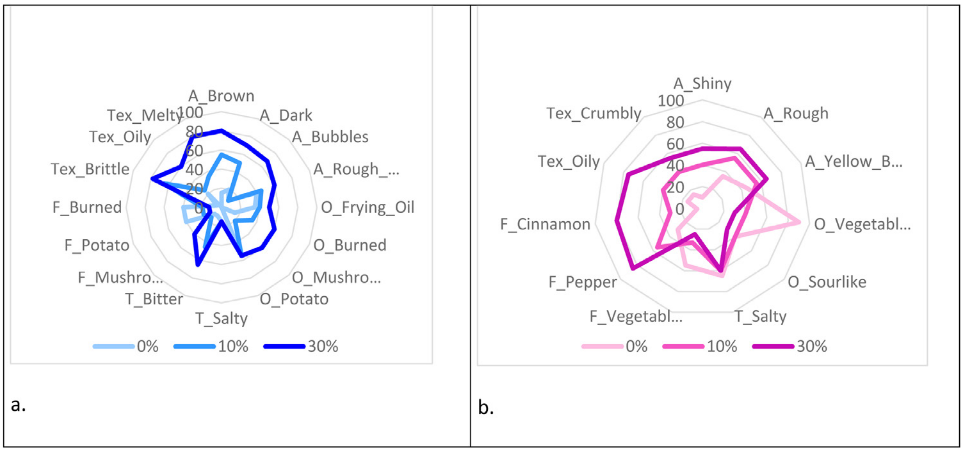

Fig. 2. a and b. Sensory profiles of the three crisp (a) and pâté (b) formulations, as evaluated by the expert panel. The formulations contained 0, 10 and 30%, respectively, of mealworm flour. 2a. Clarification for crisps' attribute A_Rough… correlates to A_Rough Structure, O_Mushro…correlates to O_Mushroom. 2b. For pâtés' attribute A_Yellow_Br… correlates to A_Yellow_Brown, O_Vegetable… correlates to O_Vegetable bouillon, F_Vegetabl…correlates to F_Vegetable_Boullion. For full descriptions on the displayed sensory attributes, see Table 3.

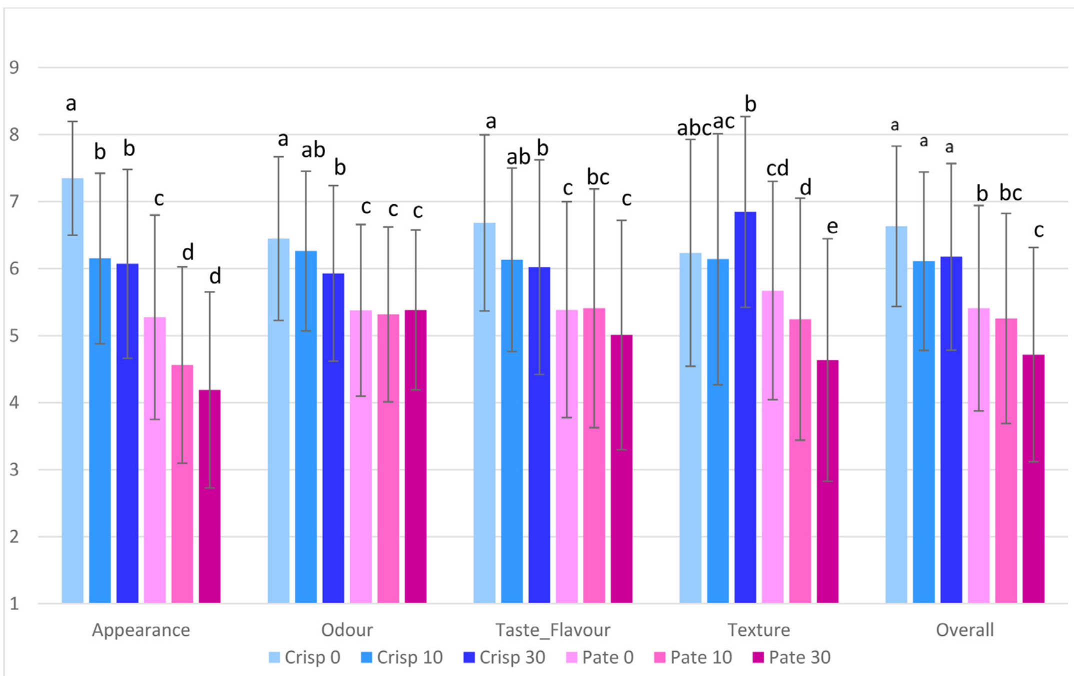

Fig. 3. Degree of liking in a consumer test, for the crisp and pâté formulations. The bars show the average and standard deviation (S.D.) for each property and product composition, according to consumer evaluations. The letter(s) above each bar indicates the degree of statistical significance between bars. Thus, if two bars have different letters, this indicates that there is a significant difference between them ($p < 0.05$). The colour coding is the same as in Fig. 2.

of the respondents indicate that they do not want to buy these products at all. All the differences between factors are statistically significant, except for the difference between Others and Not buy at all (Cochran's q-test, 95%).

5. Discussion

The objective of this study was to evaluate sensory perception and consumers' attitude and liking of products with different textures, crisps and pâtés, with added mealworm ingredient in different amounts. The crisps represent hard and brittle texture, products such as crisps, crackers, taco shells, etc. The pâté represents products with a soft texture such as pâtés, liver paste, sausage, frankfurters, etc. The results of the trained sensory panel (see Fig. 2) show that including mealworm as ingredient in crisps and pâtés has a clear effect on many sensory aspects. Considering the sensory profiles, it is evident that addition of mealworm ingredient will increase the intensity of almost all the sensory attributes. This is in line with results of mealworm addition to bread, showing that the mealworm addition gave a more flavour-intense bread (Roncolini et al., 2019). The Roncolini study meant that the feeding of mealworms has a large impact on the insect ingredient, and thus on the final products.

The appearance in both crisp and pâte turns darker and rougher with added mealworm, which seems to decrease the liking of the products. The appearance changes due to mealworm content is in line with other studies (Roncolini et al., 2019). Roncolini et al. hypothesize that the darker colour refers to an enhancement of the Maillard reaction in samples due to the higher content of amino acids in samples with higher mealworm content. Another interesting result is the increase of cinnamon flavour with increasing addition of mealworm ingredient and decreasing amount of sunflower oil, while no cinnamon is added to the pâtes. Cinnamaldehyde and to some extent eugenol are the major aroma components in cinnamon (Jayaprakasha and Rao, 2011). Eugenol occurs in many herbs and may partly explain the increasing cinnamon flavour (eugenol) when the sunflower oil, where eugenol easily may solve, decreases (Baysal and Elmaci, 2019). It may also be noted that the aromatic compound coumarin with a bitter-sweet and vanilla-like odour is

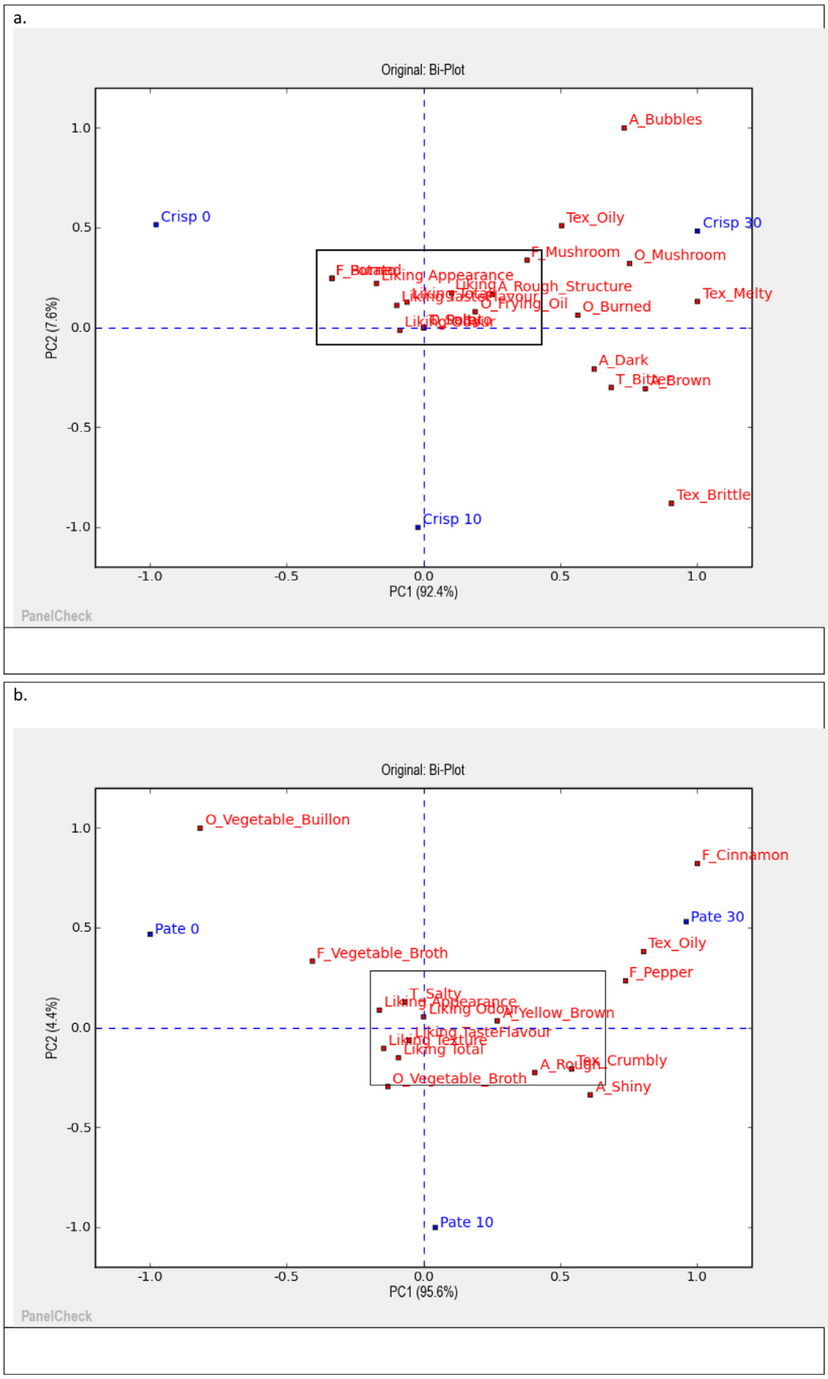

Fig. 4. a and b. Principal components (PC) plot for each of the crisp (a) and pâté (b) formulations, as well as sensory attributes and likings for both the formulations. Clarification of text in the boxes: a. O_Frying_Oil, O_Potato, T_Salty, F_Potato, F_Burned, Liking Appearance, Liking Odour, Liking Taste/Flavour, Liking Texture, Liking Overall; b. A_Rough, T_Salty, Tex_Crumbly, Liking Appearance, Liking Odour, Liking Taste/Flavour, Liking Texture, Liking Total / Overall.

present in carrots. It is also present in cinnamon where it adds to the cinnamon flavour National Library on National Center for (2021). Thus, the addition of carrots may be another explanation of the cinnamon flavour in the pâtés.

Further the flavour of pepper increases with increasing meal worm ingredient. The added cayenne pepper includes capsaicin as the typical pepper flavour. Also, here the decreasing content of sunflower oil may be an explanation of the increasing pepper flavour as due capsaicin's solubility in non-polar solvents (National Center for, 2021.

In this work, crisps were more appreciated than pâtés. It was clear that crisps were highly liked in all aspects. The liking of the texture was highest for the crisp with the largest addition of mealworm ingredient. This is in line with a study by Mancini et al. (2019), where the consumers scored high for texture liking of products with added mealworms. It is also in line with Sainte Eve et al. (2019) showing that texture attributes such as crispiness is a driver for liking. However, liking of other sensory attributes, e.g., flavour and odour, scored lower for both crisps and pâtés when the addition of mealworm ingredient increased. For example, in crisps, the bitter taste increased with mealworm addition which may explain the lower liking. In pâté there was a decrease in the odour and flavour of vegetable bouillon. However, concerning the overall liking there was no significant pairwise difference between 0 and 10% addition of mealworm, nor between 10 and 30% addition. Focusing on the texture, a study on mealworm powder in bread showed that the mealworm ingredient did not affect the technical features (Roncolini et al., 2019). This is in contrast to the present study, where large differences in perceived texture can be found by the expert panel between the different additions of mealworms, both in crisps and pâtés.

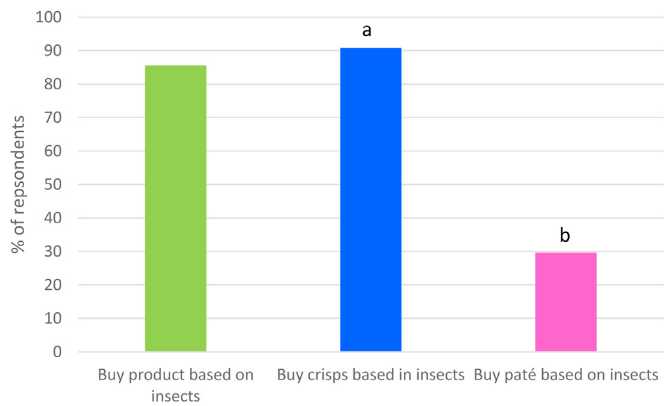

Fig. 5. Interest of buying products based on insects, as % of the respondents. The letters a and b above the bars indicate a statistically significant difference between the two bars ($p < 0.05$).

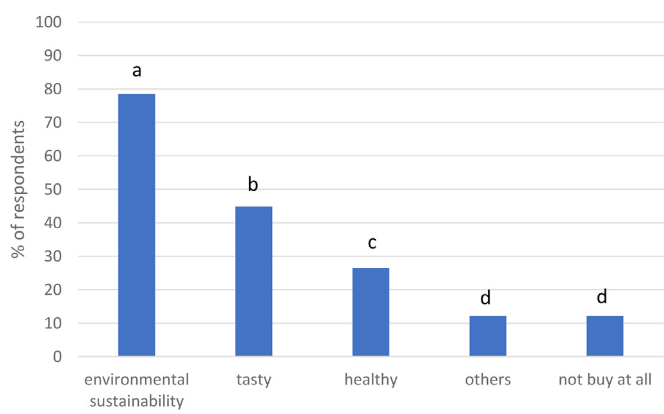

Fig. 6. Reasons for buying products based on insects, in % of the respondents. The letter above each bar indicates the degree of statistical significance between bars. Thus, if two bars have different letters, this indicates that there is a significant difference between them ($p < 0.05$).

The results showed that there was a high interest for buying food products based on insects; 85% of the consumers in this study indicated their interest. There was, however, a large and significant difference between the number of consumers who were interested in buying crisps with added mealworms, 90%, and the 30% showing their interest in buying the pâté with added mealworm. This clearly points out the importance of the sensory aspects in the liking and consideration of buying the products with added mealworm. Previous studies have clearly pointed out that sensory aspects of insect-based foods are of greatest concern for the consumers (Bartkowics and Babicz-Zielinska, 2020; Castro Delgado et al., 2020; Henault-Ethier, Marquis, Dussault, Deschamps, and Vandenberg, 2020; Palmieri, Perito, Macri, and Lupi, 2019; Rumpold and Langen, 2019). In the present study, the higher liking of the crisps could be connected to the sensory perception.

Our results further showed that the sustainability stood out as the most important reason for buying food with insect ingredients. This result is in line with several previous studies showing that environment and sustainability are strong motivators for eating insects (e.g., Ruby, Rozin, and Chan, 2015; Tuccillo, Marino, and Torri, 2020). However, the large preference for crisps and the higher interest in buying crisps than pâtés indicates that sustainability alone is not the driving force for buying food based on insects. Promoting the sustainability argument may therefore be one promising strategy, but it needs to be coupled to appealing products in order to increase the acceptance of insects as foods and food ingredients. In their review, Wendin and Nyberg (2021) showed that sustainability together with nutrition and health could be identified as important factors impacting consumer perception of insects as foods. However, they also concluded that sustainability is seldom the main factor influencing acceptability of insect consumption, and that the sensory aspects have a large influence on perception and preference.

An important aspect related to the sustainability argument for introducing insect foods is that this could result in reduced consumption of meat (Hartmann and Siegrist, 2017). To achieve this, new attractive alternative food products need to be produced. In this work, we have evaluated two products with different texture, with crisps receiving higher liking among consumers. Thus, crisps could be a good starting point, as this is a popular product and could pave the way for an increased familiarity and general acceptance of insects in food. This has the potential to expand the insect food sector in the future.

6. Conclusions

It was concluded that the mealworm ingredient could be used in products with two different textures. The sensory panel indicated that brittle texture increased with increased amount of mealworm. The consumers had a relatively high liking for addition of the mealworm component in crisps, but a lower liking for addition of the mealworm component in pâtés. Also, the interest in buying the products was higher for crisps. Environmental sustainability and sensory properties were shown to be the main reasons for buying foods with added insect ingredients .

7. Author contributions

Karin Wendin: Conceptualization, Formal analysis, Writing – Original Draft, Writing - Review & Editing, Project administration, Funding acquisition, **Johan Berg:** Writing – Original Draft, Writing - Review & Editing, **Ingemar Jönsson:** Writing - Review & Editing, **Peter Andersson:** Resources, Writing - Review & Editing, **Karina Birch:** Writing - Review & Editing, **Fredrik Davidsson:** Resources, Writing - Review & Editing, **Johanna Gerberich:** Writing - Review & Editing, **Susanne Rask:** Resources, Writing - Review & Editing, **Maud Langton:** Conceptualization, Writing – Original Draft, Writing - Review & Editing.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research was funded by The Knowledge Foundation (KK-stiftelsen), grant number 20170141.

SLU, Swedish University of Agricultural Sciences (to M. L.) and RISE Research Institutes of Sweden (to J. B.) are greatly acknowledged for financial support.

Tetra Pak is acknowledged for assistant in product preparation. Maria Nyberg, Viktoria Olsson and Per Magnusson (Kristianstad University) are acknowledged for their assistance in performing the consumer study.

APPENDIX A

Chemical analysis of raw material, *Tenebrio molitor,* analysed by ALS Scandinavia AB.

(Published in Wendin et al, 2020).

Parameter	Mean value (±) Standard deviation
TS at 105°C (%)[1]	36.6±2.0
As (mg/kg)[2]	<0.006
Cd (mg/kg)[2]	0.0329±0.0062
Pb (mg/kg)[2]	<0.01
Hg (mg/kg)[2]	<0.006
Fe (mg/kg) [2]	9.61±2.09
Zn (mg/kg)[2]	33.8±7.1
Energy (kJ/100g) [3]	679±48
Energy (kcal/100g) [3]	162±11
Fat (g/100g) [3]	10.0±0.50
Saturated fat (g/100g) [3]	2.58±0.77
Monounsaturated fatty acids (g/100g) [3]	3.79±1.14
Polyunsaturated fatty acids (g/100g) [3]	3.17±0.95
Carbohydrate (g/100g) [3]	1.98±0.14
Fibre (g/100g) [3]	0.676±0.135
Protein (g/100g) [3]	15.8±0.793
Salt (g/100g) [3]	0.0892±0.02
Water (g/100g)[3]	70.5±0.70
Myristic acid (C14:0), (g/100g fat)[4]	2.95±0.88
Palmitic acid (C16:0), (g/100g fat)[4]	18.8±5.64
Steric acid (18:0), (g/100g fat)[4]	3.32±1.00
Oleic acid (C18:1n9c), (g/100g fat) [4]	36.2±10.9
Linoleic acid (C18:2n6c), (g/100g fat)[4]	30.1±9.02
Linolenic acid (C18:3n3), (g/100g fat)[4]	1.61±0.48
Omega 3 fatty acids, total fat (g/100g fat) [4]	1.61±0.48
Omega 6 fatty acids, total fat (g/100g fat) [4]	30.1±9.02
Omega 3 fatty acids, total (g/100g) [4]	0.16±0.05
Omega 6 fatty acids, total (g/100g) [4]	3.01±0.90

1. Dry matter according to SS028113 (Water content by gravimetric method at 105°C. Ash content after 550°C)
2. Analysis with ICP-SFMS according to SS EN ISO 17294-1, 2 (mod) and EPA- method 200.8 (mod).
3. Fat content was analysed by using NMR
4. The composition of fatty acids was analysed by using GC-FID

References

Albrektsson, O., 2017. It really bugs me . . .: En deskriptiv sensorisk analys av sju atbara insekter. Bachelor's thesis. Örebro University, Örebro, Sweden.

Bartkowicz, J., Babicz-Zielinska, E., 2020. Acceptance of bars with edible insects by a selected group of students from Tri-City, Poland. Czech J. Food Sci. 38, 192–197. doi:10.17221/236/2019-CJFS.

Baysal, M., Elmacı, Y., 2019. Effect of fat content on aroma release and rheological properties of dairy desserts. In: 1st International/11 th National Food Engineering Congress, p. 98.

Castro Delgado, M., Chambers, E., Carbonell-Barrachina, A., Noguera Artiaga, L., Vidal Quintanar, R., Burgos Hernandez, A., 2020. Consumer acceptability in the USA, Mexico, and Spain of chocolate chip cookies made with partial insect powder replacement. J. Food Sci. 85, 1621–1628. doi:10.1111/1750-3841.15175.

Dobermann, D., Swift, J.A., Field, L.M., 2017. Opportunities and hurdles of edible insects for food and feed. Nutr. Bulletin 42, 293–308. doi:10.1111/nbu.12291.

Elhassan, M., Wendin, K., Olsson, V., Langton, M., 2019. Quality aspects of insects as food - nutritional, sensory, and related concepts. Foods 8, 1–14. doi:10.3390/foods8030095.

Finke, M.D., 2002. Complete nutrient composition of commercially raised invertebrates used as food for insectivores. Zoo Biol. 21, 269–285.

Hartmann, C., Siegrist, M., 2017. Consumer perception and behaviour regarding sustainable protein consumption: a systematic review. Trends Food Sci. Technol. 61, 11–25. doi:10.1016/j.tifs.2016.12.006.

Henault-Ethier, L., Marquis, D., Dussault, M., Deschamps, M.H., Vandenberg, G., 2020. Entomophagy knowledge, behaviours and motivations: the case of French Quebeckers. J. Insects Food and Feed 6, 245–259. doi:10.3920/JIFF2018.0039.

van Huis, A., 2016. Edible insects are the future? Proc. Nutr. Soc. 75, 294–305. doi:10.1017/S0029665116000069.

Jayaprakasha, G.K., Rao, L.J.M., 2011. Chemistry, biogenesis, and biological activities of Cinnamomum zeylanicum. Crit. Rev. Food Sci. Nutr. 51 (6), 547–562.

Jensen, N.H., Lieberoth, A., 2019. We will eat disgusting foods together – Evidence of the normative basis of Western entomophagy-disgust from an insect tasting. Food Qual. Preference 72, 109–115. doi:10.1016/j.foodqual.2018.08.012.

Lawless, H.T., Claassen, M.R., 1993. The central dogma in sensory evaluation. Food Technol. 47 (6), 139–146.

Lawless, H., Heymann, H., 2010. Sensory evaluation of food – principles and practices, 2nd ed. Springer.

Looy, H., Dunkel, F.V., Wood, J.R., 2014. How then shall we eat? insect-eating attitudes and sustainable foodways. Agricu. Human Values 31, 131–141. doi:10.1007/s10460-013-9450-x.

Mancini, S., Sogari, G., Menozzi, D., Nuvoloni, R., Torracca, B., Moruzzo, R., Paci, G., 2019. Factors predicting the intention of eating an insect-based product. Foods 8, 270. doi:10.3390/foods8070270.

Miglietta, P.P., Leo, F.D., Ruberti, M., Massari, S., 2015. Mealworms for food: a water footprint perspective. Water 7, 6190–6203. doi:10.3390/w7116190.

Morrison, E., and Patel, H. (2019). Insect protein: bitten by the bug. https://www.investmentbank.barclays.com/our-insights/insect-protein-bitten-by-the-bug.html. Accessed February 13, 2021.

National Center for Biotechnology Information, 2021. PubChem Compound Summary for CID 323, Coumarin. https://pubchem.ncbi.nlm.nih.gov/compound/Coumarin (accessed 23 July 2021).

National Center for Biotechnology Information, 2021. PubChem Compound Summary for CID 1548943, Capsaicin. https://pubchem.ncbi.nlm.nih.gov/compound/Capsaicin (accessed 23 July 2021).

Oonincx, D.G.A B., van Itterbeeck, J., Heetkamp, M.J.W., van den Brand, H., van Loon, J.J.A., van Huis, A, 2010. An exploration on greenhouse gas and ammonia production by insect species suitable for animal or human consumption. PLoS ONE 5, e14445. doi:10.1371/journal.pone.0014445.

Oonincx, D.G.A B., de Boer, J.M, 2012. Environmental impact of the production of mealworms as a protein source for humans – a life cycle assessment. PLoS ONE 7, e51145. doi:10.1371/journal.pone.0051145.

Palmieri, N., Perito, M.A., Macri, M.C., Lupi, C., 2019. Exploring consumers' willingness to eat insects in Italy. Br Food J 121, 2937–2950. doi:10.1108/BFJ-03-2019-0170.

Payne, C.L.R., Scarborough, P., Rayner, M., Nonaka, K., 2016. A systematic review of nutrient composition data available for twelve commercially available edible insects, and comparison with reference values. Trends Food Sci. Technol. 47, 69–77. doi:10.1016/j.tifs.2015.10.012.

Ramos-Elorduy, J., 2008. Energy supplied by edible insects from Mexico and their nutritional and ecological importance. Ecol. Food Nutr. 47, 280–297. doi:10.1080/03670240701805074.

Roncolini, A., Milanović, V., Cardinali, F., Osimani, A., Garofalo, C., Sabbatini, R., Clementi, F., Pasquini, M., Mozzon, M., Foligni, R., Raffaelli, N., Zamporlini, F., Minazzato, G., Trombetta, M.F., Buitenen, A.V., Campenhout, L.V., Aquilanti, L., 2019. Protein fortification with mealworm (*Tenebrio molitor L.*) powder: Effect on textural, microbiological, nutritional and sensory features of bread. PloS one 14. doi:10.1371/journal.pone.0211747, 0211747.

Ruby, M.B., Rozin, P., Chan, C., 2015. Determinants of willingness to eat insects in the USA and India. *J. Insects Food* Feed 1, 215–225. doi:10.3920/JIFF2015.0029.

Rumpold, B.A., Langen, N., 2019. Potential of enhancing consumer acceptance of edible insects via information. J. Insects as Food and Feed 5, 45–53. doi:10.3920/JIFF2018.0041.

Sainte Eve, A., Granda, P., Legay, G., Cuvelier, G., Delarue, J., 2019. Consumer acceptance and sensory drivers of liking for high plant protein snacks. J. Sci. Food Agric. 99 (8), 3983–3991. doi:10.1002/jsfa.9624.

Stone, H., 2012. Sensory evaluation practices. Academic Press, London, UK.

Szczesniak, A.S., 2002. Texture is a sensory property. Food Qual. Preference 13, 215–225. doi:10.1016/S0950-3293(01)00039-8.

Tabassum-Abbasi, Abbassi, T., Abbasi, S.A, 2016. Reducing the global environmental impact of livestock production: the minilivestock option. J. Cleaner Product. 112, 1754–1756. doi:10.1016/j.jclepro.2015.02.094.

Tan, H.S.G., Fischer, A.R.H., Tinchan, P., Stieger, M., Steenbekkers, L.P.A., van Trijp, H.C.M., 2015. Insects as food: exploring cultural exposure and individual experience as determinants of acceptance. Food Qual. Preference 42, 78–89. doi:10.1016/j.foodqual.2015.01.013.

Tuccillo, F., Marino, M.G., Torri, L., 2020. Italian consumers' attitudes towards entomophagy: influence of human factors and properties of insects and insect-based food. Food Res. Int. 137, 109619. doi:10.1016/j.foodres.2020.109619.

Wendin, K.M.E., Nyberg, M.E., 2021. Factors influencing consumer perception and acceptability of insect-based foods. Current Opin. Food Sci. 40, 67–71. doi:10.1016/j.cofs.2021.01.007.

Wendin, K., Mårtensson, L., Djerf, H., Langton, M., 2020. Product quality during the storage of foods with insects as an ingredient - impact of particle size, antioxidant, oil content and salt content. Foods 9, 791. doi:10.3390/foods9060791.

Wendin, K., Olsson, V., Langton, M., 2019. Mealworms as food ingredient—sensory investigation of a model system. Foods 319, 8. doi:10.3390/foods8080319.

Zhao, X., Vázquez-Gutiérrez, J.L., Johansson, D.P., Landberg, R., Langton, M., 2016. Yellow mealworm protein for food purposes - extraction and functional properties. PLoS One 11, e0147791. doi:10.1371/journal.pone.0147791.

Zielińska, E., Baraniak, B., Karaś, M., Rybczyńska, K., Jakubczyk, A., 2015. Selected species of edible insects as a source of nutrient. Food Res. Int. 77, 460–466. doi:10.1016/j.foodres.2015.09.008.

Zielińska, E., Baraniak, B., Karaś, M., 2017. Antioxidant and anti-inflammatory activities of hydrolysates and peptide fractions obtained by enzymatic hydrolysis of selected heat-treated edible insects. Nutrients 9, 970. doi:10.3390/nu9090970.