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Cover Page Footnote

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Partial Substitution of Edible Mealworms for Corn Flour in a Plant-based Food Nugget

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Abstract

The purpose of this study was to determine an acceptable level of mealworm powder (MW) substituted for corn flour (CF) to provide a higher level of protein in a plant-based food nugget. Data collection included sensory analysis evaluations and post-consumption survey responses from 44 untrained panelists. Mean sensory evaluation scores of nuggets for each of the five characteristics (crust color, interior color, texture, flavor, and aftertaste) across the four groups (0% MW, 25% MW, 50% MW, and 75% MW substituted for CF, respectively) decreased in acceptability with each percentage increase of MW substituted for CF. Post-consumption survey responses immediately following sensory analysis indicated panelists' increased interest in eating insects. Results of this study indicated that a substitution of up to 25% mealworm powder for corn flour was an acceptable method to provide a higher level of insect protein in a plant-based nugget. Further research into insect protein substitution is recommended.

Key Words: insect protein, sensory analysis, sustainability, nutrition

Introduction

The study of entomophagy is quickly becoming a trend in the world of food science. Insects of the phylum Arthropoda (subphylum Hexapoda) are not typically consumed in many of the Western countries, however, over 2,000 varieties of insects are eaten by 2 billion people across the world (La Barbera et al., 2018). As the world population is expected to increase to over 9 billion people by the year 2050, there will be a need for increased food production, including sustainable edible insect protein (Pastrana-Pastrana et al., 2025). To address the increased efficiency of food production and improvements in the nutrient density

of food products, the proposition of farming and consuming insects has been brought to the table.

The production of insect protein requires seven times less water and 100 times less land, while producing less methane than animal proteins. Insect proteins could be a solution to waste management, as they could be fed with organic waste matter from foods already being produced, such as food scraps and plant waste (Van Huis & Oonincx, 2017). For these reasons, insect protein is seen as a sustainable option to include in food protein sources.

Insects are also nutritious, containing 67 vitamins and numerous micronutrients, as well as healthy long-chain polyunsaturated fatty acids (Kumar et al., 2025; Mishyna et al., 2020). This includes riboflavin, calcium, folic acid, iron, lauric acid, magnesium, manganese, oleic acid, pantothenic acid, phosphorus, selenium, and zinc (Kumar et al., 2025; Mishyna et al., 2020). Other notable health benefits include the presence of prebiotic protein chitin, found in the exoskeletons of insects (Van Huis, 2020).

There are many reasons people may choose not to consume insects, however, the ones addressed by this study include uncertainties due to lack of social context and unfamiliarity as well as the unavailability of insect products (Tan et al., 2015). Due to the lack of common knowledge on preparation of insects in western countries (e.g., the United States), this study aimed to produce a ready-to-eat insect-based food product acceptable to the public. By producing a ready-to-eat product that was recognizable as food, it was thought that such a product could theoretically reduce panelists' perceived barriers of social context and unfamiliarity (i.e., food neophobia), thus increasing their familiarity with insect-based food products. In this study, the control nugget was plant-based. This was strategically chosen in order to exclude any other high protein (animal or plant) food sources that could potentially have confounded perceptions of the mealworm powder protein substituted in the recipe. Prior

to data collection, it was hypothesized that a 50% replacement of corn flour for mealworm powder would be acceptable, based on previous research studies.

Existing insect food products include (but are not limited to) protein bars, chips, baked goods, flours, powders, and whole insects (Boyd, 2017). Insects are incorporated into commercial food products typically in a flour or powder format. In one test of a nut-based bar, insect powders were added into the honey mixture that held the nuts together (Kowalski et al., 2022). In another study, a protein bar was created using cricket powder (Zhong, 2017). Finally, research pertaining to current insect-based products and PPIs (packaged processed insects) evaluated such products on the market, which all contained insect powders or dried insect pieces (Reverberi, 2021).

As of now, insects are a novelty food product as their production would need to be increased to produce enough protein to sustain humanity. Countries that currently farm the most insects include Thailand, France, South Africa, China, and Canada. However, companies in the United States, Europe, and Canada are focusing on raising insects for fishmeal and livestock feed. Different regulations are established for insects farmed for human and animal feed in the United States (Rowe, 2020). Current efforts in Finland, Canada, the United Kingdom, and Thailand hope to begin farming insects for mass production and human consumption (Żuk-Gołaszewska et al., 2022).

There has been an extensive amount of research done on entomophagy, however, there are still many unexplored facets, including the production of products that are palatable to those without prior experience of insect consumption. Based on the available information about sustainability and nutrition, as well as the barriers to eating insects and sensory properties of insects, this study proposed the partial substitution of powdered edible mealworms for corn flour in a plant-based food nugget product as an acceptable, nutritious,

and sustainable food product. Thus, the purpose of this study was to determine the acceptable level at which mealworm powder could be substituted for corn flour in a plant-based nugget.

Materials and Methods

Nugget preparation

The study was approved by the Institutional Review Board at a 4-year university. The recipes developed and finalized during the pilot test for the nugget preparation are presented in Table 1 (see appendices). Nuggets were prepared in four sample variations. Varying ratios of mealworm powder (MW) substituted for corn flour (CF) by weight percentage were used in each of the four sample variations. The "0MW" (control) sample contained 0% mealworms and 100% corn flour; the "25MW" sample contained 25% mealworms and 75% corn flour; the "50MW" sample contained 50% mealworms and 50% corn flour; and the "75MW" sample contained 75% mealworms and 25% corn flour. Every nugget produced was formed using a one tablespoon amount. Panelists were offered one nugget from each sample variation (four nugget samples total).

Pilot study

A pilot study was conducted to test the production of the nugget samples, the sensory analysis procedures, and the post-consumption survey data collection. A convenience sample of untrained panelists ($N = 3$) participated in the pilot test of the four nugget sample variations. The panelists provided useful feedback on the effectiveness of the sensory analysis scorecards and the post-consumption survey.

Panelists

Full data collection occurred in one location, all on the same day. During data collection, panelists (N = 44) completed an informed consent form before participating in the study. Panelists were told that the purpose of the study was to determine if a partial substitution of powdered mealworms in a plant-based food nugget recipe would yield an acceptable, nutritious, and sustainable food product. Panelists were also told that each nugget sample would contain a differing percentage of powdered edible mealworms. Panelists were required to provide written confirmation that they did not have any intolerances or allergies (i.e., eggs, latex, milk, peanuts, shellfish, soy, tree nuts, or wheat), that they agreed to participate in this study, and that they understood that they could decide not to participate in the research at any time. Panelists signed and dated the informed consent forms and returned the forms to the principal investigator for review before participating in the study.

Sensory evaluation

A convenience sample of 44 untrained panelists evaluated the four nugget sample variations (0MW, 25MW, 50MW, and 75MW) for five characteristics (crust color, interior color, tenderness, texture, flavor, and aftertaste). A 5-point hedonic scale was used for evaluation of each of the characteristics on a rating form (1 = Dislike very much, 2 = Disliked, 3 = Neither liked or disliked, 4 = Liked, 5 = Liked very much).

Each nugget sample variation was assigned a random three-digit number code to provide a blind taste test for panelists who participated in sensory analysis. The four nugget samples were placed on a white paper plate with their three-digit number codes written on the paper plate next to each respective sample. Five gluten-free crackers were placed in the center of the plate. Room temperature water was also provided. Panelists were directed to not converse with one another and separation partitions were used to ensure that panelists did not

interact with one another during sensory analysis evaluation activities. Panelists were instructed to taste each sample one at a time, in any order, record their evaluation on the sensory analysis scorecard, and to cleanse their palate with the water and crackers before evaluating the next sample.

Statistical analysis

All laboratory and sensory analysis data were analysed using Microsoft Excel 2019 (Microsoft Corporation, Redmond, WA) and SPSS Statistics version 25 (International Business Machines [IBM] Corporation, Armonk, New York). Means and standard deviations were calculated for all data. Data analysis procedures included descriptive statistics, one-way analysis of variance (ANOVA), and Tukey's Honest Significant Difference (HSD) post-hoc tests. A significance level of $p \leq .05$ was used for all statistical tests.

Results

Sensory Evaluation

Sensory evaluation scores are presented in Table 2 and Figure 1 (see appendices). Results include sensory evaluation score means and significant differences of nugget characteristics (crust color, interior color, texture, flavor, and aftertaste) between the nugget sample variations (0MW, 25MW, 50MW, and 75MW). A 5-point hedonic scale was used for evaluation of each of the characteristics on a rating form (1 = Dislike very much, 2 = Disliked, 3 = Neither liked or disliked, 4 = Liked, 5 = Liked very much). Sensory evaluation characteristic scores above three (neither liked nor disliked) on a 5-point hedonic scale were considered to be acceptable. As the percentage of mealworms increased, the mean scores decreased across all five characteristics. The 0MW (control) sample rated the highest across

all five characteristics. For the 0MW and 25MW samples, all characteristic scores fell in between the "neither liked or disliked" and "liked" ranges. Characteristics scores that rated below the acceptable threshold (i.e., below three) included the interior color of the 50MW and 75MW samples, as well as the texture, flavor, and aftertaste of the 75MW sample.

One-way analysis of variance (ANOVA)

A one-way analysis of variance (ANOVA) was carried out to analyse the five characteristic scores (crust color, interior color, texture, flavor, and aftertaste) across the four nugget sample groups (0MW, 25MW, 50MW, and 75MW). Results are shown in Table 3 (see appendices). Statistically significant differences between the four nugget sample group means were found for all five characteristics. Tukey's Honest Significant Difference (HSD) post-hoc tests were carried out for all characteristics to confirm where the differences occurred between nugget sample groups.

Crust Color

There was found to be a significant difference between the four samples for crust color ($F(3, 172) = 4.31$, $p = .006$). Post hoc tests indicated significant differences between the 0MW and 50MW samples ($p = .027$), and the 0MW and 75MW samples ($p = .088$). There were no significant differences between any other samples.

Interior Color

There was found to be a significant difference between the four samples for interior color ($F(3, 172) = 11.45$, $p < .001$). Post hoc tests indicated significant differences between the 0MW and 50MW samples ($p < .001$), the 0MW and 75MW samples ($p < .001$), and the

25MW and the 75MW samples (p = .008). There were no significant differences between any other samples.

Texture

There was found to be a significant difference between the four samples for texture (F(3, 172) = 3.87, p = .01). Post hoc tests indicated significant differences between the 0MW and 75MW samples (p = .009). There were no significant differences between any other samples.

Flavor

There was found to be a significant difference between the four samples for flavor (F(3, 172) = 9.84, p < .001). Post hoc tests indicated significant differences between the 0MW and 50MW samples (p = .045), the 0MW and 75MW samples (p < .001), and the 25MW and the 75MW samples (p = .001). There were no significant differences between any other samples.

Aftertaste

There was found to be a significant difference between the four samples for aftertaste (F(3, 172) = 11.13, p < .001). Post hoc tests indicated significant differences between the 0MW and 75MW samples (p < .001), the 25MW and 75MW samples (p < .001), and the 50MW and 75MW samples (p = .012). There were no significant differences between any other samples.

Post- Consumption Survey

A post-consumption survey was administered to panelists immediately following the completion of sensory analysis procedures (N = 44). Survey responses helped to provide

insight into the sensory analysis evaluations, as well as the panelists' opinions on entomophagy. The majority of the panelists reported being white/Caucasian between the ages 18-25. One-half (50%) of the panelists were male, 47.7% were female, and 2.3% were non-binary.

Prior to sensory analysis, 47% of panelists reported participating in the study because they wanted to help with the study. Following sensory analysis, 56% of panelists reported they would eat insects, with 45% saying that the study encouraged them to change their opinion on eating insects. One panelist stated, "Before sensory analysis, I was not that fond of the idea of eating insects but now after trying them they honestly weren't that bad and I would probably eat them again." Another panelist commented, "Before, I was worried that I would not like the look of the nuggets. After, I am a lot more open to the idea, it's more of a cultural thing as we know in other parts of the world eating bugs is common."

The majority of panelists (68.2%) reported that they could see themselves maybe adding insects to their diet, with 25% saying they would eat them yearly, 38.5% said they would eat them monthly, 20.5% said they would eat them weekly, and 2.3% said they would eat them daily if they were available at the grocery store. One-third (34%) of panelists said they would be most likely to consume insects in a ready-made meal format and 29.8% said they would be likely to consume insects as a protein powder. This provides support for further research regarding edible insects as a viable ingredient to be utilized in food nuggets.

Panelists indicated that 59% of them would consider eating a product labeled "bug" versus 63% indicating that they would consider eating a product labeled "insects." Finally, 38.6% of panelists reported that knowing that entomophagy is a common practice would make them consider eating more insects versus 77% of panelists reporting that they would be convinced to eat insects based on information about the sustainability of insect food

production. One panelist commented, “I can see how eating insects could be more sustainable as opposed to eating meat, I feel like I could be an advocate of eating insects if I had access to options that included insects.” Another panelist commented, “With the environment going through huge negative changes, finding ways to be eco-friendlier is important to me.”

Discussion

The purpose of this study was to determine the acceptable level at which mealworm powder could be substituted for corn flour in a plant-based nugget. This study found that as the percentage of powdered edible mealworms substituted for corn flour in a plant-based food nugget product increased, the panelists’ ratings of the acceptability of the nuggets across all five characteristics (interior color, exterior color, texture, flavor, and aftertaste) decreased. Based on a conservative requirement of having all five mean sensory evaluation scores rate above average (3.00), a substitution of up to 25% mealworm powder for corn flour was determined to be an acceptable method to provide a higher level of insect protein in a plant-based nugget. However, for nuggets containing a substitution of 50% mealworm powder, the only sensory evaluation score ranking below average was for interior color. This was likely due to the increasing dark-brown interior color of the nuggets as the mealworm powder percentage increased. It is possible that a substitution of up to 50% mealworm powder for corn flour could be an acceptable method to provide an even-higher level of insect protein in a plant-based nugget.

The post-consumption survey showed that panelists were persuaded by sustainable food choices and therefore would likely be interested in other insect-based food items that were deemed sustainable. Panelists also stressed the importance of the appearance of the food items, recommending that no ingredients should be identifiable as insects (i.e., the insects should be ground or powdered finely). Finally, providing educational opportunities for taste-

testing (such as providing free samples in a grocery store) could help reduce the perceived barriers that might discourage people from trying insect-based food products in the first place. Panelists' feedback from the post-consumption survey provides insight into what factors should be considered when promoting insects as a part of mainstream food consumption.

The research study consisted of a convenience sample of college students, most of whom were about the same age. Participants were self-selected, the sample was relatively small, and only one insect variety was tested. Data collection occurred in one location, all on the same day. Since participants' data was self-reported, participants could have responded to items on the post-consumption survey to appease the researchers. All of these items are limiting factors in this research study.

Further studies are necessary to develop acceptable recipes containing mealworm or other insect proteins. Other types of insects such as crickets or grasshoppers could be tested using the recipes to see if there were any differences in characteristic mean scores. It is recommended that more savory products incorporating insect protein be explored for palatability. Furthermore, marketing research could explore best practices in reaching potential consumers, changing consumers' perceptions of food choices, and identifying marketing factors that would encourage entomophagy. Entomophagy is a trend in the world of food science that continues to evolve. More research into insect agriculture, coupled with the retail and restaurant foodservice industries could help better utilize the untapped resource of insect protein in western countries. This could potentially provide more insect-based food products that are acceptable, nutritious, and sustainable.

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Appendices

Table 1

Nugget Recipe Ingredients for Four Plant-based Nugget Samples

Ingredient	0MW	25MW	50MW	75MW
Nugget:				
Corn Flour	48.72 g	36.54 g	24.36 g	12.18 g
Mealworms (powdered)	0 g	12.18 g	24.36 g	36.54 g
Flax seed	13.56 g	13.56 g	13.56 g	13.56 g
Vegan Mayonnaise	7.03 g	7.03 g	7.03 g	7.03 g
Garlic Powder	0.5 g	0.5 g	0.5 g	0.5 g
Lemon Juice	0.76 g	0.76 g	0.76 g	0.76 g
Dijon Mustard	0.7 g	0.7 g	0.7 g	0.7 g
Salt	0.85 g	0.85 g	0.85 g	0.85 g
Celery	40.67 g	40.67 g	40.67 g	40.67 g
Carrots	32.72 g	32.72 g	32.72 g	32.72 g
Onions	25.24 g	25.24 g	25.24 g	25.24 g
Olive Oil	11.21 g	11.21 g	11.21 g	11.21 g
Batter/Breading:				
Cassava Flour	27.91 g	27.91 g	27.91 g	27.91 g
Water	69.19 g	69.19 g	69.19 g	69.19 g
Cornflakes (crushed)	84.61 g	84.61 g	84.61 g	84.61 g

All ingredient amounts, excluding corn flour and mealworm powder, were held constant across the four nugget samples. The “0MW” (control) sample contained 0% mealworms and 100% corn flour; the “25MW” sample contained 25% mealworms and 75% corn flour; the “50MW” sample contained 50% mealworms and 50% corn flour; and the “75MW” sample contained 75% mealworms and 25% corn flour.

Table 2
Mean Sensory Evaluation Scores on a 5-point Hedonic Scale of Five Characteristics for Four plant-based nugget samples.

Characteristic	0MW		25MW		50MW		75MW	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Crust Color	3.89_{a}	0.97	3.57_{ab}	1.15	3.27_{bc}	0.95	3.18_{bc}	1.05
Interior Color	3.50_{a}	0.95	3.07_{ab}	0.84	2.66_{bc}	0.89	2.43_{c}	1.00
Texture	3.50_{a}	0.90	3.30_{abc}	0.95	3.05_{abc}	1.01	2.84_{bc}	1.01
Flavor	3.86_{a}	0.85	3.64_{ab}	0.84	3.36_{bc}	0.94	2.89_{c}	0.92
Aftertaste	3.57_{a}	0.87	3.41_{ab}	0.90	3.14_{ab}	0.93	2.55	0.87

Note. Panelists (N = 44) evaluated the four nugget sample variations (0MW, 25MW, 50MW, and 75MW) on a 5-point hedonic scale. The "0MW" (control) sample contained 0% mealworms and 100% corn flour; the "25MW" sample contained 25% mealworms and 75% corn flour; the "50MW" sample contained 50% mealworms and 50% corn flour; and the "75MW" sample contained 75% mealworms and 25% corn flour. Means in a row sharing subscripts are not significantly different from one another.

Mean (M) score scale:
1 = Disliked very much, 2 = Disliked, 3 = Neither liked or disliked, 4 = Liked, 5 = Liked very much.

Table 3

One-Way Analysis of Variance of Mealworm Percentages on Sensory Evaluation Characteristics for Four Nugget Samples

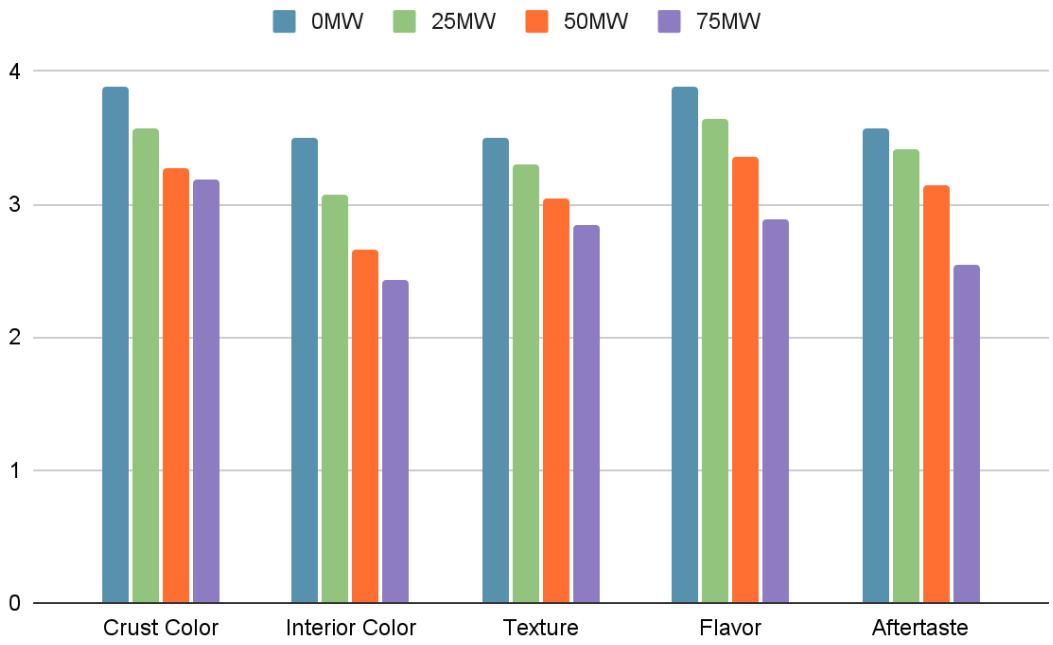
				0MW		25MW		50MW		75MW	
Characteristic	$F(3, 172)$	p	η_p^2	M	SD	M	SD	M	SD	M	SD
Crust Color	4.31	.006	.070	3.89_{a}	0.97	3.57_{ab}	1.15	3.27_{bc}	0.95	3.18_{bc}	1.05
Interior Color	11.45	< .001	.166	3.50_{a}	0.95	3.07_{ab}	0.84	2.66_{bc}	0.89	2.43_{c}	1.00
Texture	3.87	.01	.063	3.50_{a}	0.90	3.30_{abc}	0.95	3.05_{abc}	1.01	2.84_{bc}	1.01
Flavor	9.84	< .001	.146	3.86_{a}	0.85	3.64_{ab}	0.84	3.36_{bc}	0.94	2.89_{c}	0.92
Aftertaste	11.13	< .001	.163	3.57_{a}	0.87	3.41_{ab}	0.90	3.14_{ab}	0.93	2.55	0.87

Note. Panelists (N = 44) evaluated the four nugget sample variations (0MW, 25MW, 50MW, and 75MW) on a 5-point hedonic scale. The "0MW" (control) sample contained 0% mealworms and 100% corn flour; the "25MW" sample contained 25% mealworms and 75% corn flour; the "50MW" sample contained 50% mealworms and 50% corn flour; and the "75MW" sample contained 75% mealworms and 25% corn flour. Means in a row sharing subscripts are not significantly different from one another.

Mean (M) score scale:
1 = Disliked very much, 2 = Disliked, 3 = Neither liked or disliked, 4 = Liked, 5 = Liked very much.

Figure 1

Bar Graph of Mean Sensory Evaluation Scores on a 5-point Hedonic Scale of Five Attributes for Four Plant-Based Nugget Samples.



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