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Americans' acceptance of black soldier fly larvae as food for themselves, their dogs, and farmed animals

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ABSTRACT

This paper investigates consumer attitudes towards *Hermetia illucens* larvae (aka Black Soldier Fly Larvae; BSFL) and other insects in two forms: dried whole insects and insect flour incorporated into a familiar food. In two studies, we assessed the willingness of American adults to try eating them directly, eating animals fed on them, and feeding them to their pet dog. Participants were significantly more willing to try food made with insect flour than to eat the whole insects, with the same pattern emerging for acceptability of insects in dog food. BSFL were roughly as acceptable as other insects (crickets, mealworms, ants). On average, participants had negative attitudes towards eating BSFL on their own, but the majority were willing to try foods containing BSFL in the form of insect flour or rendered fat. There are also suggestions in the data that indirect routes of consumption (e.g., consuming animals that have eaten insects, or feeding insects to one's dog) are more acceptable than direct consumption. Our results suggest that BSFL are relatively well-received by consumers and are a promising alternative to the farmed animals more commonly used in pet food.

1. Introduction

Researchers have estimated that by 2050, the world population will grow to about 9.6 billion (Orsi et al., 2019; Jucker et al., 2020). The FAO estimates that food production will have to increase by 70 percent to be able to feed the world in 2050, with meat outputs – poultry, pork and beef – expected to double (IFIF, 2012). This raises concerns of food scarcity and the environmental and economic sustainability of the current food system. Today's livestock sector is estimated to be responsible for approximately 15% of the anthropogenic emissions of greenhouse gases (Gerber et al., 2013) and according to a 2006 FAO report, up to 18% of all greenhouse gases (Vries & Boer, 2010). With climate change becoming an increasingly critical issue, it is in our interest to look at more sustainable alternatives to animal protein, animal feed, and pet food.

1.1. Why focus on BSFL?

In recent years, to address the growing problem of food security, researchers have looked into insects as food (e.g., Evans, Flore, & Frøst, 2017; Halloran, Flore, Vantomme, & Roos, 2018; Hartmann & Siegrist, 2017; Looy, Dunkel, & Wood, 2014; Ruby, Rozin, & Chan, 2015; Ruby & Rozin, 2019; Van Huis et al., 2013; Zielińska et al., 2015). Insects are abundant, contain high levels of quality animal protein, typically do not emit polluting gases, and compared to the other animals commonly consumed by humans, are much more efficient at converting plant calories and protein to animal calories and protein. They require little space for rearing, and for most people, present a substantially lesser concern about cruelty in rearing or killing. Insects are regularly consumed by over a billion human beings (van Huis et al., 2013).

In the present paper, we focus on a specific insect, the larvae of *Hermetia illucens,* commonly known as Black Soldier Fly Larvae (BSFL). This species has received recent scholarly attention, for both human consumption (Delicato et al., 2020; Wang & Shelomi, 2017) and animal feed (Makkar et al., 2014; Spranghers et al., 2016; Surendra et al., 2016; Verbeke et al., 2015; Zanten et al., 2015). BSFL have also been used as a successful alternative to fish meal (Barroso et al., 2014; Belghit et al., 2019). Black soldier fly larvae are easy to breed, have an excellent nutrient composition, and are efficient converters of plant to animal food (Spranghers et al., 2016; Chen et al., 2019; Surendra et al., 2016; Zanten et al., 2015). A particular advantage of BSFL, compared to most other species of insects currently consumed by humans, is that they can

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be reared on foods that are not utilized by humans, including organic waste such as spent grains, vegetable/fruit waste, and even manure (Surendra et al., 2016).

1.2. Our aims

Until recently, there has been little research on acceptance of insects by the consumers in Western cultural contexts. Although entomophagy is practiced in many communities, particularly in Southeast Asia, Africa, and Latin America, insects are not consumed by most groups within these areas. Studies have shown that acceptance of insects for consumption is low in many Western countries; this is due to lack of sensory appeal, disgust, unfamiliarity, low availability, high price, and poor image (Ruby, Rozin & Chan, 2015; Tan, van den Berg, & Stieger, 2016). Recent research has shown that incorporating insects into familiar foods can increase appeal (Delicato et al., 2020; Gmuer et al., 2016; Schouteten et al., 2016), but there are many other ways of increasing acceptance, such as increasing availability and lowering cost. There is also an inclination to consume insects by the growing segment of the market that is concerned with sustainability (e.g., House, 2018; van Huis & Oonincx, 2017; Oonincx et al., 2010; Smetana, Palanisamy, Mathys, & Heinz, 2016).

Only 55% of world's crops are used to feed people, with a substantial 36% used to feed livestock. In the United States, 67% – more than half – of crop production by mass is directed to animal feed (Cassidy et al., 2013). In the first study, we explore the possibility that using insects – particularly BSFL – as feed for farmed animals is more acceptable to consumers than directly consuming the insects themselves.

In addition, there is a substantial pet food industry in the USA; the two major animals, cats and dogs, are principally carnivores. A study done on the environmental impacts of cats and dogs has shown that "if just one-quarter of the estimated 33% animal-derived energy in pet food was consumable by humans, it alone would support the animal-derived energy consumption of 26 million Americans" with the assumption that the typical American diet consists of about 19% animal-derived foods (Okin & Crowther, 2017, p. 10). As such, the use of insects in pet food has particular potential, and we explore this in our second study.

2. Study 1 participants and method

We recruited a total of 259 participants via Amazon.com's Mechanical Turk testing service for a study entitled "Novel Foods Survey". Participants were paid a modest sum for their time. To ensure accuracy in responses, we excluded any participants ($n = 66$) who failed more than one of two catch questions. The catch questions were "I enjoy eating plastic in my food" and "I regularly eat rocks", and both used a standard seven-point agree-disagree scale. Agreeing with either question counted as a failure. We also excluded any participants who had not been raised in the United States ($n = 16$).

The final sample included 177 American adults (47% women, $M_{age} = 35.11$, $SD_{age} = 9.15$). The sample was highly educated (48% with a Bachelor's degree or above), and primarily self-identified as White (75%), followed by Black (11%), Asian (6%), Latinx (5%), and multiracial (3%). Participants were largely omnivores (85%), followed by reducetarians (6%), partial vegetarians (4%), vegetarians (3%), and vegans (2%).

The questionnaire included a series of sections, in fixed order, that assessed knowledge about insects, attitudes towards eating insects, and willingness to eat products that included insects. The exact measures included in the present manuscript are detailed below, organized thematically. The information on knowledge about insects is not included in this manuscript. The study, which conformed to the Declaration of Helsinki, was part of a project deemed exempt from ongoing ethical review by the The University of Pennsylvania Institutional Review Board.

2.1. Attitudes towards insects as feed

Participants were told "Suppose some scientists discovered a new species of bird, similar to a chicken. It has a mild taste and is safe to eat." They then rated their willingness to try eating some cooked meat from this bird on a scale from 0 (not at all willing to try) to 100 (completely willing to try) depending on the bird's diet: "vegetation (e.g., fruit, leaves, and grass)"; "other animal flesh (including birds, fish)"; "insects"; and "garbage in a landfill (i.e., is a scavenger)". Unipolar scales are more contoured, allowing users to instead focus on a single item's absence or presence (e.g., willingness). This unipolar 0 to 100 scale, adapted from several previous studies (e.g., Haidt, McCauley, & Rozin, 1994; Rozin & Ruby, 2020) was chosen to provide more discrimination than a typical 7-point Likert-type scale and to be more intuitive for participants.

2.2. Attitudes towards BSFL as food and feed

Participants were presented with a description of black soldier fly larvae: "Black soldier fly larvae are efficient, nutritious, and eco-friendly. They can taste good when prepared correctly–their fat can be extracted and used in various dishes. The flavor of the fat has been compared to that of rendered duck or chicken fat by the Nordic Food Lab, which had experimented using it in a noodle stir-fry. They are also a promising source of protein for both animal feed and human consumption. The larvae/pupae contain high levels of protein, calcium, magnesium, unsaturated fatty acids, manganese, vitamin D and extremely high levels of vitamin B12. Another quality of black soldier fly larvae is that they are extremely durable and can survive many harsh conditions; They can live on food sources that are unacceptable to humans, that often go wasted. Contrary to popular belief about most insects, black soldier fly larvae are actually very hygienic. Their digestive systems have antimicrobial activity and adult black soldier flies, unlike other insects, do not bite nor spread diseases (Warner, 2014)."

Participants were shown a series of four pictures with descriptions: a plate of cookies made with ground black soldier fly larvae, ground black soldier fly larvae, a black soldier fly larva next to a penny to indicate its size, and a 10-day-old black soldier fly larva.[1]

Participants rated their attitudes toward eating a series of foods, and for all of these, to "assume there is no risk of toxicity or infection from consuming insects, as they have been washed, heat-sterilized and certified safe to eat." They indicated their attitudes toward eating the following foods on a sliding scale from −100 (I feel very negative) to 0 (I feel neither negative nor positive) to 100 (I feel very positive). This bipolar −100 to 100 scale was adapted from Rozin and Ruby's (2020) paper, in which a scale in the same format assessed the extent to which participants reported their attitudes and beliefs about insects and insect foods.

First, they indicated their attitudes toward eating…

Roasted chicken raised on black soldier fly larvae
Grilled fish raised on black soldier fly larvae
Roasted whole black soldier fly larvae, as is

They then indicated their attitudes toward eating "roasted whole black soldier fly larvae fed on…"

[1] These images can be viewed via the following links: The third image in this article (https://www.theguardian.com/environment/2018/aug/21/species-watch-black-soldier-fly-the-uks-newest-farmed-creature); the imagine in section 10 of this article (http://heilufood.com/blog/black-soldier-fly-larvae); via this link (https://images-na.ssl-images-amazon.com/images/I/61FIXli3n4L._AC_SL1000_.jpg); and in Figure 4.1 of this manual (https://scholarworks.umass.edu/cgi/viewcontent.cgi?article=1015&context=sustainableumass_studentshowcase).

Human food leftovers (fruits, vegetables, grains)
Human waste (feces)
Vegetables, but their parents were fed on human waste (feces)

Finally, they indicated their attitudes toward eating "roasted chickens raised on sterilized black soldier fly larvae that were raised on…"

Human food leftovers (fruits, vegetables, grains)
Human waste (feces)

2.3. Acceptable levels of black soldier fly larvae in consumer goods

Participants were told, "Black soldier fly larvae flour is made from roasted black soldier fly larvae. The larvae have been bred on fruits and vegetables. The flour has a mild, nutty, malty flavor." On a sliding scale from 0 to 100%, they completed the statement "I would be comfortable tasting a cookie containing up to _ % black soldier fly larvae flour."

Participants were then told, "Black soldier fly larvae fat is extracted from roasted (heat sterilized and non-toxic) black soldier fly larvae. The fat has a relatively strong savory flavor, comparable to that of rendered duck fat." On the same 0 to 100% scale, they completed the statement "I would be comfortable tasting French fries fried in oil containing up to _ % Black soldier fly larvae fat."

Participants then indicated how much money they would require to taste black soldier fly larvae, incorporated whole and roasted as an ingredient in their favorite cereal or stew. Their choices were $0, $50, $100, $1,000, $10,000, $100,000, and "No amount of money could convince me".

Participants indicated which of the following would be the most appealing name for black soldier fly larvae on a menu: "Black soldier fly larvae", "Earth caviar", "Black butter pods", "Malaysian butter grub" and "Other" (please specify).

2.4. Past experience eating insects

Participants indicated (yes or no) whether they had "ever voluntarily eaten a whole insect as food or as an ingredient in food", and if they had "ever voluntarily eaten ground insects as food or as an ingredient in food".

3. Study 1 results

We set a p level of .05 (2-tailed) as the threshold for statistical significance for all inferential tests. All analyses were performed using SPSS 25 (IBM Corp, 2018). For all ANOVAs in this study, Mauchly's test indicated that the assumption of sphericity had been violated ($p < .001$), so we report results using Greenhouse-Geisser corrections.

3.1. Attitudes towards insects as feed

We ran a repeated measures ANOVA on participants' willingness to eat the novel bird as a function of its diet. There was a significant effect of the bird's diet, $F(2.49, 437.62) = 203.01$, $p < .001$, $\eta_p^2 = .54$. Bonferroni-corrected pair-wise comparisons indicated that people were most willing to eat the bird if it fed on vegetation ($M = 75.62$, $SD = 33.01$), followed by if it fed on insects ($M = 66.20$, $SD = 36.65$), followed by if it fed on animal flesh ($M = 57.00$, $SD = 38.48$), and finally if it fed on garbage ($M = 18.56$, $SD = 28.86$). All differences were significant at $p < .001$; see Fig. 1 for a graph of the results.

3.2. Attitudes towards BSFL as food and feed

We ran a repeated measures ANOVA on participants' feelings about eating fish fed on BSFL, chicken fed on BSFL, and BSFL themselves. There was a significant effect of the type of animal, $F(1.35, 238.34) = 126.18$, $p < .001$, $\eta_p^2 = .42$. Bonferroni-corrected pair-wise comparisons indicated that people felt most positively about eating chicken fed on BSFL ($M = 26.11$, $SD = 71.01$), followed by fish fed on BSFL ($M = 21.23$, $SD = 73.09$), followed by BSFL themselves ($M = -33.16$, $SD = 67.55$). All differences were significant at $p < .001$, except for chicken vs. fish ($p = .04$).

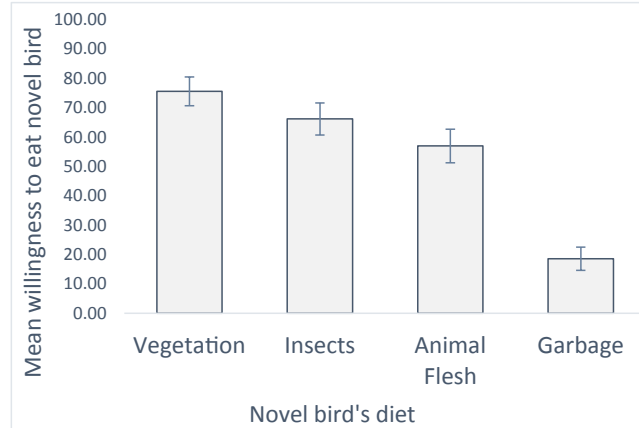

Fig. 1. Willingness to eat a novel bird as a function of its diet (n = 177). Note. Error bars indicate 95% confidence intervals.

Next, we ran a repeated measures ANOVA on participants' feelings about eating BSFL fed on leftovers, BSFL fed on feces, and BSFL fed on vegetables but whose parents were fed on feces. There was a significant effect of BSFL diet, $F(1.51, 266.12) = 88.78$, $p < .001$, $\eta_p^2 = .34$. Bonferroni-corrected pair-wise comparisons indicated that people felt least negatively about eating BSFL fed on leftovers ($M = -19.92$, $SD = 70.18$), followed by BSFL fed on vegetables but whose parents were fed on feces ($M = -55.32$, $SD = 58.45$), followed by BSFL fed on feces ($M = -74.05$, $SD = 49.82$). All differences were significant at $p < .001$.

Finally, we ran a paired samples t-test on participants' feelings about eating chicken raised on BSFL that were raised on leftovers vs. chicken raised on BSFL that were raised on feces. Ratings were significantly more positive for chicken raised on BSFL raised on leftovers ($M = 20.54$, $SD = 72.06$) than chicken raised on BSFL that were raised on feces ($M = -48.91$, $SD = 63.48$), $t(176) = 13.64$, $p < .001$, $d = 1.02$.

3.3. Acceptable levels of black soldier fly larvae in consumer goods

On average, participants reported being comfortable tasting a cookie containing a modest percentage of BSFL flour ($M = 30.54$, $SD = 33.25$), and comfortable tasting French fries fried in oil containing a modest percentage of BSFL fat ($M = 29.49$, $SD = 32.93$). A large minority of participants indicated that they would not be comfortable eating these foods made with any amount of BSFL flour (25%) or BSFL fat (23%).

In order to taste whole roasted BSFL as an ingredient in their favorite cereal or stew, 22% of participants would do it without a financial incentive, 18% for at least $50, 16% for at least $100, 15% for at least $1,000, 7% for at least $10,000, 12% for at least $100,000, and 10% claimed that no amount of money could convince them.

Participants said that they would be mostly likely to eat BSFL if they were called earth caviar (36% of participants), followed by black butter pods (29%), Malaysian butter grub (18%), black soldier fly larvae (10%), and other (8%; the majority of whom said they would not eat BSFL no matter what name was used).

3.4. Past experience eating insects

A minority of participants indicated that they have voluntarily eaten a whole insect as food or as an ingredient in food (20%) or have voluntarily eaten ground insects as food or as an ingredient in food

(14%). Those with previous experience eating insects scored significantly higher on all measures of acceptance of BSFL as food (all $p < .005$, d ranging from 0.72 to 1.60).

4. Study 1 discussion

Our results indicate much greater willingness to consume animals fed on insects than directly eating the insects themselves. We also found that the diet of the insects greatly affects people's acceptance. BSFL bred on "disgusting" things, such as feces, were considered much less acceptable. Notably, BSFL were more unacceptable if they had fed on feces than if their parents had. Somewhat surprisingly, we found that birds fed on insects were more acceptable as food than those fed on animal flesh. Participants were more willing to eat chicken raised on BSFL than fish raised on BSFL, but it's possible that this was simply indicative of a preference for chicken over fish. The majority of participants were willing to at least try BSFL, with only 10% expressing complete resistance to the idea.

Having discovered that insects were more acceptable as food if they are ingested indirectly, via consumption of animals fed on insects, we turned to the acceptability of insects as part of dog food. People have relations to their pet dogs that may vary from treating them as a member of the family to treating them in a much more distant way. We measured this relationship and hypothesized that the more intimate participants were with their dog, the more reluctant they would be to feed the dog insects (assuming the participants themselves were averse to consuming insects). Furthermore, we wished to explore whether some forms of dog food (i.e., occasional treats containing insect flour) would be more acceptable than others (i.e., daily dog food containing insect flour, and whole dried insects).

5. Study 2 participants and method

We recruited a total of 251 participants via Amazon.com's Mechanical Turk testing service. This study was advertised as "Foods Survey For Dog Owners". Participants were paid a modest sum for their time. To ensure accuracy in responses, we excluded any participants who failed more than one of two catch questions (37 participants). The catch questions were, "the total population of the USA is larger than two million people", and "insects are larger than humans." Both used a standard seven-point agree-disagree scale. Disagreeing with the first or agreeing with the second counted as a failure. All remaining participants indicated that they had been raised in the USA.

The final sample included 214 American adults (42% women, $M_{age} = 36.22$, $SD_{age} = 10.52$. The sample was highly educated (55% with a Bachelor's degree or above) and primarily self-identified as White (77%), followed by Latinx (8%), Asian (6%), multiracial (5%), and Black (4%). Participants were largely omnivores (83%), followed by reducetarians (9%), vegetarians (5%), and partial vegetarians (2%).

The questionnaire included a series of sections, in fixed order: participants' relationship with their dog, general attitudes towards insects, their attitudes towards insects as food and feed, and their attitudes towards feeding their dog insects directly and as an ingredient in dog food. The exact measures included in the present manuscript are detailed below, organized thematically.

5.1. Insect eating beliefs

Participants were asked to rate their beliefs about eating insects, using a 7-point scale ranging from "Strongly Disagree" to "Strongly Agree" (from Ruby & Rozin, 2019). These items covered the benefits of eating insects ("Rearing insects for food generates less pollution and greenhouse gas than rearing conventional livestock", "Rearing insects as food is more efficient and requires fewer resources than rearing conventional livestock", "Insects are highly nutritious") and the disgustingness of eating insects ("The idea of eating insects makes me nauseous", "I am offended by the idea of eating insects", "Eating insects is disgusting").

The internal reliability of both scales was excellent (Benefits $\alpha = .87$; Disgust $\alpha = .90$).

5.2. Attitudes toward BSFL as food and feed

Using a scale of 0 ("not at all willing") to 100 ("completely willing"), participants indicated their willingness to eat roasted chicken and grilled fish, in order to have a baseline comparison for their willingness to eat chicken or fish raised on BSFL.

Next, participants were given the same description and pictures of BSFL as in Study 1.

Again, they indicated their attitudes toward the same series of foods (chicken raised on BSFL, fish raised on BSFL, roasted BSFL, and BSFL raised on three different diets). In this study, however, the response scale was different, ranging from 0 (not at all willing) to 100 (completely willing).

5.3. Acceptable levels of black soldier fly larvae in consumer goods

Participants completed the same measures as in Study 1 on maximum acceptable BSFL flour in a cookie, maximum acceptable BSFL fat in French fry oil, amount of money required to taste roasted BSFL, and preferred name for BSFL on a menu.

5.4. Attitudes towards feeding dogs foods made with insects

In this section, participants were shown an image of 20% insect flour dog treats (Fig. 2), told that the product "looks and smells like normal dog treats; you cannot see the insects, and has been certified as safe". All questions in this section used a scale ranging from 0 (not at all willing) to 100 (completely willing). Each type of dog food was presented in four varieties: made with crickets, black soldier fly larvae, mealworms, and ants.

They first rated their willingness to give their dog a treat that contains 20% insect flour, followed by their willingness to feed their dog daily pet food made with 20% insect flour, followed by their willingness to feed their dog a "bowl of whole dried insects".

5.5. Relationship between pet owner and dog

Participants were asked to pick the dog they have the closest relationship to when answering the questions. If they did not have a favorite, they were asked to designate one.

Fig. 2. Insect flour dog treats.

Using 5-point scale from "Never" (1) to "Always or almost always" (5), participants were asked: "Does your dog usually sleep in the bed with you?", "Do you treat your dog as if it were your child?", "Do you talk to your dog as if it were a child?", and "Do you feed your dog pieces of some of the foods you are eating while you are at the table?"

Internal reliability analyses revealed that the item measuring feeding one's dog at the table performed relatively poorly (corrected item total correlation = .26); after dropping this, the remaining three items displayed acceptable internal reliability (α = .71).

6. Results

We again set a *p* level of .05 (2-tailed) as the threshold for statistical significance for all inferential tests. All analyses were performed using SPSS 25 (IBMCorp, 2018). For all ANOVAs in this study, Mauchly's test indicated that the assumption of sphericity had been violated ($p < .001$), so we report results using Greenhouse-Geisser corrections.

6.1. Attitudes towards BSFL as human food

We ran a repeated measures ANOVA on participants' willingness to eat fish fed on BSFL, chicken fed on BSFL, and BSFL themselves. There was a significant effect of the type of animal, $F(1.53, 324.74) = 142.56$, $p < .001$, $\eta p^2 = .40$. Bonferroni-corrected pair-wise comparisons indicated that people were most willing to eat chicken fed on BSFL ($M = 63.12$, $SD = 40.58$), followed by fish fed on BSFL ($M = 58.10$, $SD = 42.17$), followed by BSFL itself ($M = 26.14$, $SD = 34.32$). All differences were significant at $p < .01$.

We then created a score for participant willingness to eat chicken raised on BSFL and fish raised on BSFL, adjusting for their baseline preferences for those items (e.g., willingness to eat chicken raised on BSFL minus general willingness to eat chicken). A paired-samples *t*-test indicated that willingness dropped significantly less for fish ($M = -21.77$, $SD = 37.08$) than chicken ($M = -26.59$, $SD = 37.63$), $t(213) = 3.33$, $p < .001$, $d = 0.13$.

6.2. Acceptable levels of black soldier fly larvae in human foods

On average, participants reported being comfortable tasting a cookie containing a modest percentage of BSFL flour ($M = 26.39$, $SD = 31.76$), and comfortable tasting French fries fried in oil containing a modest percentage of BSFL fat ($M = 27.79$, $SD = 35.00$). A large minority of participants indicated that they would not be comfortable eating these foods made with any amount of BSFL flour (29%) or BSFL fat (32%).

In order to taste whole roasted BSFL as an ingredient in their favorite cereal or stew, 21% of participants would do it without financial incentive, 16% for at least $50, 15% for at least $100, 14.0% for at least $1,000, 9% for at least $10,000, 12% for at least $100,000, and 13% claimed that no amount of money could convince them. Participants said that they would be most likely to eat BSFL if they were called earth caviar (38% of participants), followed by black butter pods (31%), Malaysian butter grub (15%), black soldier fly larvae (8%), and other (7%; the majority of whom said they would not eat BSFL no matter what name was used).

6.3. Attitudes towards feeding dogs foods made with insects

We ran a repeated measures ANOVA on participants' willingness to feed their dog treats made with 20% insect flour as a function of the species of insect used. There was a significant effect of insect species, $F(2.45, 522.74) = 18.68$, $p < .001$, $\eta_p^2 = .08$. Bonferroni-corrected pair-wise comparisons indicated that people were most willing to feed their dog treats made with cricket flour, followed by BSFL, followed by both mealworms and ants. All differences were significant at $p < .05$, save mealworm vs ant ($p = 1.00$). For an overview of means and standard deviations, see Table 1.

Table 1
Participant willingness to feed insect foods to their dogs (n = 214).

	Dog treats with 20% insect flour		Dog food with 20% insect flour		Bowl of whole dried insects	
Insect Type	*M*	*SD*	*M*	*SD*	*M*	*SD*
Crickets	53.39	39.70	53.59	39.78	31.58	37.69
BSFL	53.04	41.10	52.79	40.90	30.36	38.41
Mealworms	48.29	41.48	47.74	41.43	29.26	37.85
Ants	47.72	41.10	45.57	40.80	36.65	37.09
Average	51.63	39.03	50.15	39.20	29.22	36.68

Note. Participants indicted their willingness to feed these foods to their dogs on a scale ranging from 0 (not at all willing) to 100 (completely willing).

We then ran a repeated measures ANOVA on participants' willingness to feed their dog daily pet food made with 20% insect flour as a function of the species of insect used. There was a significant effect of insect species, $F(2.60, 553.52) = 16.13$, $p < .001$, $\eta_p^2 = .07$. Bonferroni-corrected pair-wise comparisons indicated that people were most willing to feed their dog daily pet food made with crickets or BSFL than either mealworms or ants. All differences were significant at $p < .001$, save cricket vs. BSFL and mealworm vs. ant (both $p = 1.00$).

Next, we ran a repeated measures ANOVA on participants' willingness to feed their dog a bowl of dried insects as a function of the species of insect used. There was a significant effect of insect species, $F(2.48, 527.91) = 9.60$, $p < .001$, $\eta_p^2 = .04$. Bonferroni-corrected pair-wise comparisons indicated that people were most willing to feed their dog a bowl of dried crickets or BSFL than either mealworms or ants. All differences were significant at $p < .05$, save cricket vs. BSFL ($p = 1.00$) and mealworm vs. ant ($p = .55$).

Finally, we created composites by averaging scores on the four dog treat items (α = .97), the four daily pet food items (α = .97), and the four dried insect items (α = .98). A repeated measures ANOVA indicated that people were less willing to feed their dog a bowl of dried insects than either dog treats made with 20% insect flour or daily pet food made with 20% insect flour, both $p < .001$. Ratings for treats and daily pet food did not significantly differ ($p = .44$).

6.4. Willingness to eat BSFL vs. Willingness to feed BSFL to dogs

A paired-samples *t*-test indicated that participants own willingness to eat roasted BSFL ($M = 26.14$, $SD = 34.32$) did not significantly differ from their willingness to feed a bowl of dried BSFL to their dog ($M = 30.36$, $SD = 38.41$), $t(213) = 1.84$, $p = .07$, $d = 0.12$.

6.5. Predicting willingness to eat BSFL and to feed insect foods to dogs

We created a composite score of people's overall willingness to try eating BSFL, by averaging their scores for highest acceptable level of BSFL flour in a cookie, highest acceptable level of BSFL fat in French fry oil, and willingness to directly eat whole roasted BSFL (α = .79). We also created a score of their overall willingness to feed their dogs foods containing insects, by averaging their scores on the four dog treat items, the four daily pet food items, and the four dried insect items (α = .98). The correlation of these measures with insect eating beliefs and dog closeness is displayed in Table 2.

We ran a multiple regression, entering insect eating disgust and insect eating benefits to predict participants' overall willingness to eat BSFL. The regression was significant, $F(2, 211) = 90.51$, $p < .001$, $R^2_{adj} = .46$. Insect eating disgust emerged as a significant predictor (β = -0.62, $p < .001$) but insect eating benefits did not (β = 0.19, $p = .10$).

We then ran a multiple regression, entering insect eating disgust and insect eating benefits to predict participants' overall willingness to feed their dogs foods containing insects. The regression was significant, $F(2, 211) = 72.62$, $p < .001$, $R^2_{adj} = .40$. Both insect eating disgust (β = -0.39, $p < .001$) and insect eating benefits emerged as significant predictors (β

Table 2
Correlations between insect acceptance measures, insect eating beliefs, and dog closeness (n = 214).

	1	2	3	4	5
1. Overall BSFL Willingness	–				
2. Overall Insect Dog Food Willingness	.66 ***	–			
3. Insect Eating Disgust	.43 ***	.55 ***	–		
4. Insect Eating Benefits	0.67 ***	0.57 ***	0.52 ***	–	
5. Dog Closeness	0.04	0.16 *	0.14 *	.13	–

Note. * p < .05, *** p < .001.

= 0.35, $p < .001$). We then re-ran this regression, adding dog closeness as an additional predictor. This regression remained significant, F (3, 210) = 49.13, $p < .001$, $R^2_{adj} = .40$, but did not explain significantly more of the variance, $R^2_{change} = .00$, $p = .20$. Both insect eating disgust (β = -0.38, $p < .001$) and insect eating benefits emerged as significant predictors (β = 0.34, $p < .001$), but dog closeness did not (β = -0.07, p = .20).

7. General discussion

We have presented evidence for American adults' willingness to eat insect foods directly, eat animals that had been fed insects, and feed insect foods to their pet dogs. Participants were more willing to eat insects indirectly as animal feed than directly as food. Notably, participants were particularly willing to eat birds raised on insects.

We found that perceptions of the disgustingness and the benefits of insect foods predicted both people's willingness to eat these foods themselves and their willingness to feed them to their dogs. We predicted that the closer participants felt to their dogs, the more resistant they would be to feeding the dogs insect foods, but this prediction was at best weakly supported.

A primary goal of the present studies was to explore BSFL as a particularly promising way of introducing insects directly or indirectly into the human diet. We generally found, in both studies, that BSFL were quite acceptable, almost as acceptable as crickets and more acceptable than mealworms or ants. In general, there were not large differences in acceptability of these four types of insects. This is somewhat at odds with recent results from American and Indian adults, in which ants were more acceptable than crickets or mealworms (Ruby & Rozin, 2019).

Prior findings (Delicato et al., 2020; Hartmann & Siegrist, 2017; Ruby et al., 2015) suggest that the optimal means of delivery of BSFL is via flour, and our findings support this. The sensory properties of whole insects, while not innately aversive, do not resemble the properties of animal muscle, while the sensory properties of insect flour are quite comparable to those of the grain flour that it would usually replace.

The present manuscript has some limitations. First, our subjects were only sourced from the USA, and we relied solely on self-report data. Further studies could address both limitations by administering an experimental study in different cultural contexts, in which participants blind taste-test products that contain BSFL flour and fat. Also, we focused on willingness to try insect foods– there are other measures such willingness to consume insect foods over a period of days or weeks, after an initial sampling, or more direct measures of liking.

We expect, based on what is known about the acquisition of food preferences and liking (e.g. Rozin, Cohen, & Ruby, 2019), that indirect consumption of insects might encourage direct human consumption. Mere exposure would be accomplished by the indirect route, along with greater familiarity and a positive context for ingestion. These forces should all encourage liking.

Many more studies are needed on the sensory properties of insect foods and their real-life acceptance in a broad array of cultural contexts. For example, researchers could test whether consumers report higher liking for food products labeled as containing "earth caviar" or "black butter pods", vs. "black soldier fly larvae."

In the present study, although most respondents had negative feelings towards consuming BSFL directly, we have shown acceptability for BSFL and some other insects as both a food animal food and a pet dog food, with a suggestion that these two indirect routes may be more acceptable than direct consumption. Given the efficiency of BSFL (e.g., Shumo et al., 2019; Spranghers et al., 2016; Wang & Shelomi, 2017), incorporating them into pet food, especially for animals that are obligate carnivores, could greatly contribute to environmental sustainability. For consumers who are concerned about the environmental costs of meat production, using insects as feed for farmed animals may also be appealing, although this route would do little to address the concerns of those who are concerned about the welfare and rights of farmed animals.

Previous research has identified psychographic profiles of consumers who would be more willing to adopt insects in– e.g., Ruby, Rozin, and Chan (2015) noted that men who are low in disgust sensitivity and food neophobia, high in sensation seeking, and inclined to tell others about their unusual eating experiences are particularly likely consumers of insects. Similarly, Verbeke (2015, p. 154) identified "younger males with a weak attachment to meat, who are more open to trying novel foods and interested in the environmental impact of their food choice" as likely consumers. Identifying characteristics of consumers provides important information for the sustainable protein industry to accurately segment, target, and market to consumers. As such future researchers should consider exploring how consumers' demographics, psychographics, and food-related values may determine not only their own willingness to eat insects themselves, but also their willingness to consume animals fed on insects and their willingness to feed their pets insects or treats containing insects. As scientists and industry continue to grapple with the problem of feeding a growing human population with finite resources, deeper insight regarding consumer attitudes toward BSFL and other insects will likely play an important role in making the food industry more sustainable.

Declaration of Competing Interest

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.

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