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NOTE

The nutritional composition of common wild-harvested insects in the Canadian province of Nova Scotia

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INTRODUCTION

Insects have long been an important component of human diets across the world (Rumpold and Schlüter 2013). Insects are eaten for a variety of reasons including cultural importance, taste and nutrition (Ramos-Elorduy 2009). The act of eating insects, termed "entomophagy", is undergoing a resurgence across the Global North, with insects being championed by many as "a food of the future" owing to their high nutritional value and small environmental footprint (Payne et al. 2019). These same qualities have also positioned insects as a "feed of the future", through transforming low-quality feedstocks into safe nutrient-rich animal feed sources. To date, insect biomass has shown promise as a feed ingredient incorporated into the diets of terrestrial (e.g., broiler hens) and aquatic (e.g., rainbow trout) farmed animals (Al-Qazzaz et al. 2016; Fisher et al. 2020).

Though industrial rearing of insects is widely-considered to be necessary in sustainably scaling entomophagy (Rumpold and Schlüter 2013) many insect species are unsuitable to be raised at an industrial scale. This may be due to challenges posed by complex life cycles, highly specialized diets, or relatively slow growth. A curated list of the world's edible insects indicates that >92% of edible insect species are harvested from the wild (Jongema 2017), such as the various wood-boring and root-feeding larvae of moths and beetles consumed by Aboriginal Australians (Yen et al. 2018).

Wild-harvested insects may play a role in the future diets of inhabitants of the Atlantic Provinces of Canada (Nova Scotia, New Brunswick, Newfoundland and Labrador, and Prince Edward Island). Though entomophagy is not widely practiced in the Atlantic Provinces today, historically, Indigenous (Mi'kmaq and Wolastoqiyik) populations throughout the region sometimes included ants (Carr 1951) and grasshoppers (Stoddard 1966) as part of their diets. There are early indications that entomophagy may be a palatable amendment to diets across Atlantic Canada today. A recent study based in Nova Scotia combined a sensory evaluation of cricket-based protein powder with a survey of attitudes toward entomophagy, finding broad acceptance of insects as a food ingredient (Barton et al. 2020).

Today, processed insect products (e.g., cricket powder) remain costly relative to comparable alternative-protein products (e.g., pea powder). However, many wild insects found in Atlantic Canada can occur in high abundance and can be easily collected. Encouraging the sustainable collection of wild-harvested insects could be an effective pathway to promote entomophagy as part of a varied nutritional diet. Collection of wild insects could be a complement to more widely established wild-harvested foods like fruits and herbs (Ruhl 2021), and wild game (Roebothan and Aucoin 1998).

In this study, we aimed to explore the nutritional value (protein, fat, and micronutrients) of several wild-harvested insects that can be quickly and easily collected in the Canadian province of Nova Scotia. We also estimated the nutritional variability of Junebugs (*Phyllophaga* spp. Harris (Coleoptera: Scarabaeidae)) across three different geographic locations.

METHODS

Wild insects were collected in the summer and autumn of 2021. Species were selected for the study based on their ubiquity, abundance, body-size, and ease of capture (Table 1, Figure 1). Insects were caught by hand searching, use of sweep nets, and hand-collection at lights during night-time hours. We purposely targeted species spanning a range of dietary strategies, life stages, and seasonal peaks in abundance. Junebugs (*Phyllophaga* spp.) were collected in

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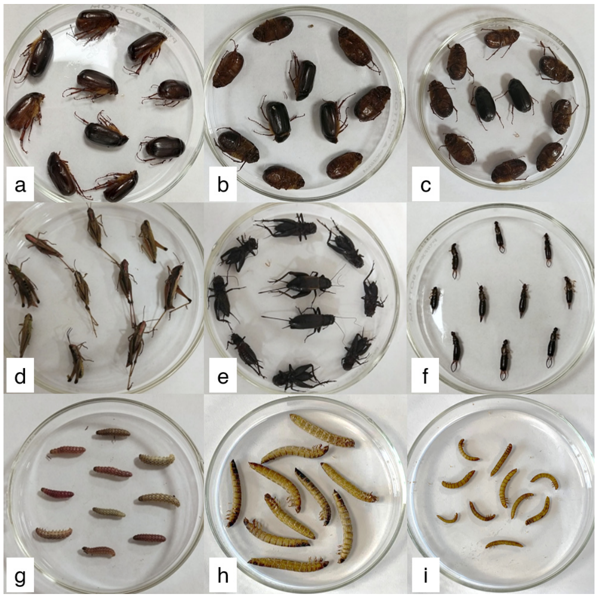
Table 1. Insect species included in the study. Two commercially available species of beetle larvae were also compared. Greenfield sites were located on the Dalhousie Agricultural Campus (Truro, Nova Scotia) 63°15′50.83′′W, 45°22′17.83′′N.

Common name	Binomial name (Order: Family)	Status	Life-stage	Capture method	Date collected	Habitat	Number per 10g sample
Junebug[1]	*Phyllophaga* spp. Harris (Coleoptera: Scarabaeidae)	Native	Adult	Hand-collected at lights	4-18 June 2021	Residential gardens	20 – 21
Spur throat grasshoppers	*Melanoplus* spp. Stål (Orthoptera: Acrididae)	Native	Adult	Sweep net	10-15 September 2021	Greenfield site	49
Fall field cricket	*Gryllus pennsylvanicus* Burmeister *(Orthoptera: Acrididae)*	Native	Adult	Hand-collected	10 September – 13 October 2021	Residential garden	21
Carrot seed moths	*Depressaria depressana* Fabricius (Lepidoptera: Depressaridae) *Sitochroa palealis* Denis and Schiffermüller (Lepidoptera: Crambidae)	Introduced	Larva	Hand-collected	10-13 September 2021	Greenfield site	130
European earwig	*Forficula auricularia* L. *(Dermaptera: Forficulidae)*	Introduced	Adult	Hand-collected	20 August 2021	Residential garden	120
Super worms	*Zophobas morio* Fabricius (Coleoptera: Tenebrionidae)	Cultivated	Larva	Industrially-reared	15 September 2021	N/A	22
Yellow mealworms	*Tenebrio molitor* L. (Coleoptera: Tenebrionidae)	Cultivated	Larva	Industrially-reared	15 September 2021	N/A	94

[1] *Phyllophaga* spp. were collected at three different sites (Canning, Berwick, Truro) across Nova Scotia, to determine variability in nutritional properties. Canning and Berwick are located respectively *c.* 90 and 120 km southwest of Truro.

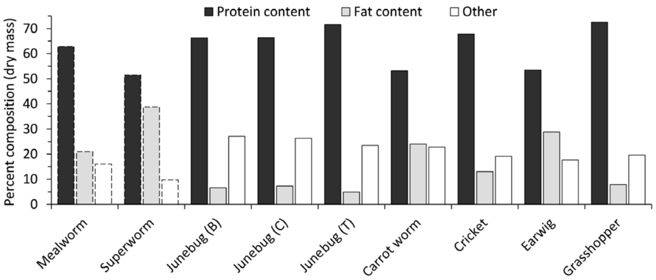
Figure 1. A representation of 10 individuals for each of the insect samples. Samples include Junebug (*Phyllophaga* spp) samples from three locations Berwick (a), Canning (b), Truro (c), *Melanoplus* spp grasshoppers (d), *Gryllus pennsylvanicus* (e), European Earwig (*Forficula auricularia*) (f), Carrot seed moths (*Depressaria depressana* and *Sitochroa palealis*) (g), commercially-reared superworms (*Zophobas morio*) (h), and commercially reared mealworms (*Tenebrio molitor*) (i).



Truro (45°21′53″N 63°16′48″W), Berwick (45° 02′ 43″N, 64° 44′ 0″ W), and Canning (45°09’26”N, 64°25’13”W). All other wild-captured insects were collected in Truro, Nova Scotia. Two commercially reared insect species (Mirdo Importations Canada, Montreal, Quebec) were also included for comparison (Table 1). These species were included either due to their existing use as a food ingredient (*Tenebrio molitor*) or their recognized potential as a food ingredient (*Zophobas morio)* (e.g., Li et al. 2013; Rumbos and Athanassiou 2021). All insects were euthanized by freezing at -20 °C and were stored in the same freezer until processing.

For each species, 10g (wet weight) of insects were ground together to produce one homogenous sample. The number of individuals per sample varied across insects (Table 1). Samples were submitted to a diagnostic lab (Department of Agriculture Laboratory Services in Truro, Nova Scotia) to determine nutritional composition. A series of eleven endpoints were measured, which is standard practice for analyzing feed samples. Dry matter (DM; 100-moisture (AOAC 2005; method no. 934.01)), crude protein (AOAC 2005; method no. 990.03), Leco protein/N analyzer (Model FP-528, Leco Corp., St. Joseph, MI, USA), crude lipid (AOAC 2005; method AM 5–04), ANKOM XT15 extraction system (ANKOM Technology, Macedon, NY, USA)), and mineral content (AOAC 2003; method no. 968.08) of all insect samples were determined.

Figure 2. Comparison of protein and fat content of five wild-harvested and two industrially-reared insects. Junebug (*Phyllophaga* spp) samples from three locations were compared to make an initial assessment of geographic variability in nutritional value (B = Berwick, C = Canning, T = Truro). Canning and Berwick are located approximately 90 and 120 km southwest of Truro respectively. All values are presented relative to total dry mass of the sample.



RESULTS

Industrially-reared insects (i.e., mealworms and superworms) were comparable in protein content but lower in fat content than the wild-harvested insects (Figure 2). However, European earwigs (28.8%) and carrot seed moths (23.4%) had a greater fat content than mealworms (21%) but not the superworms (38.8%).

Wild-harvested insects had comparable levels of minerals with the industrially-reared controls (Table 2). In some cases, wild-harvested insects had higher concentrations of individual minerals relative to the most mineral-rich control. Crickets and carrot seed moths both had higher concentrations of calcium relative to superworms (3.4 and 2.2 times greater respectively; Table 2). Carrot seed moths had 1.8 times the potassium (K) of mealworms. Wild-harvested insects had manganese (Mn) levels 2.4, 7.9, and 2.8 times (grasshopper, cricket, and Junebugs (Truro) respectively) greater than the most Mn rich control (mealworm).

Junebug samples harvested from three different locations were similar in terms of protein, fat and mineral content (Figure 2, Table 2). The greatest variability among Junebug samples was in manganese (Table 2) which varied 1.8 times between the lowest (Berwick) and the highest sample (Canning).

DISCUSSION

Our results demonstrate that a subset of common and abundant insects within the region have a nutritional profile that is comparable to industrially-reared insects. Much of the published literature on the nutritional value of wild-harvest insects is from areas of the world where wild-harvested insects have a more established role in traditional diets, such as Zimbabwe (Manditsera et al. 2019), Nigeria (Ekop et al. 2010), and India (Chakravorty et al. 2014). This work demonstrates the potential role that wild-harvested insects might have for human diets in Atlantic Canada.

When comparing the three Junebug samples collected at different locations across the province, the chemical profiles were very consistent (Figure 2; Table 2). This similarity occurs despite a strong likelihood that these samples would have included various species within the genus *Phyllophaga*. Variability in the nutritional content of edible insects is widely known to be influenced by factors including: diet (e.g., Spranghers et al. 2017), light (Oonincx et al. 2018), and the developmental stage of the insect (e.g. Kulma et al. 2020). Further investigating the nutritional variability of insects from different geographic areas may provide new insights into the suitability of wild-harvested insects for human consumption.

A major caveat associated with this research, is that we do not know whether the nutrients within these insects are biologically available. The term "bioaccessibility" describes the fraction of a nutrient that is soluble in the gastrointestinal environment and is available for absorption (Hedren et al. 2002). Anti-nutritional components can bind to iron and zinc, limiting the availability of these essential nutrients to the human body. In a study by Ekop *et al.* (2010) four anti-nutrients (oxalate, hydrocyanic acid, phytic acid and tannins) were measured in four commonly wild-harvested insects. Among these anti-nutrients, the authors found high levels of oxalate (28.4 mg oxalate / 100g insect) in the yam beetle (*Heteroligus meles* Billberger (Coleoptera: Dynastidae). Oxalate, which is also found in numerous leafy vegetables, can reduce the bioavailability of calcium, magnesium and iron in the human body (Rahman et al. 2013).

Another caveat with harvesting insects from the wild concerns food safety. Limited knowledge of edible insect food safety is a significant barrier and concerns need to be addressed to encourage use of insects in human diets (van der Fels-Klerx *et al.* 2018). A critical factor influencing food safety hazards in insects is the food substrate that the insect consumes throughout development (van der Fels-Klerx *et al.* 2018), which poses a significant challenge in the case of wild-harvested insects.

Insects can impact human health through different exogenous and endogenous mechanisms, which are broadly categorized as chemical or biological in nature. Chemical risks include heavy metals, microplastics, and pesticide residues. Most of the available evidence

Table 2. Results of the mineral analysis for two industrially-reared (mealworms and superworms) and five varieties of wild-harvested insects. Junebugs (Phyllophaga spp.) were sampled from three locations to make an initial assessment of geographic variability in nutritional value (B = Berwick, C = Canning, T = Truro). Canning and Berwick are located approximately 90 and 120 km southwest of Truro respectively. All micronutrient values are reported relative to total dry mass (DM) of the sample. Percentage dry mass (DM) of each sample is provided in the last column.

Insect	Ca (%)	K (%)	Mg (%)	P (%)	Na (%)	Cu (ppm)	Mn (ppm)	Zn (ppm)	DM (%)
Mealworm	0.07	1.09	0.30	0.96	0.17	23.21	12.49	161.55	33.1
Superworm	0.04	0.78	0.13	0.55	0.10	8.76	<10.00	70.20	41.1
Junebug (B)	0.06	1.28	0.19	0.69	0.16	21.87	19.83	166.13	30.7
Junebug (C)	0.05	1.30	0.19	0.71	0.17	22.66	31.00	170.66	31.8
Junebug (T)	0.05	1.36	0.17	0.75	0.18	20.89	36.03	179.95	28.1
Carrot worm	0.16	1.97	0.20	0.89	0.04	8.84	21.28	87.48	24.0
Cricket	0.25	1.23	0.12	0.91	0.37	31.57	98.48	185.36	26.7
Earwig	0.10	0.68	0.07	0.53	0.16	15.74	<10.00	114.99	37.8
Grasshopper	0.08	1.28	0.11	0.87	0.07	28.21	30.61	165.26	25.0

of chemical risk associated with entomophagy concerns heavy metals. Relatively high concentrations of heavy metals can accumulate in insects if they consume plants grown in contaminated soils (Butt et al. 2018). Three heavy metals of high concern are cadmium, lead and arsenic because they have a high potential to bioaccumulate in insects (Zhang et al. 2009; van der Fels-Klerx et al. 2018). Given that our insects were harvested from areas with a legacy of industrial activity and ongoing agricultural production, they may have contained high concentrations of heavy metals. Confirming the safety of wild-caught insects with respect to heavy metal concentrations, must occur before recommending wild-caught insects as a food source. Future studies of wild-harvested insects might also consider quantifying microplastics, and pesticide residues to validate their safety for human consumption.

Biological risks associated with entomophagy include microbial, parasite, and fungal contamination (Testa et al. 2017). Pathogenic microorganisms (Garofalo et al. 2017) and mycotoxins (Simpanya *et al.* 2000) that pose risks to human health have been found in industrially-reared insects, however little is known about the potential biological risks associated with consumption of wild insects. The inherent enzymatic and macromolecular properties of an insect species may also pose a risk to human health. For example, in a human population with high levels of thiamine deficiency, consumption of roasted *Anaphe venata* Butler (Lepidoptera: Notodontidae) larvae, caused the onset of ataxia (abnormal, uncoordinated movements) in 34 individuals in the hours following consumption (Adamolekun and Ibikunle 1994). The onset of symptoms was caused by enzymes that degraded thiamine in the body but was quickly reversed following treatment with multi-vitamins.

Although insects are not often wild-harvested for human consumption in Atlantic Canada, unsustainable harvesting practices might have a local effect on the population and the health of the wider ecosystem. Indirect effects associated with unsustainable harvest can also occur when harvest is unregulated and requires invasive techniques. For example, in Australia, reports of severe soil erosion in riparian areas have become more frequent owing to an increase in the recreational and unregulated harvest of root-feeding caterpillars (Lepidoptera: Hepialidae) using red river gum trees (*Eucalyptus camaldulensis* (Myrtaceae)) as a host plant (Yen 2009). Successful stewardship models are practiced elsewhere, where the Basi people of Zambia have consumed caterpillars for time immemorial and regulate harvest by monitoring populations, protecting host plants, and imposing temporal restrictions to harvesting (Mbata et al. 2002). The insects we considered here are all abundant and were collected relatively quickly but effort should be made to establish and promote best practices to conserve the long-term health of these populations, should collecting increase in popularity (Yen 2009).

Many of the insects that we sampled within our study can be classified as pests. The two species of carrot worm (*Depressaria depressana* and *Sitochroa palealis*) are both relatively new to the region, having been introduced accidentally via anthropogenic means (Ogden 2017). These species are classified as "pests" when they feed on seeds of domesticated carrot cultivars. However, both moth species are commonly found feeding on the seeds of wild carrot (*Daucus carota (Apiaceae)*) which is a widespread "weed" in disturbed environments including roadsides and brownfields. Similarly, the larvae of Junebugs (*Phyllophaga* spp) are belowground herbivores widely considered as pests due to damage that the larvae exert upon agricultural crops and turfgrass (Forschler and Gardner 1990). The European earwig (*Forficula auricularia)* is omnivorous, but is an agricultural pest of numerous grain crops at the seedling stage (Kirkland et al. 2020), and is known to damage numerous vegetable and flower crops in home gardens (Beall 1932). Some conservationists argue that, with some important caveats (Nuñez et al. 2012), promoting the consumption of pest species might be a suitable means to facilitate public outreach, and in a narrower range of circumstances might have a positive outcome in reducing pest populations at a local level.

The social perception of consuming insects remains a major barrier to widespread adoption of insect protein into diets. The consumption (actual or hypothetical) of an insect commonly evokes a feeling of disgust amongst consumers, even when willingness to eat insects is high (Ruby et al. 2015). Similar to industrially-reared insects, species selection (Caparros Megido et al. 2014), processing of raw insect material (Ruby et al. 2015), and the qualities of the final food product (Barton et al. 2020, Caparros Megido et al. 2014) will all influence the success of insects being used as a protein source in Atlantic Canada.

Our work demonstrates promise for common insects within Atlantic Canada to be used as edible insects. Protein and mineral content were generally comparable between wild-harvested and industrially-reared insects. Our analysis suggests that some minerals (potassium, manganese, and calcium) may occur in higher concentrations in wild-harvested insects in comparison to industrially-reared insects, however further research is required to further confirm these differences. The promise for wild-harvested insects to serve as a food of the future, requires further research to continuously improve the safety and sustainability of this potential food source. Research is also required on the value-added side to determine preparation practices that can improve the taste and the public's perception of edible insects.

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