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Comparison of Functional, Nutritional, and Sensory Properties of Spray-Dried and Oven-Dried Cricket (*Acheta domesticus*) Powder

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Master of Science

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ABSTRACT

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Three dried cricket products – Oven-roasted Cricket Meal (ORCM), Oven-roasted Cricket Powder (ORCP), and Spray-dried Cricket Powder (SDCP) – were prepared and compared to assess their relative nutritional, functional, and sensory properties. The range of particle sizes in SDCP was wider than that of ORCP; while SDCP had more particles in the 7.78-22.0 µm range, it also had more particles in the 176-498 µm range, which contributed to differences in functional and sensory properties. ORCM and SDCP meet the FDA definition of an “excellent source” of vitamin B_2, ORCP is a “good source” of vitamin B_2, and all three products are an “excellent source” of vitamin B_{12} and vitamin E at a serving size of 100 g. The addition of ORCP to a protein drink at 30% did not significantly affect its sensory acceptance, while the drink prepared with SDCP was rated significantly worse in every attribute, and the drink prepared with ORCM had varied effects on the different sensory attributes.

Keywords: cricket, *Acheta domesticus*, insect, entomophagy, powder, spray dry, roast, protein, fat, mineral, vitamin, fatty acid profile, lipid oxidation, viscosity, sedimentation, color, consumer acceptance

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Three dried cricket products – Oven-roasted Cricket Meal (ORCM), Oven-roasted Cricket Powder (ORCP), and Spray-dried Cricket Powder (SDCP) – were prepared and compared to assess their relative nutritional, functional, and sensory properties. The range of particle sizes in SDCP was wider than that of ORCP; while SDCP had more particles in the 7.78-22.0 μm range, it also had more particles in the 176-498 μm range, which contributed to differences in functional and sensory properties. ORCM and SDCP meet the FDA definition of an "excellent source" of vitamin B_2, ORCP is a "good source" of vitamin B_2, and all three products are an "excellent source" of vitamin B_{12} and vitamin E at a serving size of 100 g. The addition of ORCP to a protein drink at 30% did not significantly affect its sensory acceptance, while the drink prepared with SDCP was rated significantly worse in every attribute, and the drink prepared with ORCM had varied effects on the different sensory attributes.

INTRODUCTION

With the world population projected to reach 9 billion by 2050, finding a sustainable way to feed its inhabitants is becoming increasingly urgent (van Huis and others 2013). Discovering new ways to produce high quality protein is important now and in the near future, to combat undernutrition around the globe. While the thought of eating insects may be unappealing to many, entomophagy – the consumption of edible insects – could be an important part of addressing the need for sustainably-produced, nutrient-dense food. Insects in general require less land, water, and feed than cattle, pigs, or poultry, to provide an equivalent amount of edible mass, and produce fewer greenhouse gases in the process (Oonincx and others 2010; van Huis and others 2013). The house cricket (*Acheta domesticus*) is making inroads as a human food in the U.S. market. Crickets are a good source of high quality protein, providing the recommended amount or more of each essential amino acid/gram of protein, with the possible exception of methionine/cysteine. In addition, it is a good source of riboflavin, folic acid, vitamin B_{12}, tocopherols, and several minerals (Rumpold and Schlüter 2013). Crickets may be eaten whole, particularly as a novelty, but companies in the cricket business are hoping to increase their consumption by producing a variety of products from what they hope will be more versatile and acceptable commodities: cricket meal and cricket powder (Tan and others 2015).

There are two main manufacturing processes currently in use to produce cricket powder. The most common method involves grinding whole crickets to a coarse paste, followed by drying in an oven to make "cricket cake" and further particle size reduction in an industrial food processor. The product of this method will hereafter be referred to as oven-roasted cricket meal (ORCM). The major issue with ORCM is that particles – often exceeding 300 microns – are left intact because the chitinous cricket exoskeleton resists grinding. This is not a problem in products such as bars or some baked goods, in which such particles sizes are acceptable or even expected; but it can greatly reduce sensory acceptance in other products that require a smooth mouthfeel, such as beverages or puddings. In these products, particles as small as 100 microns may seem large or objectionable to the human tongue and oral palate, which is very sensitive to such particles.

Other processors have produced a finer cricket powder by wet-blending the cricket mass to form a slurry and partially removing the chitinous exoskeleton, followed by spray drying. This process results in a spray-dried cricket powder (SDCP) with very apparent differences in color, flavor, and textural properties from oven-roasted crickets, but these differences – along with any differences in nutritional quality – have never been reported in the literature. In addition, it is believed that, with the correct processing equipment, cricket cake could be ground to a smaller particle size than ORCM to produce an oven-roasted cricket powder (ORCP) with a particle size to match that of SDCP. The potential for significant differences in product attributes and sensory acceptance between these two different manufacturing processes merits further study.

This research aims to assess the relative feasibility of two cricket powder production methods (ORCP and SDCP), and to evaluate and compare the nutritional, functional, and sensory properties of the powders produced by each method and compare them to ORCM.

MATERIALS AND METHODS

Powder production and sampling

Crickets. In order to minimize the differences in the starting material, all crickets used in this study were raised in the same batch by a commercial cricket grower and processor. All crickets were euthanized with carbon dioxide prior to processing. Dry cricket cake, which was the starting material for ORCM and ORCP, was produced by grinding the euthanized crickets into a rough paste and roasting in an oven at 138°C for about an hour. The starting material for SDCP was whole frozen crickets, which were frozen following euthanization. Unless otherwise stated, all materials were stored and shipped at -20°C in polyethylene bags between and after processing steps. See Figure 1 for an outline of the production process.

Oven-roasted cricket meal (control). Two 12 kg batches of dry cricket cake were ground according to the commercial grower/processor's proprietary specifications in a Thermomix TM5 food processor (Vorwerk & Co. KG, Wuppertal, Germany) to produce two batches of ORCM.

Oven-roasted cricket powder. Two 12 kg batches of dry cricket cake were milled using a Pulvocron PCS-20 air-swept mill (Bepex International, Minneapolis, MN). Mill speed was set to 10,000 rpm, the classifier speed was set to 3,000 rpm, the airflow was set to 476 cubic meters/hour, the air intake temperature ranged between 12.2 and 17.2°C, and the cricket cake feed rate was set to 11.6 kg/hour.

Spray-dried cricket powder. Ninety-six kg of whole frozen crickets and 72 L tap water were made into a slurry with a Bepex Disintegrator RP-6-K115 hammer and screen mill (Minneapolis, MN) set to 10,400 rpm with a 152 μm screen. Following frozen shipping and storage, preliminary attempts to spray dry the slurry resulted in fat adhering to the sides of the drying chamber. To combat this, the slurry was heated to 60°C to allow for increased flow into the homogenizer (APV Gaulin, Inc. Model 15MR-8TBA Everett, MA) and homogenized (stage 1 pressure: 3.45 MPa, stage 2 pressure: 27.6 MPa), then stored at 4°C until spray drying. The homogenized slurry was spray dried over the course of eight days. The spray dryer (GEA Niro, (Copenhagen, Denmark) Mobile Minor laboratory-scale) was equipped with a centrifugal disk wheel-type atomizer set at 4.2 kg/cm^2, the inlet temperature was 155-167°C, and the outlet temperature was 53-82°C. The powder from each day of spray drying was collected in sealable polyethylene bags. When all the slurry had been spray dried, in order to have enough powder for all the necessary analyses and keep the replication pattern consistent across treatments, the daily batches of powder were combined into two comingled batches by placing them in pairs chronologically (day 1 with day 2, day 3 with day 4, etc.) and randomly assigning the bags from each pair to one comingled batch or the other.

Sampling. See Figure 2 for an outline of the sampling process. Prior to sampling, each batch of meal or powder was placed in a 115 L drum lined with a polyethylene bag. The drum was alternatingly rotated and inverted for 15 minutes to homogenize. Ten 20 g portions were taken from different regions of the mixed powder or meal and placed in a resealable polyethylene bag to create a composite, then shaken for 5 minutes to mix. Three such composites were made from each batch of powder or meal. Nutritional and color analyses were performed on samples taken from these composites.

Protein drink preparation. For sensory, viscosity, and sedimentation rate analyses, a protein drink was prepared by combining a portion of the remaining powder or meal with a proprietary commercial vanilla-flavored plant protein blend, formulated for use with cricket powder in a 30:70 ratio, followed by mixing with chilled (4°C) distilled water in a 10:90 ratio immediately prior to analysis.

Functional Analyses

Particle size distribution. The particle size distribution of the ORCP and SDCP was determined by an external analytical lab using a Microtrac Analyzer (Microtrac GmbH, Krefeld, Germany).

Color. The color of the cricket products was determined using a Hunter colorimeter (HunterLab Colorflex, Reston, VA) with CIELAB coordinates (L*, a*, b*). In the CIELAB color space, L* represents lightness, from black (0) to white (100), positive a* values represent red, negative a* values represent green, positive b* values represent yellow, and negative b* values represent blue.

Sedimentation. The sedimentation behavior of the protein drink was analyzed by filling 100-mL glass graduated cylinder to volume with the protein drink, then recording the volume (mL) of the sedimented layer every 30 seconds for 10 minutes at 4°C.

Viscosity. The viscosity of the protein drink was measured using a Brookfield Model DV1 viscometer (AMETEK, Inc., Berwyn, PA) fit with an LV-1 spindle at 30 rpm. The temperature of the protein drink was 4°C.

Proximate Analysis

Moisture determination. Moisture content was determined on a wet weight basis by AOAC Official Method 925.10.

Protein determination. Protein content was determined on a dry weight basis by an external analytical lab, using AOAC Official Method 992.15.

Fat determination. Fat content was determined on a dry weight basis by AACC Official Method 30-25.01.

Ash determination. Ash content was determined on a dry weight basis by an external analytical lab, using AOAC Official Method 923.03.

Carbohydrate determination. Carbohydrate content was determined by difference.

Lipids Analysis

Fatty acid profile analysis. Fatty acid profile of ORCM was determined by the method of Christopherson and Glass (1969). The fatty acid profile of the two cricket powders was not analyzed because it was assumed that the fatty acid profile would not be prone to changing with the different treatments.

Conjugated dienes determination. Conjugated dienes content was determined on a lipid weight basis by AOCS Official Method Ti 1a-64.

Fiber Determination

Neutral detergent fiber. Neutral detergent fiber content was determined on a dry weight basis by an external analytical lab using ANKOM Technology Method 13 (2017).

Soluble fiber. Soluble fiber content was determined on a dry weight basis by an external analytical lab, using AOAC Official Method 991.43 with modifications.

Vitamin Analysis

Riboflavin. Vitamin B_2 (riboflavin) content was determined on a dry weight basis by the method of Arella and others (1996) with modifications. Due to the high protein and low starch content of the cricket products, the amylase and takadiastase digestion was replaced with a protease digestion. Duplicate 5 g samples of powder were dispersed in 50 mL 0.1 M HCl in a 250-mL Erlenmeyer flask and autoclaved at 120°C for 30 minutes. After cooling to room temperature, the pH of the samples was adjusted to 4.5 with 2.5 M sodium acetate, then to 6.0 with 15% NaOH. Proteolysis was performed by adding 0.2 g papain and incubating at 37°C for 3 hours. 50% HCl was added to adjust pH to 4.5, and the solution was filtered through Whatman 541 filter paper under vacuum into a 250-mL Buchner flask, rinsing the Erlenmeyer flask and filter paper three times each with 10 mL distilled water. The filtrate was transferred, and the Buchner flask was rinsed three times with 10 mL distilled water into a 200 mL volumetric flask, which was then filled to volume with distilled water. A 2 mL aliquot was filtered through a cellulose acetate microfilter into a glass, amber-colored autosampler vial for chromatographic quantification.

Separation by reversed-phase HPLC was accomplished with an octodecylsilyl stationary phase (4 mm i.d. × 250 mm; 10 µm particle size) isocratically with a mobile phase consisting of methanol-0.05 M sodium acetate (30:70 v/v). The separation was performed at ambient temperature and a flow rate of 1 ml/min. The fluorometric detector operated at an excitation wavelength of 422 nm and at an emission wavelength of 522 nm. Data were quantified using external calibration.

Folic acid. Vitamin B_9 (folic acid) content was determined on a dry weight basis by an external analytical lab, using AOAC Official Method 992.05.

Vitamin B_{12}. Vitamin B_{12} content was determined on a dry weight basis by an external analytical lab, using AOAC Official Method 952.20.

Tocopherols. Preliminary analysis of the cricket products analyzed for α-, β-, γ-, and δ-tocopherol, but only α- and γ-tocopherol were detected. The determination of α- and γ-tocopherol (both components of vitamin E) on a dry weight basis was carried out by extracting the lipid portion of the cricket products in petroleum ether (35-60°C b.p.) containing 0.2% BHT in a Soxhlet apparatus for four hours at 5-6 drops/second. The lipid fraction was then washed twice with a 20% NaCl solution, dried with anhydrous Na_2SO_4, and diluted to 10 mL in iso-octane containing 0.2% BHT, after which a 2 mL aliquot was filtered through a cellulose acetate microfilter into a glass, amber-colored autosampler vial for chromatographic quantification.

The sample was then separated by reverse phase HPLC and α- and γ-tocopherol were detected by fluorescence (excitation: 280 nm, emission: 310 nm).

Mineral Analysis

Sodium, magnesium, phosphorus, potassium, calcium, manganese, iron, copper, and zinc were measured on a dry weight basis by an external analytical lab, using nitric acid-hydrogen peroxide microwave digestion (Milestone, Shelton, CT, USA) followed by ICP-OES analysis (Thermo Electron, Madison, WI, USA).

Microbiological Safety Analysis

Prior to the consumer panel, samples of the dry mix used to prepare the protein drink were tested for *Salmonella*, aerobic plate count, general *E. coli*, and coliforms.

Sensory Analysis

The protein drinks were evaluated in a two-session consumer panel alongside a control drink made with the same vanilla-flavored plant protein blend, but no cricket product. Each of the two batches of ORCM, ORCP, and SDCP was randomly assigned to one of the two sessions, so that each type of protein drink presented in each session. The drinks were prepared immediately before serving to the panelist. Consumer testing was performed at the BYU Sensory Lab (Provo, UT), under Institutional Review Board approval, with panelists randomly selected from a database of university students, faculty, and other community members based on their willingness to try foods prepared with insects as an ingredient and an absence of allergenicity to it. Panelists were evenly distributed within gender and age groups (18 to 29, 30 to 39, 40 to 49, 50 to 59, and 60 years and older). Data were collected using Compusense *five*® software (Guelph, Ontario, Canada). Panelists were compensated monetarily for their time and effort.

For each panel, 1-oz (29.6 mL) samples of each treatment (three with cricket product and one control) served in 2-oz (59.1 mL) translucent plastic cups were presented on a tray, side-by-side with a napkin, an unsalted cracker, and a 5.5-oz (162.7 ml) translucent plastic cup with room temperature filtered water. Each panelist received samples in a randomized order and sample containers were labeled with 3-digit blinding codes. While completing the questionnaire, but before evaluating the samples, panelists were asked, "How do you feel about trying a protein drink containing cricket powder?" on a discrete 5-point scale (1 = highly negative, 3 = neither positive nor negative, 5 = highly positive). The panelists then read the following description:

> "The drinks you're about to evaluate contain cricket protein powder blended with plant proteins, fibers, and flavors to create a high-protein, nutrient-dense powder. It contains a balanced, complete amino acid profile and prebiotic fiber, and is free from the hormones and allergens found in some soy and whey."

After reading the description, panelists were asked to rate how their feelings about trying a protein drink containing ground crickets had changed, on a discrete 5-point scale (1 = definitely more negative, 3 = no different, 5 = definitely more positive).

Panelists were then asked to evaluate the products based on their overall, appearance, aroma, flavor, and mouthfeel acceptability. These characteristics were evaluated using a discrete

9-point hedonic scale including a corresponding numerical value 1 (dislike extremely) to 9 (like extremely). Panelists were instructed to take a bite of unsalted cracker and a sip of room temperature filtered water between samples to refresh their sense of taste. After evaluating mouthfeel, panelists were asked to rate the level of grittiness of each sample on a non-discrete 100-point scale from 1 (not detectable) to 100 (extremely prevalent) to quantify any differences in each powder's suitability in a drink application with greater specificity. After tasting and evaluating the products, panelists were asked to rate how their feelings about a protein drink containing cricket powder had changed on a discrete 5-point scale (1 = definitely more negative, 3 = no different, 5 = definitely more positive). Panelists were also asked to rate their likelihood to purchase each product if it were priced comparably to similar products where they normally buy protein drinks on a discrete 9-point scale (1 = extremely unlike, 9 = extremely likely). Finally, as the last question for each product, panelists were asked to rank the products in order of preference.

Statistical Analysis

Where averages are reports, the results are given as mean ± SEM. Data were analyzed for significance using Statistical Analysis Software version 9.3 (Cary, North Carolina). Values for proximate composition data, insoluble fiber, minerals, vitamins, conjugated dienes, color, sedimentation rate, and particle size distribution were analyzed by one-way ANOVA, followed by a Tukey all pair-wise comparison to determine which powders were different from each other for each attribute. Due to the presence of several values below the limit of detection for soluble fiber, a Kruskal-Wallis test was used to determine whether there were any significant differences between treatments. The average numerical score for each sample attribute from both sessions of the consumer panel was calculated, and the results were analyzed to rule out session, gender, age, and attitude about trying insect food products as confounding variables. Sensory attributes were then analyzed by one-way ANOVA, followed by a Tukey-Kramer adjustment for all pair-wise comparisons. The significance level for all statistical analyses was set at $\alpha=0.05$.

RESULTS AND DISCUSSION

Functional Properties

Particle Size Distribution. The particle size distributions of ORCP and SDCP are shown in Figure 3. One objective of this research was to produce an oven-roasted powder with a similar particle size to that of SDCP. However, while the range of particle sizes between the two powders was similar, the particle size distribution of SDCP was bimodal, while that of ORCP was unimodal. SDCP had a larger proportion of particles smaller than 26 µm than ORCP, but it also had a larger proportion of particles larger than 176 µm. Since the human palate can recognize particles as small as 100 µm as gritty, based on their respective particle size distributions, ORCP is more suitable for use in beverages and other applications requiring a smooth mouthfeel than SDCP.

Color. CIELAB color values for all three cricket products are shown in Table 1. ORCM is a coarse meal with a dark- to medium-brown color, ORCP is a fine powder with an intense reddish-brown color, and SDCP is a fine powder with a pale grayish-brown color. The lighter, less colorful appearance of the SDCP compared to ORCM and ORCP, corresponding with a higher L* value and lower a* and b* values, can be explained by the lack of an oven roasting step that would promote non-enzymatic browning, which would in turn produce darker, redder, and yellower colors. The brighter color of ORCP compared to ORCM, corresponding with higher L*, a*, and b* values, appears to be due to the difference in particle size. Powders with smaller particle sizes generally have higher L* values due to increased light scattering capacity (Ahmed and others 2015). The increase in a* and b* values with the smaller particle size could be a result of the same effect.

Viscosity. Viscosity values for the protein drinks prepared with the three cricket products can be found in Table 1. In general, the viscosity of a beverage helps to prevent sedimentation of larger particles and can affect how gritty particles of a given size are perceived. However, due to the formulation of the commercial plant protein blend, none of the protein drinks were very viscous. Still, differences in viscosity were observed between the protein drink prepared with the different cricket products. The protein drink prepared with ORCM had a lower viscosity than the drinks prepared with ORCP and SDCP, which can most likely be attributed to the large particle size. As a smaller fraction of the product can be colloidally dispersed – or even suspended – its effect on viscosity is lessened. The protein drink prepared with SDCP had a lower viscosity than that prepared with ORCP. This may be due in part to the larger fraction of particles larger than 176 μm, and another possible explanation will be discussed with later on.

Sedimentation Rate. The volume of sedimentation over time in the protein drinks prepared with the three cricket products can be found in Figure 4. In general, suspensions with larger particles and lower viscosity will undergo faster sedimentation. As expected, the drink prepared with ORCM had more sediment than the drinks prepared with the other two powders, due to ORCM's larger particle size and the drink's lower viscosity. However, despite SDCP having more particles larger than 176 μm than ORCP, the protein drink prepared with SDCP had less sedimentation. This difference in sedimentation could be due the fact that the slurry was homogenized prior to spray drying, which could have stabilized the less soluble portions of the powder by producing a larger number of small colloidal particles that remained in suspension.

Proximate Analysis

The proximate composition of the three cricket products is shown in Table 2.

Moisture. Because they underwent identical direct heat treatment, the lack of significant difference in moisture content between ORCM and ORCP is expected. The significantly higher moisture content in SDCP compared to the other two products likely indicates that the spray drying process could be further optimized for producing cricket powder, since other products, like skim milk (Botros and others 2013), whole milk (Kim and others 2009), and chicken meat (Kurozawa and others 2009) can be spray dried to moisture levels of 1-4%. Some of the advantages of a lower moisture product include reduced clumping, increased stability against microbiological and oxidative degradation, and reduced browning over time. Further research would be beneficial to discovering if a lower moisture content could be reached through spray drying by raising the temperature in the spray dryer, lowering the flow rate of slurry into the atomizer, and/or reducing the initial moisture content of the slurry.

Fat. The difference in fat content between ORCM and ORCP can be explained by the fatty deposit that built up inside the mill during the milling step of the ORCP production. The build-up was significant and required periodical stops to the milling process to remove it to maintain the mill's efficiency. It is likely that the decrease in fat content was due to the removal of this fatty deposit.

The difference in fat content between the SDCP and the other two products was not expected. There was no obvious significant removal of fat at any point during the production of the SDCP. Whatever the reason for it, the difference in fat content between ORCP and SDCP is likely responsible for the difference in viscosity in the protein drinks prepared with those two powders. Alcantara and others (2012) and Kaushik and others (2015) observed that higher fat content results in higher viscosity in cow and buffalo milk.

Protein. There was no difference in protein content between ORCP and SDCP. However, the protein content of ORCM was significantly lower than that of both ORCP and SDCP. Given the decrease in fat content between in ORCP and SDCP compared to ORCM, a relative increase in other components would be expected. Since protein content is higher than that of any other constituent in all of the products, it is not surprising that that increase would be most marked for protein content.

Ash. There were no significant differences in ash content between the three cricket products.

Carbohydrate. There were no differences in carbohydrate content between the three cricket products.

Lipids

Fatty Acid Profile. The fatty acid profile of ORCM is reported in Table 3. Compared to beef or pork fat, the fat from ORCM has less monounsaturated fat and more polyunsaturated fat; compared to chicken fat, ORCM fat has more saturated fat, less monounsaturated fat, and more polyunsaturated fat (Damodaran and others 2007a).

Conjugated Dienes. Conjugated dienes content of the three cricket products is reported on a fat weight basis in Table 2. There was no significant difference in conjugated dienes content between ORCM and ORCP, but that of SDCP was over ten times greater. This could be explained by the extended time between disruption of the cricket cells and any heat treatment that could inactivate lipoxygenase enzymes. Even though the slurry was frozen for most of the time after it was produced, there was still time to start the autoxidation process before it was heated, homogenized, and spray dried. Further, once the autoxidation process had started, the heat applied before homogenization and during spray drying, along with the increased exposure to oxygen during atomization, likely accelerated it. This could be prevented in future process optimizations by pasteurizing, homogenizing, and spray drying the slurry immediately following its production, or by adding a heat treatment step to blanch the crickets prior to slurry production.

Fiber

The neutral detergent fiber content of the three cricket products is shown in Table 2. There was no difference in neutral detergent fiber content between ORCP and SDCP, but ORCM had more neutral detergent fiber than either of the other two products. However, since the particle size of ORCM is so much larger than that of the two powders, and the method of analysis for fiber relies on digestion, filtration, and gravimetric quantification, it is possible that the difference was due to incomplete digestion and excessive retention on the filter.

Several values for soluble fiber were below the limit of detection (0.75%), so reliable estimates of the mean could not be obtained for any of the products. However, when analyzed with a Kruskal-Wallis test, there was no significant difference between treatments (p=0.322).

Vitamins

The riboflavin, folic acid, vitamin B_{12}, α-tocopherol, and γ-tocopherol content of the three cricket products is reported in Table 4.

Riboflavin. SDCP had the highest riboflavin content of all the powders, which suggests that the heat treatment applied to it was less harsh than the oven roasting process used to dry the cricket cake in preparation to make ORCM and ORCP. Further, ORCM had a higher riboflavin content than ORCP. Because riboflavin degradation is primarily photochemical (Damodaran and others 2007b), it is possible that the increased exposure to light due to the smaller particle size of ORCP is responsible for this difference in riboflavin content, but this difference is probably not practically significant. A 100 g serving of any of these products has >20% of the RDA for riboflavin (with 100 g SDCP providing 88% of the RDA), meaning that it would meet the FDA requirements for an excellent source of riboflavin.

Folic Acid. There was no significant difference in folic acid content between any of the powders. All three products provide >40% of the RDA for folic acid in a 100 g serving, well above the 20% threshold required by the FDA for an excellent source of folic acid.

Vitamin B_{12}. SDCP had a significantly higher vitamin B_{12} content than the other two products, and ORCP had a significantly higher vitamin B_{12} content than ORCM. Vitamin B_{12} is produced exclusively by microorganisms (Damodaran and others 2007c), and animal products are the main source of vitamin B_{12} in the human diet, as it is virtually nonexistent in plant foods. At 1332% (SDCP), 821% (ORCP), and 767% (ORCM) of the RDA of vitamin B_{12} in a 100g serving, any of these products far exceed the 20% RDA requirement set by the FDA for an excellent source of vitamin B_{12}. In fact, the full RDA of vitamin B_{12} could be obtained by consuming just 7.51 g of SDCP, 12.17 g of ORCP, or 13.04 g of ORCM. This is a major advantage of dry cricket products as a source of protein over plant sources of protein. The large difference between SDCP and the oven-roasted products could be the result of the spray-drying heat treatment being less harsh than the oven-roasting treatment. The difference between ORCP and ORCM, which statistically significant, is probably not practically significant because it is <10%, especially considering how high the vitamin B_{12} content is in both products.

Tocopherols. There was no significant difference in α-tocopherol content between ORCM and SDCP. However, those two products did have different γ-tocopherol levels, with the γ-tocopherol content of ORCM being significantly lower than that of SDCP. Two factors increase the significance of this finding: that tocopherols are fat soluble; while SDCP has a lower fat content than ORCM; and that SDCP had a much higher conjugated dienes content, while the primary function of tocopherols is as an antioxidant. This could be explained by noting that vitamin E acts primarily as a peroxyl radical scavenger (Traber and Atkinson 2007), and peroxyl radicals form later in the autoxidation process than conjugated dienes. A 100 g serving of SDCP meets the FDA requirement of 20% of the RDA for an excellent source of vitamin E, while the same serving of ORCM would fall just below the 20% RDA threshold and qualify as a good source of vitamin E (>10% RDA).

Compared to ORCM and SDCP, ORCP had significantly lower α-tocopherol and γ-tocopherol content. This may be due to increased heat from friction during the milling process used to produce ORCP, but that is likely compounded by the fact that fat was removed as a build-up inside the mill during ORCP production. Because vitamin E is fat soluble it is likely that it was removed from the ORCP along with that fatty deposit. At just over 10% of the RDA, a 100 g serving of ORCP would meet the FDA requirement a good source of vitamin E.

Minerals

The mineral content of the three dried cricket products is shown in Table 5. SDCP had more of every mineral reported than ORCM or ORCP. However, because the cricket slurry wouldn't pass through the screen of the hammer mill used to make it without added water, and because distilled water was not available where the cricket slurry was made, tap water was added to the slurry. Since any and all of the differences in mineral content could be due to the addition of tap water, nothing can be concluded on the mineral content of SDCP.

Compared to ORCM, ORCP had higher sodium, potassium, manganese, and iron content. Iron and manganese are both components of stainless steel (Verhoeven 2007), so the increase in those two minerals between ORCM and ORCP is expected, given the extra milling step in ORCP production. The other two minerals that are significantly different between ORCM and ORCP are sodium and potassium, but the increase (7.6% and 3.1%, respectively) is small enough that it probably isn't practically significant. There was no significant difference in the amount of any other minerals analyzed between ORCM and ORCP.

Microbiological Safety

The results of the microbiological safety analyses are shown in Table 6. All three products were determined to be safe for human consumption for the consumer panel.

Sensory Analysis

Consumer acceptance. Overall, appearance, aroma, flavor, and mouthfeel acceptance data are reported in Figure 5. Overall, the No Cricket drink and the ORCP drink were not rated significantly differently. The SDCP drink was liked least overall, and the ORCM drink was liked more than the SDCP drink but less than the other two drinks.

There was no difference in how much the panelists liked the appearance of the No Cricket drink and the ORCP drink, on average. The panelists like the SDCP drink less than those two drinks, and the ORCM drink least of all. Several panelists left comments about the large particulates in the ORCM being visible as "floaties," and some said that the SDCP drink had a gray hue that they found unattractive.

There was no difference between the No Cricket drink, the ORCM drink, and the ORCP in how much the panelists liked their aroma, and the aroma of the SDCP drink was liked less than the aroma of any of the others. Prior to heating, homogenizing, and spray drying, the cricket slurry used to make the SDCP had a fishy odor – probably due to lipid and protein oxidation – that persisted into the final product. This significantly impacted the aroma acceptance of the SDCP drink, but steps to reduce lipid oxidation (like pasteurizing the crickets before making a slurry or homogenizing and spray drying immediately after making the slurry) could reduce the formation of these odors.

There was no difference in flavor liking between the No Cricket drink and the ORCP drink or between the ORCP drink and the ORCM drink. This does not only indicate that the flavor of oven-roasted crickets did not lower the consumer acceptance of the protein drink, but also that the reduction in particle size between ORCM and ORCP did not affect how much the panelists liked its flavor. The flavor of the SDCP drink was liked least of all, due to off flavors that developed along with the off odors previously discussed.

There was no significant difference in how much the panelists like the mouthfeel of the No Cricket drink and the ORCP drink. The mouthfeel acceptance of the SDCP drink and the ORCM drink were liked less than the other two drinks, which is expected due to the greater number of larger particles in each of those products.

In summary, the ORCP drink was not rated differently in any acceptance attribute than the No Cricket drink, while the ORCM drink received the worst ratings in appearance and mouthfeel acceptance and the SDCP drink received the worst ratings in overall, aroma, and flavor acceptance. It was expected for the differences between ORCP and ORCM to be the physical attributes, due to their similar preparation but drastically different particle sizes, while the differences between ORCP and SDCP are primarily aroma and flavor, due to the off odor and off flavor development in the slurry, but more similar particle sizes between the two powders. It is worth noting that even the No Cricket drink did not score significantly higher than 6 (like slightly) in any of the above attributes, which may have affected the ability to detect a difference between it and any of the drinks with cricket powder. Further research using a more acceptable base formulation could potentially find a difference that was not detectable in this test.

Purchase Likelihood. The purchase likelihood results are shown in Figure 5. There was no difference in purchase likelihood between the No Cricket drink and the ORCP drink. The SDCP drink had to lowest purchase likelihood, and the ORCM drink came in between. These results mirror those of overall acceptance.

Preference Ranking. On average, there was no difference in how the No Cricket drink and the ORCP drink were ranked. This mirrors the lack of difference between the No Cricket drink and the ORCP drink in any of the attributes discussed so far. The ORCM drink was ranked third on average, and the SDCP drink was ranked last. This also mirrors the overall acceptance of the four drinks relative to each other.

Grittiness. The ORCM drink was rated the grittiest of the four drinks by a large margin, with a difference of 40 points (out of 100) between the ORCM drink and the SDCP drink. There was a smaller, but statistically significant, difference of 8 points between the SDCP drink and the ORCP drink. The difference between the grittiness scores of the ORCP drink and the No Cricket drink was not statistically significant. The grittiness scores mirror the mouthfeel acceptance ratings of the four drinks, which also mirror the differences in particle size distribution between the three dried cricket products.

Cricket Protein Drink Attitude. Before reading a product description or tasting any of the drinks, the average attitude toward a protein drink containing cricket powder was 3.833 (somewhat positive). After reading a description, the average change in attitude was 4.177 (somewhat more positive). After tasting the products, the average change in attitude was 3.128 (no change). This indicates that, even though their attitude toward a cricket-containing protein drink was somewhat positive, learning more about cricket powder improved the panelists' attitude toward protein drinks made with cricket powder. It also shows that tasting the four drinks did not worsen that attitude.

CONCLUSION

ORCM is a coarse, dark- to medium-brown meal that is an excellent source of riboflavin, folic acid, and vitamin B_{12} and a good source of vitamin E. However, it contains particles too large to be added to a beverage without detrimental effects on consumer acceptance. The fatty acid profile of ORCP is similar to beef or pork, but with less MUFA and more PUFA.

ORCP is a fine, medium-brown powder, and an excellent source of riboflavin, folic acid, and vitamin B_{12} and a good source of vitamin E. It can be added to beverage applications without negative effects on the beverage's consumer acceptance due to its fine particle size and relatively neutral flavor. Further process optimization could reduce the formation of the fatty buildup inside the mill seen during ORCP production.

SDCP is a fine, brownish-gray powder, and an excellent source of riboflavin, folic acid, and vitamin B_{12}, and vitamin E. Adding it to a beverage produces a grittier mouthfeel than ORCP, and fishy off odors and flavors developed in the slurry prior to homogenizing and spray drying. Further work could minimize or reduce these odors and flavors by pasteurizing the crickets before making the slurry, or by pasteurizing, homogenizing, and spray drying immediately after making the slurry.

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TABLES

Table 1: CIELAB Color Values and Viscosity of Oven-roasted Cricket Meal (ORCM), Oven-roasted Cricket Powder (ORCP), and Spray-dried Cricket Powder (SDCP). (Color, n = 6; Viscosity, n = 4)

	Color (L*)	Color (a*)	Color (b*)	Viscosity (mPa·s)
ORCM	34.68 ± 0.71 c	10.58 ± 0.14 b	19.72 ± 0.37 b	7.38 ± 0.37 c
ORCP	52.15 ± 0.71 b	11.61 ± 0.14 a	29.18 ± 0.37 a	10.38 ± 0.37 a
SDCP	59.42 ± 0.71 a	6.69 ± 0.14 c	16.51 ± 0.37 c	8.75 ± 0.37 b

Values with like letters within each column are not significantly different from one another ($\alpha > 0.05$).

Table 2: Proximate Composition of Oven-roasted Cricket Meal (ORCM), Oven-roasted Cricket Powder (ORCP), and Spray-dried Cricket Powder (SDCP). (n = 6)

	Moisture (wet weight basis)	Protein (dry weight basis)	Fat (dry weight basis)	Ash (dry weight basis)	Carbohydrate (dry weight basis)	Conjugated Dienes (fat weight basis)	Neutral Detergent Fiber (dry weight basis)
ORCM	2.30 ± 0.38% b	65.87 ± 0.16% b	17.70 ± 0.15% a	6.44 ± 0.70% a	9.99 ± 0.73% a	0.47 ± 0.07% b	15.99 ± 0.52% a
ORCP	2.58 ± 0.38% b	67.21 ± 0.16% a	15.40 ± 0.15% b	5.25 ± 0.70% a	12.14 ± 0.73% a	0.44 ± 0.07% b	11.53 ± 0.52% b
SDCP	7.53 ± 0.38% a	67.72 ± 0.16% a	13.04 ± 0.15% c	7.78 ± 0.70% a	11.46 ± 0.73% a	4.72 ± 0.07% a	11.37 ± 0.52% b

Values with like letters within each column are not significantly different from one another ($\alpha > 0.05$).

Table 3: Fatty acid profile of Oven-roasted Cricket Meal (ORCM). (n = 4)

	12:0	14:0	16:0	16:1	17:0	18:0	18:1	18:2	18:3	20:0	20:1
Peak Area (%)	0.1 ± 0.0	0.6 ± 0.0	26.0 ± 0.5	0.6 ± 0.0	0.2 ± 0.0	11.5 ± 0.2	23.4 ± 0.5	34.1 ± 0.7	0.7 ± 0.0	2.7 ± 0.1	0.0 ± 0.0

	Total Saturated Fatty Acids	Total Monounsaturated Fatty Acids	Total Polyunsaturated Fatty Acids
Peak Area (%)	41.2 ± 0.4	24.0 ± 0.3	34.8 ± 0.4

Table 4: Vitamin B2, B9, B12, and E Content of Oven-roasted Cricket Meal (ORCM), Oven-roasted Cricket Powder (ORCP), and Spray-dried Cricket Powder (SDCP). (n = 6)

	Riboflavin (ppm)	Folic Acid (ppm)	Vitamin B12 (ppm)	α-tocopherol (ppm)	γ-tocopherol (ppm)
ORCM	1.10 ± 0.01 b	1.92 ± 0.06 a	0.18 ± 0.003 c	2.49 ± 0.13 a	3.07 ± 0.10 b
ORCP	1.00 ± 0.01 c	1.86 ± 0.06 a	0.20 ± 0.003 b	1.38 ± 0.13 b	2.53 ± 0.10 c
SDCP	1.50 ± 0.01 a	1.72 ± 0.06 a	0.32 ± 0.003 a	2.73 ± 0.13 a	3.84 ± 0.10 a

Values with like letters within each column are not significantly different from one another ($\alpha > 0.05$).

Table 5: Mineral Content of Oven-roasted Cricket Meal (ORCM), Oven-roasted Cricket Powder (ORCP), and Spray-dried Cricket Powder (SDCP). (n = 6)

	Na (ppm)	Mg (ppm)	P (ppm)	K (ppm)	Ca (ppm)	Mn (ppm)	Fe (ppm)	Cu (ppm)	Zn (ppm)
ORCM	3373.81 ± 28.15 c	1168.82 ± 9.53 b	8649.62 ± 42.03 b	10961.82 ± 86.01 c	1664.31 ± 21.69 b	22.56 ± 0.22 c	48.93 ± 1.87 c	47.45 ± 0.57 b	138.47 ± 1.43 b
ORCP	3631.42 ± 28.15 b	1186.25 ± 9.53 b	8595.71 ± 42.03 b	11305.40 ± 86.01 b	1661.08 ± 21.69 b	24.14 ± 0.22 b	56.79 ± 1.87 b	46.56 ± 0.57 b	139.66 ± 1.43 b
SDCP	4021.44 ± 28.15 a	1358.33 ± 9.53 a	9332.09 ± 42.03 a	12565.99 ± 86.01 a	1939.43 ± 21.69 a	29.93 ± 0.22 a	70.62 ± 1.87 a	53.88 ± 0.57 a	160.33 ± 1.43 a

Values with like letters within each column are not significantly different from one another ($\alpha > 0.05$).

Table 6. Total Coliform, General *E. coli*, Aerobic Plate Count, and *Salmonella* Results of Oven-roasted Cricket Meal (ORCM), Oven-roasted Cricket Powder (ORCP), and Spray-dried Cricket Powder (SDCP). (n = 2)

	Total Coliform (CFU/g)	General *E. coli* (CFU/g)	Aerobic Plate Count (CFU/g)	*Salmonella*
ORCM	<10	<10	2350	NEG
ORCP	<10	<10	2116	NEG
SDCP	<10	<10	<10	NEG

FIGURES

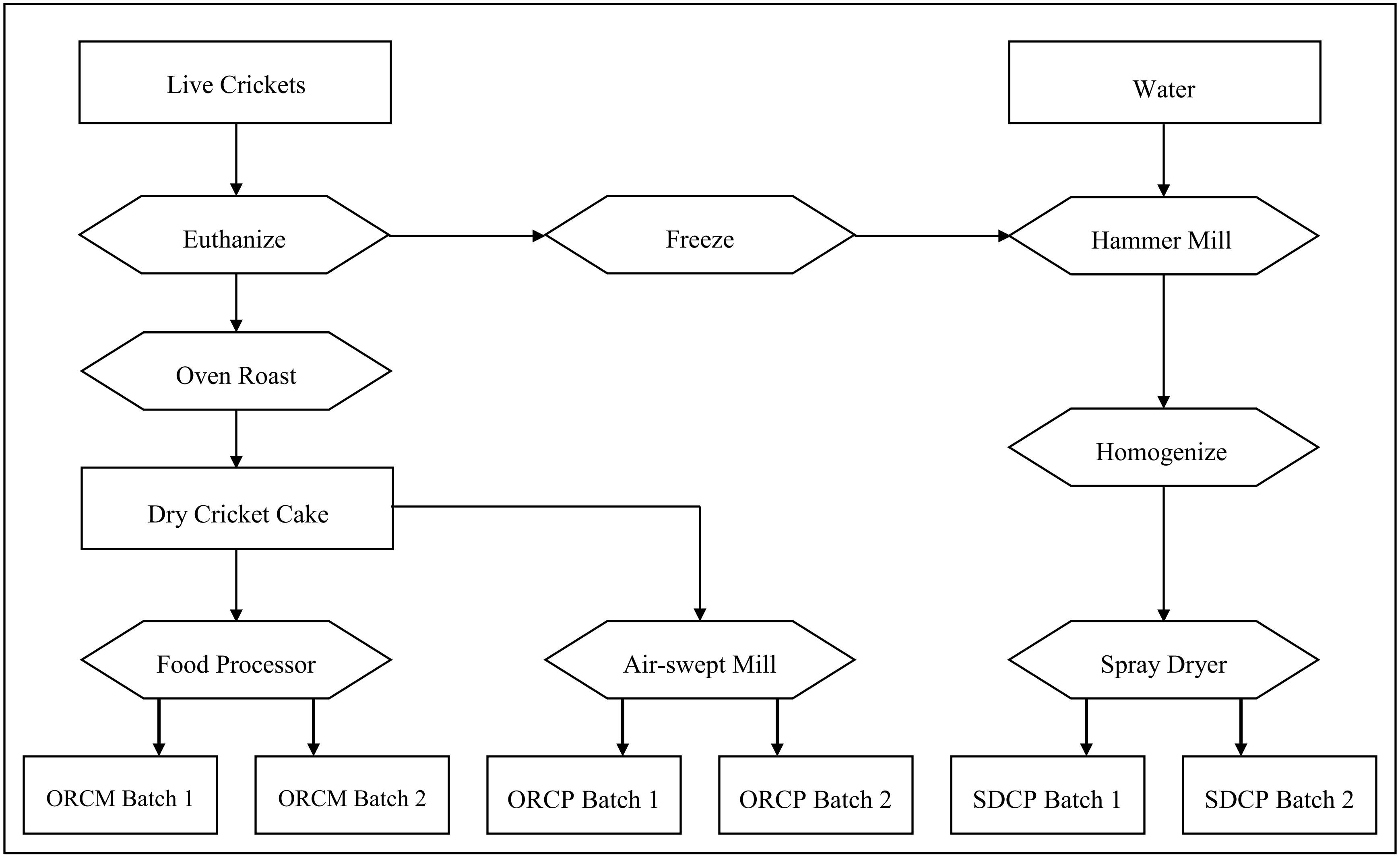

Figure 1: Powder Production Flow Outline

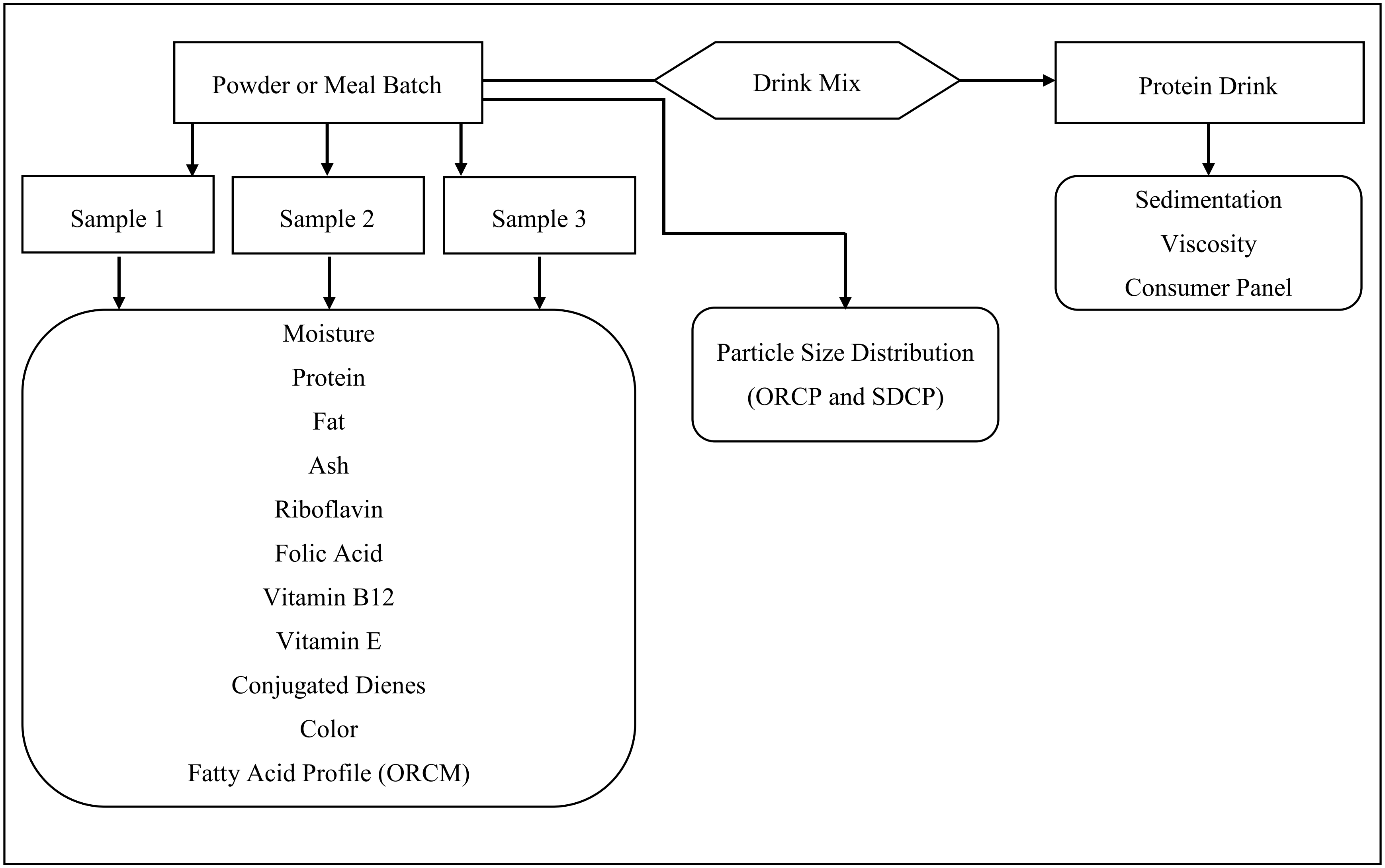

Figure 2: Sampling Outline for Each Batch of Cricket Powder

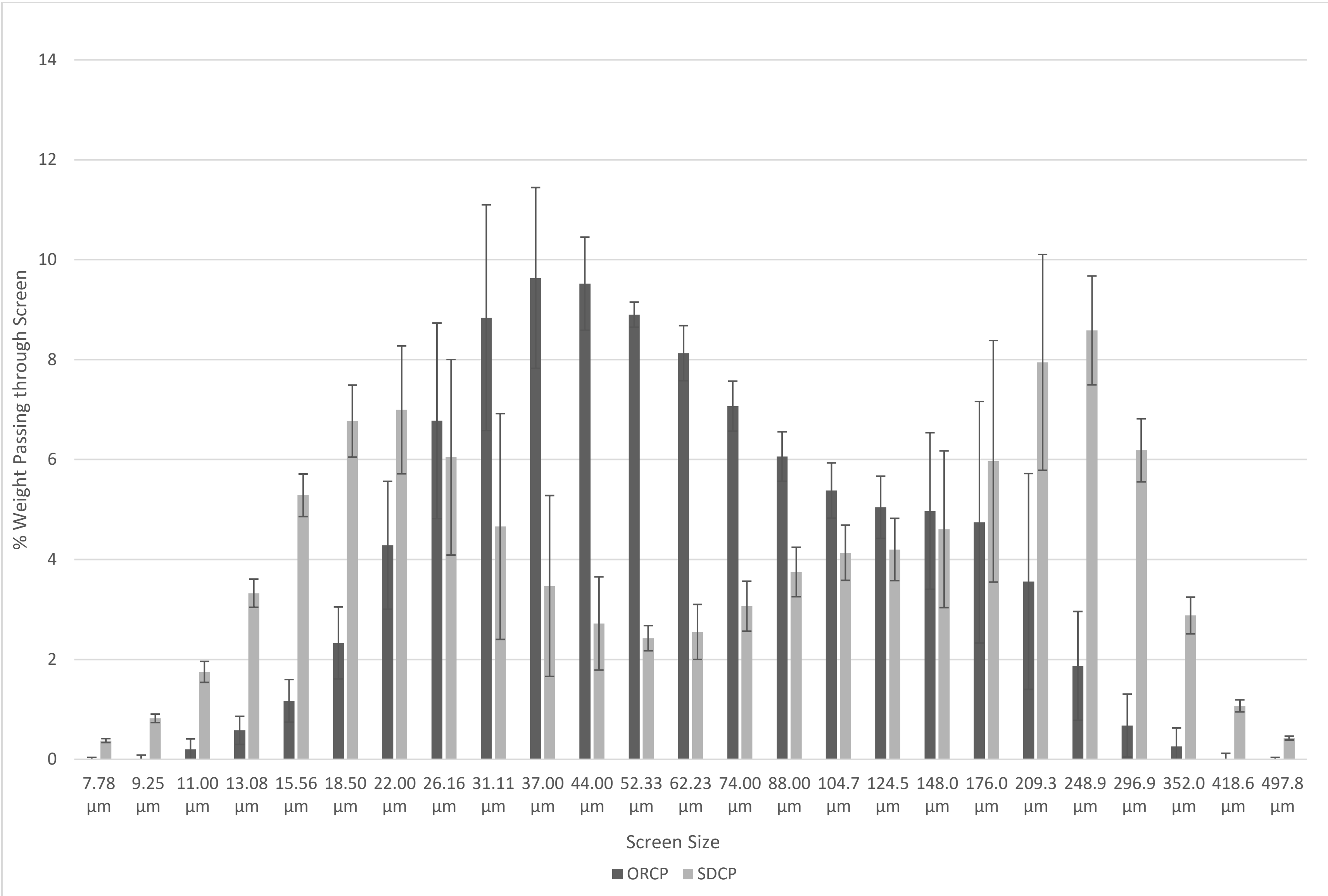

Figure 3: Particle Size Distribution of Oven-roasted Cricket Powder (ORCP) and Spray-dried Cricket Powder (SDCP). (n = 2)

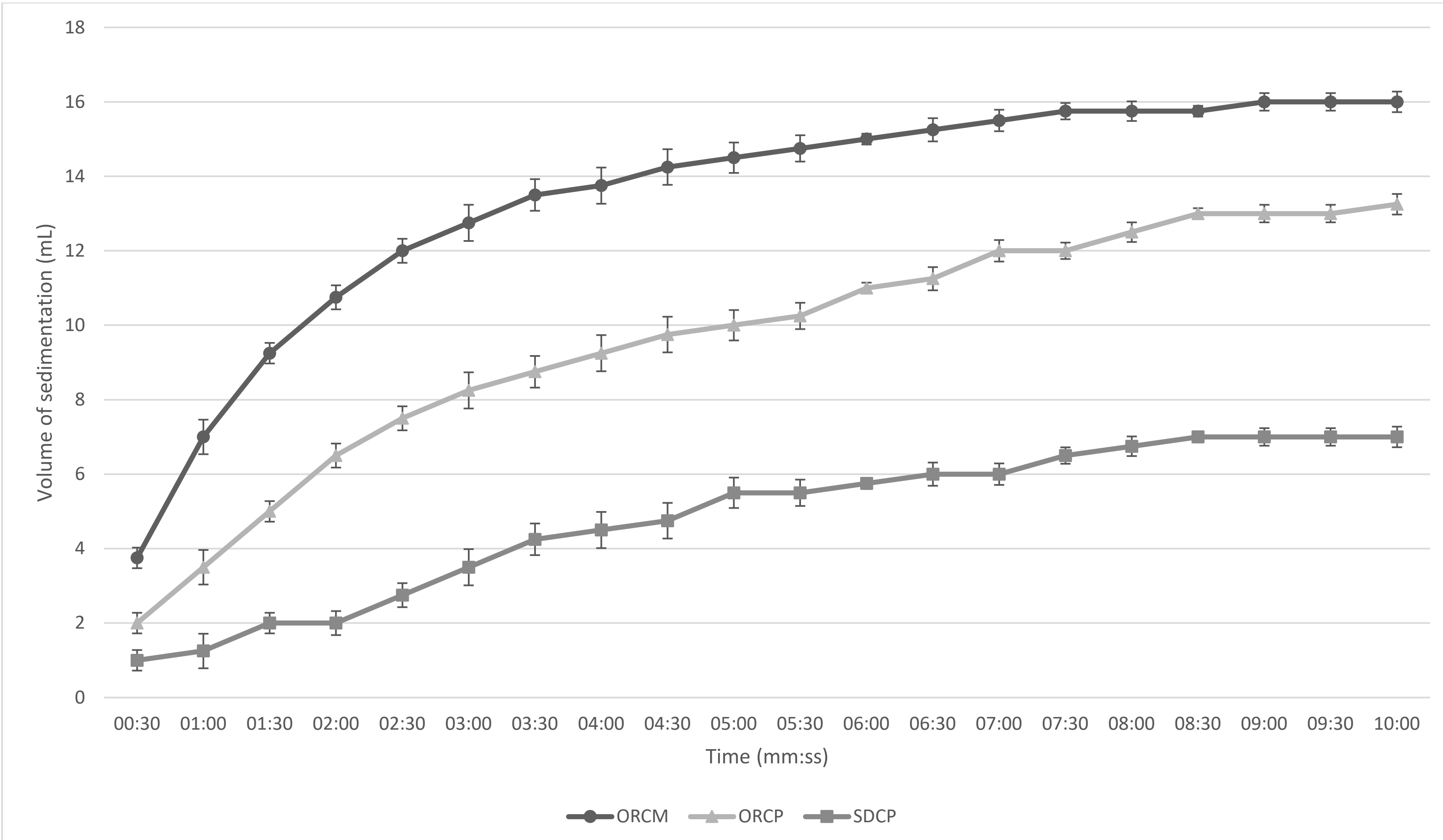

Figure 4: Sedimentation Over Time of Drinks Prepared with Oven-roasted Cricket Meal (ORCM), Oven-roasted Cricket Powder (ORCP), and Spray-dried Cricket Powder (SDCP). (n = 4)

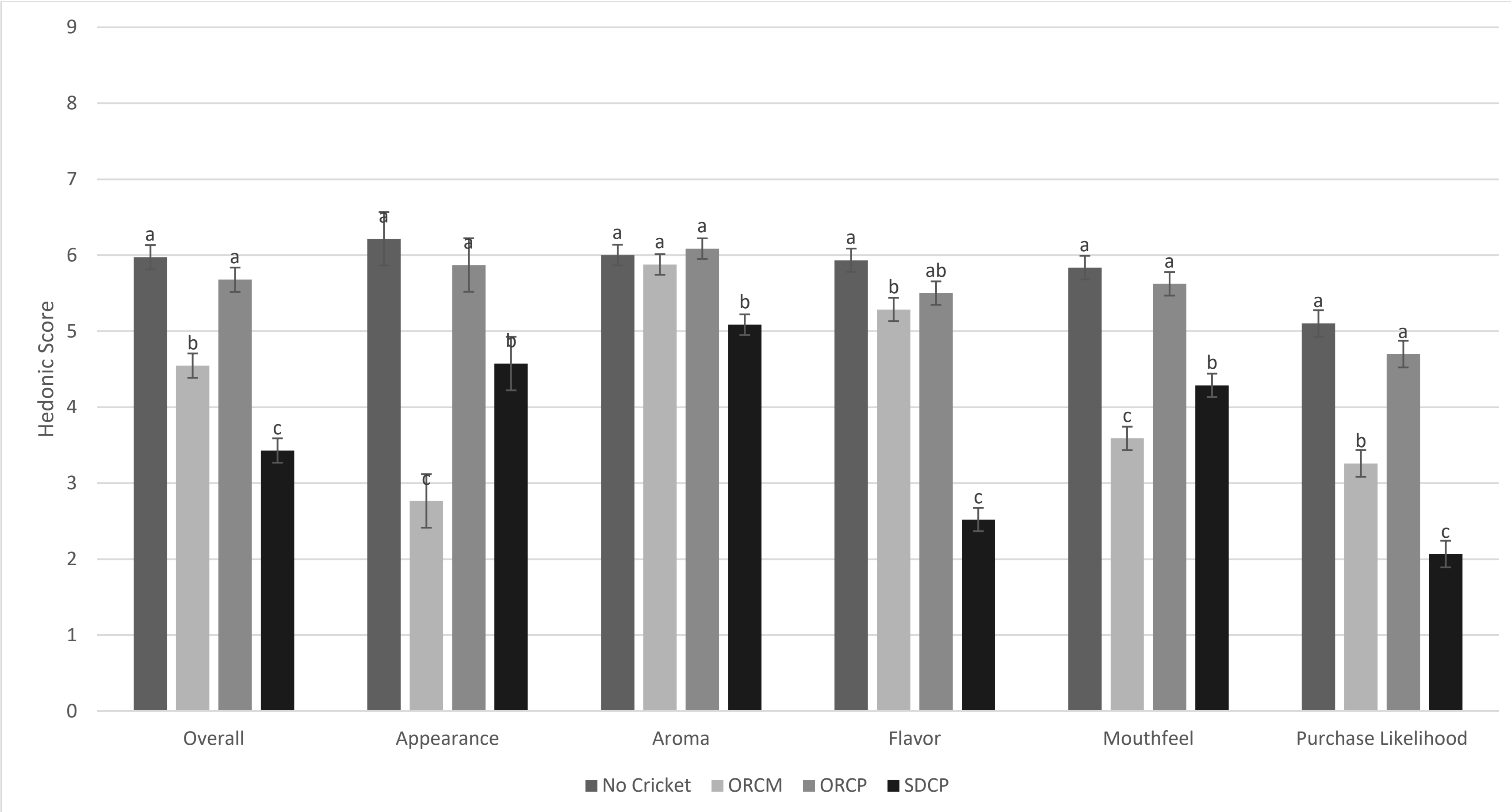

Figure 5: Overall, Appearance, Aroma, Flavor, and Mouthfeel Acceptance and Purchase Likelihood of Drinks Prepared with Oven-roasted Cricket Meal (ORCM), Oven-roasted Cricket Powder (ORCP), Spray-dried Cricket Powder (SDCP), and without Crickets. (n = 203)

Values with like letters within each cluster are not significantly different from one another ($\alpha > 0.05$).

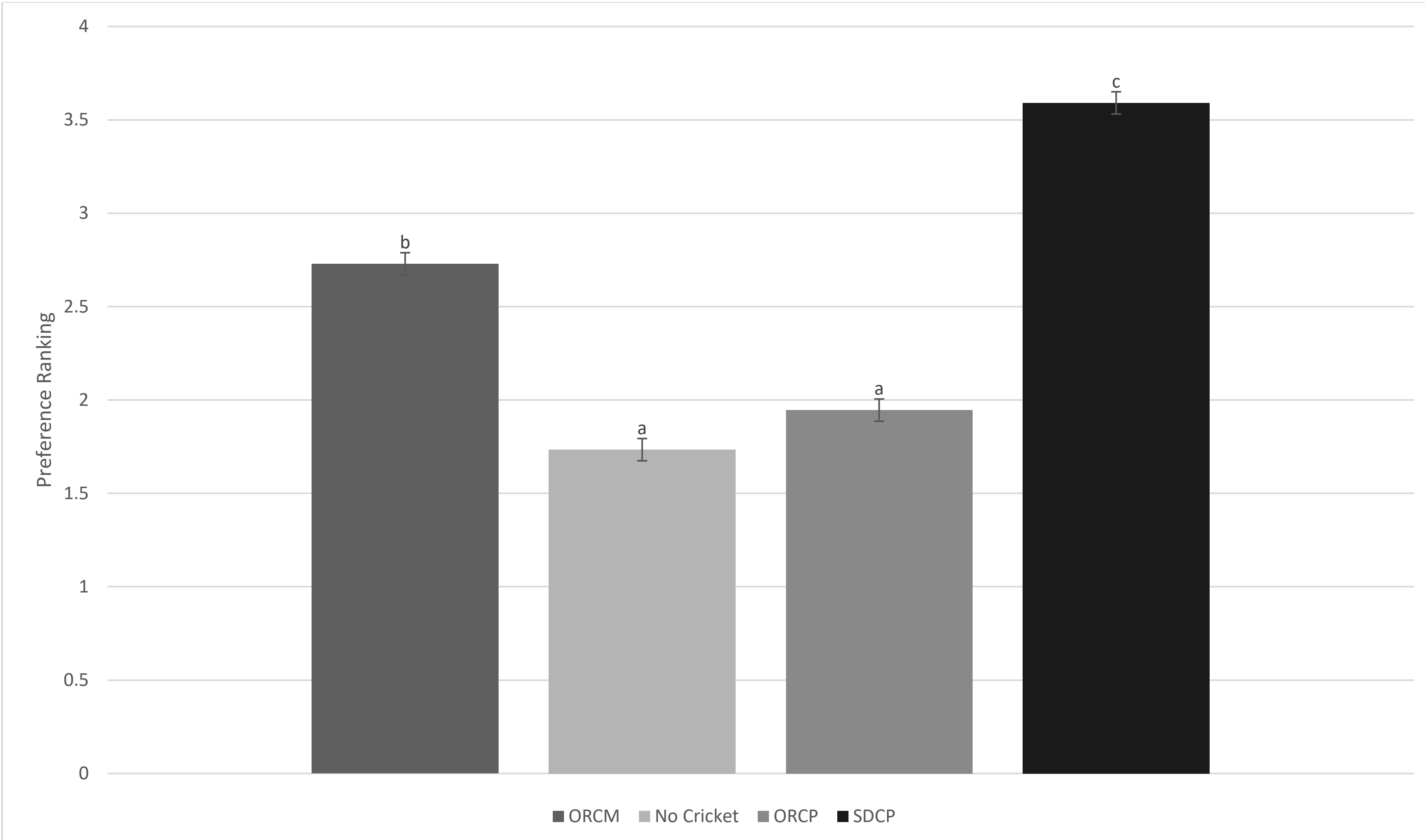

Figure 6: Average Preference Ranking of Drinks Prepared with Oven-roasted Cricket Meal (ORCM), Oven-roasted Cricket Powder (ORCP), Spray-dried Cricket Powder (SDCP), and without Crickets. (n = 203)

Values with like letters within each cluster are not significantly different from one another (α > 0.05).

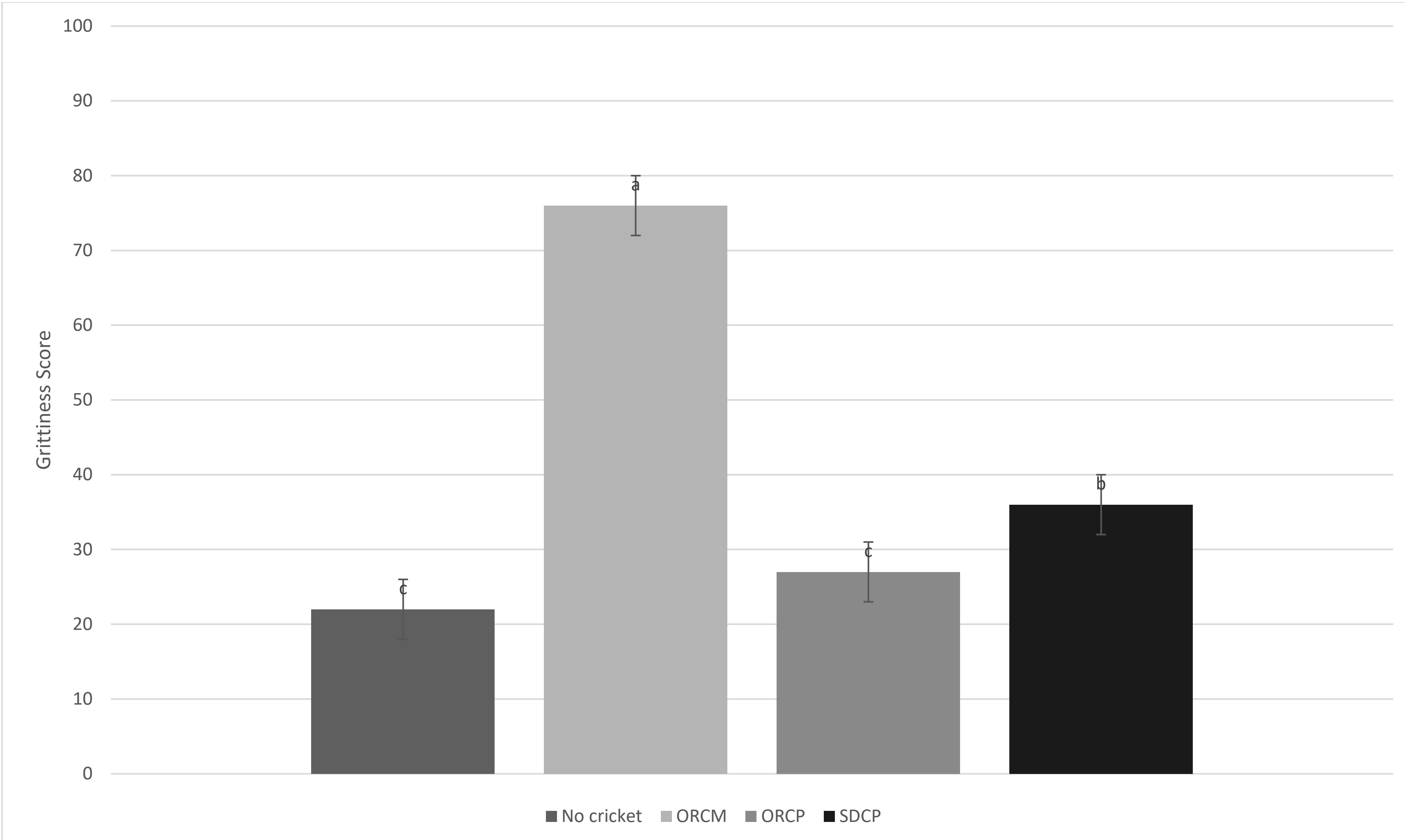

Figure 7. Grittiness Ratings of Drinks Prepared with Oven-roasted Cricket Meal (ORCM), Oven-roasted Cricket Powder (ORCP), Spray-dried Cricket Powder (SDCP), and without Crickets. (n = 203)

Values with like letters within each cluster are not significantly different from one another ($\alpha > 0.05$).

APPENDIX

Consumer Panel Ballot

VANILLA PROTEIN DRINK WITH CRICKET POWDER

Name_________________________ Signature____________________________

(sign after reading consent form)

Welcome to the Food Science Sensory Laboratory. A copy of the form titled "Consent to Be a Research Subject" is posted in each booth. Please read it carefully before continuing. By signing your name above, you acknowledge that you have read and understand the consent form, and desire of your own free will and volition to participate in this study. Please inform the receptionist if you wish to withdraw.

In this session, you will evaluate **FOUR** samples of **VANILLA-FLAVORED CRICKET PROTEIN DRINK**. Please read all instructions and questions carefully; we are depending on your conscientious evaluation. Before you get the samples, please answer these questions by checking the appropriate circles.

* What is your age category?

○ Under 18 years
○ 18 - 29 years
○ 30 - 39 years
○ 40 - 49 years
○ 50 - 59 years
○ 60 - 70 years
○ Older than 70 years

* What is your gender?

○ Female
○ Male

* What is your attitude about **PROTEIN DRINKS**?

○ I like them
○ I neither like nor dislike them
○ I dislike them
○ I've never had one

…Turn the page and continue…

* How often do you drink **ANY KIND** of protein drink?

- ○ At least once a week
- ○ At least every two weeks
- ○ At least once a month
- ○ At least every three months
- ○ Less than every three months
- ○ Never

* How do you feel about trying a **PROTEIN DRINK containing GROUND CRICKETS**?

- ○ Highly positive
- ○ Somewhat positive
- ○ Neither positive or negative
- ○ Somewhat negative
- ○ Highly negative

The drinks you're about to evaluate contain cricket protein powder blended with plant proteins, fibers, and flavors to create a high-protein, nutrient-dense powder. It contains a balanced, complete amino acid profile and prebiotic fiber, and is free from the hormones and allergens found in some soy and whey.

Now that you've read more about this product, how do you feel about trying a **PROTEIN DRINK containing GROUND CRICKETS**?

- ○ Definitely more positive
- ○ Somewhat more positive
- ○ No different
- ○ Somewhat more negative
- ○ Definitely more negative

…Turn the page and continue…

Locate the set of lights to the right of the computer screen and **press the red button next to the green "READY" light** to indicate that you are ready to receive your samples. Please be patient; they should arrive shortly.

If at any time during the test you need more sample or any other help, **press the button by the "HELP" LIGHT** to the right of the screen.

TASTE THE SAMPLES, but remember to save enough sample for further questions. Use a bite of Cracker and a sip of water between them to refresh your sense of taste.

* **EVERYTHING CONSIDERED**, how do you feel about the **OVERALL ACCEPTABILITY** of each sample?

	Sample # (please write in the number)			
	____	____	____	____
Like extremely	O	O	O	O
Like very much	O	O	O	O
Like moderately	O	O	O	O
Like slightly	O	O	O	O
Neither like nor dislike	O	O	O	O
Dislike slightly	O	O	O	O
Dislike moderately	O	O	O	O
Dislike very much	O	O	O	O
Dislike extremely	O	O	O	O

* How much do you like or dislike the **APPEARANCE** of each sample?

Like extremely	O	O	O	O
Like very much	O	O	O	O
Like moderately	O	O	O	O
Like slightly	O	O	O	O
Neither like nor dislike	O	O	O	O
Dislike slightly	O	O	O	O
Dislike moderately	O	O	O	O
Dislike very much	O	O	O	O
Dislike extremely	O	O	O	O

…Turn the page and continue…

Smell the sample before answering the next question.

* How much do you like or dislike the **AROMA** of each sample?

	Sample # (please write in the number)			
	____	____	____	____
Like extremely	O	O	O	O
Like very much	O	O	O	O
Like moderately	O	O	O	O
Like slightly	O	O	O	O
Neither like nor dislike	O	O	O	O
Dislike slightly	O	O	O	O
Dislike moderately	O	O	O	O
Dislike very much	O	O	O	O
Dislike extremely	O	O	O	O

* How much do you like or dislike the **FLAVOR** of each sample?

Like extremely	O	O	O	O
Like very much	O	O	O	O
Like moderately	O	O	O	O
Like slightly	O	O	O	O
Neither like nor dislike	O	O	O	O
Dislike slightly	O	O	O	O
Dislike moderately	O	O	O	O
Dislike very much	O	O	O	O
Dislike extremely	O	O	O	O

* How much do you like or dislike the **MOUTHFEEL** of each sample?

	____	____	____	____
Like extremely	O	O	O	O
Like very much	O	O	O	O
Like moderately	O	O	O	O
Like slightly	O	O	O	O
Neither like nor dislike	O	O	O	O
Dislike slightly	O	O	O	O
Dislike moderately	O	O	O	O
Dislike very much	O	O	O	O
Dislike extremely	O	O	O	O

…Turn the page and continue…

How would you rate the **LEVEL OF GRITTINESS** or particulates in each sample?

Sample #____
Not detectable ____ Extremely Prevalent

Sample #____
Not detectable ____ Extremely Prevalent

Sample #____
Not detectable ____ Extremely Prevalent

Sample #____
Not detectable ____ Extremely Prevalent

Now that you've tasted this product, how do you feel about **PROTEIN DRINKS containing GROUND CRICKETS**?

- ○ Definitely more positive
- ○ Somewhat more positive
- ○ No different
- ○ Somewhat more negative
- ○ Definitely more negative

* How likely or unlikely would you be to **PURCHASE** each sample if it were priced comparably to similar products where you normally purchase protein drinks?

	Sample #'s (please write in the numbers)			
	____	____	____	____
Extremely likely	O	O	O	O
Very likely	O	O	O	O
Moderately likely	O	O	O	O
Slightly likely	O	O	O	O
Neither likely nor unlikely	O	O	O	O
Slightly unlikely	O	O	O	O
Moderately unlikely	O	O	O	O
Very unlikely	O	O	O	O
Extremely unlikely	O	O	O	O

…Turn the page and continue…

* While comments are not necessary, you may leave a brief comment below. Include the sample number you are referring to.

____
____
____
____
____
____
____

* **RANK** the samples in order of **PREFERENCE** by writing the sample code in the appropriate space below.

____________	____________	____________	____________
Liked best	Liked second best	Liked third best	Liked least

You are finished. Please place the sample and tray in the pass-through compartment and **PRESS THE BUTTON BY THE "FINISHED" LIGHT**. Please give this questionnaire to the receptionist. **THANK YOU!**

THIS IS THE LAST PAGE