Development of a Nutritional Delivery System to Feed Crew in a Pressurized Suit

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ABSTRACT

The contingency scenario for an emergency cabin depressurization event may require crewmembers to subsist in a pressurized suit for up to 144 hours. This scenario requires the capability for safe nutrition delivery through a helmet feed port against a 4 psi pressure differential to enable crewmembers to maintain strength and cognition to perform critical tasks. Two nutritional delivery prototypes were developed and analyzed for compatibility with the helmet feed port interface and for operational effectiveness against the pressure differential. The bag-in-bag (BiB) prototype, designed to equalize the suit pressure with the beverage pouch and enable a crewmember to drink normally, delivered water successfully to three different subjects in suits pressurized to 4 psi. The BiA restrainer pouch, designed to provide mechanical leverage to overcome the pressure differential, did not operate sufficiently. Guidelines were developed and compiled for contingency beverages that provide macro-nutritional requirements, a minimum one-year shelf life, and compatibility with the delivery hardware.

OBJECTIVES

1. Develop and evaluate prototypes for dispensing liquid through a feed port into a pressurized suit.
2. Develop food product parameters that meet nutritional requirements and suit interface criteria.

METHODS – Prototype Development

BOA Restrainer Pouch Prototype

Bag-in-Bag (BiB) Prototype

Basic Instant Beverage Analog

(1) Formulation: The instant beverage analog formulation met macronutrient requirements determined for contingency events. Ingredients were mixed together: 90 g of powder mix was combined with 175 ml of water for all tests.

(2) Viscosity measurements: Dynamic viscosity was determined for the instant beverage analog and two existing beverage products (US Army Natick Laboratories Dairy Shake (Natick, MA) and Kroger Instant Breakfast (Cincinnati, OH)) using a Brookfield Viscometer (Brookfield Engineering, Middleboro, MA) at 20, 50, and 100 rpm using spindle #5 and #8.

(3) Pouch compatibility / flow rate: The flow rates under normal drinking conditions were determined for a range of viscous fluids (the instant beverage analog, water and glycerol) in prototype pouches against an 8 psi pressure differential in the vacuum chambers. Flow rates (in ml/s) were calculated using the amount of fluid removed from each pouch and the amount of time required for removal.

(4) Rehydration Ratio: Rehydration efficiency was assessed for the instant beverage analog in the BiB pouch by measuring the time required for adequate rehydration with manual kneading.

(5) Shelf life Prediction: Isotherm curves of two existing beverage products and the instant beverage analog were generated on the Vapor Sorption Analyzer (Decagon Devices; Pullman, WA). The generated curves were used to predict shelf-life of products stored in a BiB package. A computation tool (Decagon Devices) was used to analyze data and predict shelf-life based on water uptake and critical water activity.

METHODS – Prototype Testing

Chamber Tests

A vacuum chamber and data acquisition system were used to measure the pressure required to obtain a range of viscous fluids (water, glycerol, and beverage analog) from each prototype bag against a pressure differential of 8 psi. The system was constructed to enable simulation of the required drinking force (Tube A), the pressure differential that needed to be overcome (Tube B, Boa Restrainer Pouch), or pressure equalization into the outer pouch (Tube B, BiB Pouch).

RESULTS and DISCUSSION

Boa Restrainer Pouch Prototype

• The Boa Restrainer Pouch was designed so that tightening the ratcheting system would empty the beverage pouch. Likewise, it was designed to prevent the suit pressure from backfilling the pouch during drinking, which would inhibit the extraction of the remaining beverage.

• The 8 psi pressure differential caused a 100% failure rate in the inner beverage bags. The failures were instant and in the subjects' ability to drink water from the model pouch.

• Evaluation results and food product parameters have the potential to be used to improve future prototype designs and develop complete nutritional beverages for contingency events. These feeding capabilities would have additional use on extended surface mission EVAs, where the current in-suit drinking device may be insufficient.

Basic Instant Beverage Analog Parameters and Recommendations

• The use of existing beverages is not feasible due to nutrition incompatibility. A custom beverage formula would provide the necessary nutrients without risk of vitamin toxicity. However, existing beverages with target functional properties were used to guide the development of the instant beverage analog.

• Formulation of Beverage Analog: The nutritional content of the prototype was determined by the Nutritional Biochemistry Laboratory. The prototype's nutrient composition is 36.2% fat, 16.2% protein and 47.6% carbohydrates.

• Viscosity measurements of the instant beverage analog were compared to two existing beverages that provided a target viscosity range. The results indicate that the beverage analog fell within the target viscosity range, and was most similar to the Natick Dairy Shake, yielding shear-thinning properties.

• Water, the rehydratable beverage analog, and glycerol were tested in the vacuum chamber to demonstrate the systems capabilities with a range of viscosities. The beverage analog had a similar flow rate to other nutritional rehydratable beverages, but the acceptability of this flow rate during testing would have to be confirmed in future subject testing.

Basic Instant Beverage Analog

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>% Mass</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dextrose*</td>
<td>45.2%</td>
<td>99.9% glucose, 0.1% water</td>
</tr>
<tr>
<td>Whole Milk</td>
<td>24.1%</td>
<td>99.9% water, 0.1% milk solids</td>
</tr>
<tr>
<td>Whey Protein Isolate**</td>
<td>12.06%</td>
<td>99.9% protein, 0.1% water</td>
</tr>
<tr>
<td>Sucrose</td>
<td>6.05%</td>
<td>99.9% water, 0.1% sucrose</td>
</tr>
<tr>
<td>Modified Starch</td>
<td>3.02%</td>
<td>99.9% water, 0.1% starch</td>
</tr>
<tr>
<td>Gum Blend*</td>
<td>0.27%</td>
<td>99.9% water, 0.1% gum blend</td>
</tr>
</tbody>
</table>

* Dextrose – high calorie nutritional supplement by NutraSol
** 28.5% milk fat solids supplied by Hormel Foods.
*** 90% sugar by Carnoys Food Ingredients

1. Ulltrapure 2000 supplied by Ingredion.
2. Tocasol Ultratoc Powder supplied by TIC Gums.