DEVELOPMENT OF NUTRITIONALLY DEFINED METABOLIC DIETS FOR AEROSPACE TRAVEL

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Foreword

This study was initiated by the Biomedical Laboratory, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio. The original research and development work was accomplished by the Food Division, U.S. Army Natick Laboratories, Natick, Massachusetts, under Military Interdepartmental Purchase Request No. AMD-AM 4-40011, "Development of Food Items to Meet Air Force Requirements for Space Travel." This work represents development of nutritionally defined metabolic diets for space feeding. Mr. F. P. Mehrlick, Director, was the principal investigator for the Food Division. Elwood W. Speckmann, PhD, of the Biospecialties Branch was the contract monitor for the Aerospace Medical Research Laboratories. The work was performed in support of Project 7164 "Biomedical Criteria for Aerospace Flight," Task 716405 "Aerospace Nutrition." The research sponsored by this MIPR was started in January 1964 and was completed in December 1964.

This technical report has been reviewed and is approved.

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Abstract

Determination of the precise nutritional requirements of men in space requires a knowledge of, and careful control of, all environmental factors including the food consumed. The most suitable diet for experimental metabolic studies in a space system is therefore a nutrient defined diet composed of highly purified ingredients of known composition. Data compiled during the development of a nutrient defined diet in various flavors and physical forms are presented. The formulation of a liquid form of this diet including the nutrient composition, emulsion stability, antifoaming agents, flavor selection, and the techniques of packaging are discussed. An assessment of the organoleptic quality of the U.S. Army Natick Laboratories (NLABS) liquid nutrient defined diet by taste panel experts revealed a rating of 6.0 or above for the vanilla and chocolate flavors using a 9 point hedonic scale. Although slightly acceptable to taste panelists, this diet needs major flavor improvement if it is to be considered for use as the sole nutrient source for humans for prolonged periods of time. At the present time, this nutrient defined formulation is considered the best available liquid diet for sole support of humans in aerospace systems.

SECTION I

Introduction

Determination of the precise nutritional requirements of man in space requires a knowledge of, and careful control of, all environmental factors including the food consumed. The most suitable diet for experimental metabolic studies in a space system is therefore a nutrient defined diet composed of highly purified ingredients of known composition.

Early in 1964, after surveying the availability and composition of commercial and other formula diets, none of these diets were found to have sufficient nutrients for the present experimental studies. Accordingly, preliminary feasibility studies on the development of a nutrient defined diet were conducted by the Metabolism Section, Nutrition Branch, Food Division, U.S. Army Natick Laboratories, Natick, Mass. (NLABS). A number of crude prototype samples of semisynthetic diet in dry, water-dispersable compressed bar and freeze dried forms were prepared and evaluated at NLABS.

Tentative diet specifications were discussed with Air Force and NASA personnel in April 1964. Broad guidelines established for the metabolic diet called for a combination of purified components to supply a daily allowance of 2800 kcal. The diet was to contain 60-70 gm protein, fat was to make up to 40 percent of the total calories, and carbohydrates were to furnish the remainder of the energy. To facilitate constant intake and alleviate stability and off-taste problems, vitamins and minerals were not included in the diet specifications. The vitamins and minerals were to be supplied in capsules. At that time, the nutrient defined metabolic diet was also to be developed in many different food forms and should incorporate many of the physical properties of natural food.

Further discussions with Air Force representatives indicated continued interest in these types of products for their various research studies. In fact, the Air Force was interested in accelerating the program.

Based on these discussions, laboratory-scale development of liquid and candy-type metabolic diets proceeded at an increased pace during the summer of 1964. In June, a request was made for NLABS to supply the Air Force with 700 man days of the best available liquid nutrient defined formulation. This diet was fed chilled as the sole nutrient source (except vitamins and minerals) to human volunteers confined to a simulator for 28 consecutive days.* The specifications for this diet were prepared by the Biomedical Laboratory, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, and were as follows:

a. To be a liquid or a dry form capable of reconstitution to a liquid.

b. To supply a daily allowance of 2800 kcal with 70-75 gm high quality protein, approximately 415 gm carbohydrate (corn syrup solids), approximately 90 gm fat (vegetable-origin), a maximum of 800 mg calcium, 500-800 mg phosphorous, and no more than 8 gm of sodium chloride.

c. To be so designed that 10% of the energy was derived from protein, 30% from fat, and 60% from carbohydrate.

*Walch, 1965, Personal Communication, School of Aviation Medicine, Aerospace Medical Division, Brooks AFB, Tex.

d. To have a bland flavor.

e. To contain no trace of vitamins and minor elements.

f. To be packaged as a sterile canned liquid if possible. Otherwise, freeze dried and packaged in conveniently sized containers.

g. To be stable for 90 days at room temperature.

As NLABS were not in a position to process a production quantity of this product, contacts were made with custom packers of such products and a service contract was subsequently awarded to Amboy Sterile Packaging Company, Amboy, Illinois. The required amount of product was processed on technical requirements furnished by NLABS.

SECTION II

Methods

Development began with the formulation of a simple model basic diet where different individual or various combinations of ingredients could be changed providing the amounts of total protein, carbohydrate, and fat remained rather constant. For example, purified protein sources, such as casein and egg albumin, were used individually or together in various combinations to make up 4% to 5% by weight of the diet. It was convenient to use hydrolyzed corn starch in the form of corn syrup as the major carbohydrate source. As with semisynthetic animal diets used in nutrition research, corn oil and other vegetable oils of known origin were considered satisfactory sources of fat in the initial diets. Stabilizing, emulsifying, flavoring, antifoaming, and other additives were added as experimental variables to this diet. The nutrient composition of the basic diet developed was as follows: purified proteins, 4-5%; carbohydrate, 24%; fat, 6%; additives as required, and water to make to 100% by weight.

Ingredients – Since the diet was to be nutrient defined, every effort was made to obtain the most purified ingredients available which were of known chemical composition and which were consistent with practical food technology considerations. The food ingredients used are listed in table I. Table II lists the manufacturer's chemical and physical data for the protein and carbodrate used in the canned diets.

Emulsion Stability and Foaming – The following are typical additive combinations which stabilized the oil-in-water emulsion system of laboratory produced liquid diets.

Protein	*Emulsifier Mixture*
Sodium caseinate	0.1% algin, 0.1% CMC, 0.05% monoglycerides, plus 1% calcium citrate
Sodium caseinate and egg albumin, 1:1	0.1% algin and 0.05% monoglycerides

ASEPTIC CANNING

Amboy Sterile Packaging Company, which uses the continuous short time, high temperature process method of the Dole Aseptic Canning System, was awarded contracts to produce the two large lots of the liquid nutrient defined formulation. The processing method combined flash sterilization and cooling with aseptic methods in canning, thus eliminating the retorting and subsequent cooling required in conventional canning procedures. As a result, more of the original nutritive value, flavor, color, and texture were retained.

In this process, the liquid diet was pumped continuously under pressure through the heating section of the sterilizer where it was quickly brought up to sterilization temperature of 144.4C then through a holding tower maintained at 144.4C for 8 seconds to insure complete sterilization, and finally through cooling towers to the aseptic canning unit. Sanitary-type cans and covers were sterilized with superheated steam at a temperature about 260C. Thus, a cold sterile product flowed from the heat exchanger towers into sterile cans and was sealed, in a continuous aseptic operation. Diet formulations are given in table III, and the chemical composition data on NLABS Metabolic Diet No. 1 are shown in table IV.

SECTION III

Results

Flavor – Laboratory batches of the diet were prepared in several flavors, and personnel were asked to select two flavors from samples of diet flavored with (1) vanilla, (2) banana, (3) butterscotch, (4) chocolate No. 4, (5) chocolate No. 5, and (6) chocolate No. 6. The flavors chosen were vanilla and chocolate No. 5.

While the initial canned diets had a strong unpleasant aftertaste, progress has been made in the improvement of diet palatability by the use of flavoring agents.

Acceptability and Palatability of Canned Diets – Taste panel tests conducted by the Acceptance Laboratory of the NLABS' Psychology Laboratories, Pioneering Research Division, were used to evaluate initial reaction to NLABS canned metabolic diets. Acceptability scores of NLABS and other liquid diets, based on a 9 point hedonic scale, are given in table V. The scores indicate that some NLABS second generation liquid diets have received ratings of 6.0 or above.

When freeze-dried, the canned liquid diets gave products which offered a potential for good acceptability when eaten "as is," however, some difficulty was experienced in reconstitution back to a liquid form. Considerable time and effort were required, and a small amount of diet residue that did not go into solution remained. Laboratory tests showed that sonic homogenization of the liquid diet for 10 minutes before freeze drying considerably improved rehydration time and reduced nonsoluble residue particles.

SECTION IV

Discussion

Tests indicated that, while emulsion stability was dependent on the formulation used, a combination of additives and mechanical homogenization usually produced the best results. Inclusion of a few percent of pregelatinized starch or processed waxy maize starch also appeared to increase emulsion stability. Foaming was a problem only with egg albumin formulations and was minimized with the use of 30 ppm of food grade silicone antifoam.

The selection of vanilla and chocolate as flavors stemmed not only from the taste panel evaluation, but also from the fact that many nutritionists are of the opinion that less flavor fatigue will occur in long-term feedings on the more bland and common flavors than on the more exotic or intense flavors, such as coffee, strawberry, or cherry.

These data further indicate that the various flavors of the NLABS liquid nutrient defined diet rated superior to similar flavors of commercially available liquid formulations in terms of organoleptic quality.

Human feeding studies for 28-consecutive days using the NLABS liquid nutrient defined formulation revealed that these formulations were tolerable but were not very acceptable even in a chilled condition.

The recommendation to use liquid diets for aerospace missions by the Space Science Board, National Research Council, Washington, D.C., has promoted considerable research to formulate complete liquid nutrient diets. The results contained herein indicate the progress to date in formulation and production of a liquid diet for use in aerospace missions. The development of such a diet under Air Force guidance has progressed rapidly, yet still requires major improvements in organoleptic quality for prolonged human consumption.

The ability to alter the physical form as well as the flavor of a nutrient defined diet offers many advantages. Development of freeze dried, compressed bite size, chewable candy and baked forms, in addition to the liquid form of this metabolic diet are now under intense evaluation by NLABS. The composition of these formulas will be generally similar to that described herein.

TABLE I

INGREDIENTS USED IN DEVELOPMENT OF NLABS' NUTRIENT DEFINED METABOLIC DIETS

Proteins —	Sodium caseinate
	Calcium caseinate
	Potassium caseinate
	Lactalbumin
	Egg albumin
	Wheat gluten (in baking)
Carbohydrates —	Sucrose
	Glucose
	Dextrine
	Corn starch
	Corn starch hydrolyzate (corn syrup)
	Pregelatinized or processed starches
Fats —	Corn oil
	Cottonseed oil
	Coconut fat
	Partially hydrogenated vegetable oil
Other Additives —	Sodium cyclamate
	Sodium saccharin
	Sorbital
	Sodium chloride
Emulsifying Stabilizing or Thickening Agents —	Algin
	Carrageenan
	Agar-agar
	Lecithin
	Gelatin
	Methyl cellulose
	Acetylated monoglycerides
	Mono- and Di-glycerides
Flavors —	Vanilla
	Chocolate
	Coffee
	Orange
	Cherry
	Cream soda
	Banana
	Butterscotch
	Caramel
	Coconut

TABLE II

MANUFACTURER'S CHEMICAL AND PHYSICAL DATA FOR SOME INGREDIENTS USED IN NLABS' CANNED METABOLIC DIETS

Product	*Technical Data*	*Percent by Weight*
Sodium Caseinate	Protein (N x 6.38) db	90.0
	Fat	1.5
	Ash	4.0
	Moisture	3.5
	Reducing substances	2.0 (maximum)
	pH (2% solution)	6.4
	Sodium	1.5
	Color	Cream white
	Particle size	Through 100 mesh
	Sediment	#2 ADMI disc
	Bacteria	
	Std plate count	Less than 30,000 per gm
	Thermophile	Less than 20,000 per gm
	Yeast and mold	Less than 100 per gm
	Coliform	None
Corn Syrup	Dextrose equivalent (DE)	42
	Baumé	43
	Moisture	19.7
	SO_2	40 ppm (maximum)
	Ash	0.3
	Carbohydrate (db)	
	Monosaccharides (Dextrose)	5.9
	Disaccharides (Maltose)	44.4
	Trisaccharides	12.7
	Tetrasaccharides	3.3
	Penta & higher	33.7
	Viscosity	
	26.6C	560.0 poise
	37.7C	145.0 poise
	48.8C	49.0 poise
	Conversion	Acid-enzyme

TABLE III

INGREDIENT COMPOSITION OF NLABS NUTRIENT DEFINED METABOLIC LIQUID DIETS

Ingredient	*NLABS No. 1* *Chocolate and Vanilla Percent by Weight*	*NLABS No. 2* *Chocolate Percent by Weight*	*NLABS No. 2* *Vanilla Percent by Weight*
Sodium caseinate	5.0	4.5	4.5
Hydrolyzed corn starch (42 DE, 80% solids corn syrup)	16.0	7.5	17.5
Hydrolyzed corn starch (42 DE, corn syrup solids)	—	6.0	—
Processed waxy maize starch	2.0	2.0	2.0
Sucrose	4.0	5.0	3.0
Corn oil	6.0	—	—
High stability partially hydrogenated vegetable oil	—	6.0	6.0
Flavor and emulsifier	0.3	1.7	0.3
Water	66.7	67.3	66.7
TOTAL	100.0	100.0	100.0

TABLE IV

NUTRIENT COMPOSITION OF NLABS NUTRIENT DEFINED METABOLIC LIQUID DIET No. 1*

	Per 100 gm		*Per Can 230 ml*		*Per 8 Cans (Daily Allowance)*	
	Choc.	*Vanilla*	*Choc.*	*Vanilla*	*Choc.*	*Vanilla*
Dry Matter, gm	30.8	30.5	70.8	70.2	566.0	562.0
Moisture, gm	69.2	69.5	159.0	160.0	1272.0	1280.0
Protein, gm	4.7	4.6	10.8	10.6	86.4	84.8
Fat, gm	6.3	6.3	14.5	14.5	116.0	116.0
Carbohydrate,** gm	19.6	19.4	45.1	44.6	361.0	357.0
Calories,** kcal.	154.0	153.0	354.0	352.0	2832.0	2816.0
Ash, gm	0.34	0.27	0.78	0.62	6.2	5.0
Calcium, mg	10.8	10.6	24.8	24.4	198.4	195.2
Phosphorous, mg	50.0	40.0	115.0	92.0	92.0	736.0
Sodium, mg	180.0	120.0	410.0	280.0	3280.0	2240.0
Potassium, mg	15.5	4.2	35.65	9.66	285.20	77.28
Magnesium, mg	5.0	2.4	11.50	5.52	92.00	44.16

*Analyses not available at this date for NLABS No. 2 diets.
**Calculated.

TABLE V

ACCEPTABILITY SCORES OF NLABS AND OTHER LIQUID DIETS*

Liquid Diets	*No. Tasters*	*Frequency of Scores* 1	2	3	4	5	6	7	8	9	*Total Score*	*Ave. Score*
NLABS Choc. (111964)	37	1	1	3	4	3	9	6	7	3	222	6.0 (a)***
(N) Chocolate	37	5	4	0	6	4	6	9	3	0	180	4.9 (b)
NLABS Coffee (111964PM)	36	1	1	3	3	5	8	7	7	1	213	5.9
NLABS Choc. No. 1 (121264)	40	0	3	5	7	8	8	8	1	0	201	5.0 (a)
NLABS Choc. No. 2	40	0	2	6	6	6	7	9	4	0	213	5.3 (a)
NLABS Choc. No. 3	40	0	3	1	10	9	9	8	0	0	204	5.1 (a)
(N) Chocolate	40	6	6	6	5	4	6	4	3	0	164	4.1 (b)
NLABS Vanilla (ADL) (11165)	30	0	1	6	2	3	8	6	3	1	166	5.5 (a)
(N) Vanilla	30	3	2	5	1	5	5	6	3	0	147	4.9 (a)
NLABS Choc. No. 4 (11365)	40	1	1	2	2	7	7	9	10	1	246	6.2 (a)
NLABS Choc. No. 5	40	1	1	1	3	5	7	15	7	0	246	6.2 (a)
NLABS Choc. No. 6	40	1	1	1	3	7	7	14	6	0	241	6.0 (a)
(N) Chocolate	40	4	4	4	7	2	9	6	3	1	191	4.8(b)
NLABS Banana (ADL) (11965)	30	1	1	1	3	3	8	6	6	1	180	6.0 (a)
(S) Banana	30	3	3	4	8	4	1	6	1	0	129	4.3 (b)
NLABS Butterscotch (ADL) (11265)	30	0	1	4	9	4	3	2	6	1	159	5.3 (a)
(M) Butterscotch	30	1	3	0	6	2	6	10	1	1	164	5.5 (a)
(P) Choc. (11365)**	36	1	4	8	4	3	5	7	4	0	175	4.9
(P) Vanilla	36	1	2	2	4	1	11	11	4	0	207	5.8
(P) Strawberry	36	1	1	0	1	5	7	12	8	1	231	6.4
NLABS Choc. No. 4 (11465)**	30	1	3	1	3	1	6	6	7	2	179	6.0 (a)
(P) Chocolate	30	0	2	6	9	0	5	3	3	2	151	5.0 (b)

*Conducted by Acceptance Laboratory, Psychology Laboratory, Pioneering Research Division, U.S. Army, Natick Laboratories.
**Solids content adjusted to be similar to NLABS diets.
***Scores with common letters are statistically similar by analysis of variance.

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