Nutritional Acceptability of a Dehydrated Diet

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Precooked, dehydrated and bite size compressed foods were arranged into a nutritionally balanced four-day cycle experimental menu with four meals per day. A control menu composed of frozen, fresh and heat processed foods was prepared to match the experimental diet. The control and experimental diets were prepared and/or reconstituted with room temperature water and both diets were served at room temperature to four healthy college students for 20 days while they were confined to an experimental metabolic facility. A difference in the organoleptic quality of the experimental and control diets could not be ascertained in the duration of this study. No evidence of monotony was revealed in either diet during the 20-day feeding trial. Both diets were highly digestible when fed to human volunteers. Subjects fed the control or experimental diet were maintained in nitrogen and energy balance. The subjects did not notice an increased gas production on either the control or experimental diet nor did they encounter gastrointestinal distress at any time.

THE LOGISTICS of prolonged aerospace missions necessitate the reduction of all carry-aboard materials to the absolute minimum of space and weight. It is essential that optimum nutrition be supplied to men in sustained flight so as to provide maximum physical performance and mental acuity. Food per man-day on the Gemini spacecraft has been reduced to 1,803 cubic centimeters (110 cubic inches) of space and has a weight of approximately 555 grams (1.2 pounds).[19] The immediate problem then is how to reduce all carry-aboard food items to these minimal requirements and yet maintain man's nutritional well-being.

The present state of the art of precooked freeze-dehydrated foods has advanced to the point whereby a wide variety of these items can be produced which are nutritionally adequate, highly acceptable, reconstitute well and maintain good shelf-life characteristics.[12] The use of freeze-dehydrated foods for Projects Gemini and Apollo has been proposed.[26] Studies have been performed with rats to assess the influence of dehydration of foods on digestibility and biological value of the protein.[8]. This research demonstrated that foods maintained better nutrient quality when freeze-dehydrated than when dehydrated by other methods. The feeding of diets consisting solely of precooked, dehydrated food items to young, healthy human volunteers has been reported.[20,21,23,25]

In the experiments reported by Nunes, et al. (1961), Senter (1963), Page et al. (1954) and Welch (1964), however, only acceptability of the foods were evaluated. To the authors' knowledge no studies have been reported in the literature whereby precooked dehydrated foods have been evaluated nutritionally by precise balance studies when fed to human volunteers. The studies now underway in the 6570th Aerospace Medical Research Laboratories involve an evaluation of the nutritional acceptability of a precooked dehydrated diet. The data reported herein represent the initial experiment during which precooked dehydrated foods were fed to four healthy college students for 20 days.

EXPERIMENTAL PROCEDURE

Precooked dehydrated and bite-size compressed foods were arranged into a nutritionally balanced four-day cycle experimental menu with four meals per day.* A control menu composed of frozen, fresh and heat-processed foods was prepared[3] to match the experimental diet as close as possible (Table I). There were 60 different foods in each diet. The daily diets were calculated so that they contained an average of 2500 digestible Kcal whereby 56 per cent of the calories were derived from carbohydrate, 30 per cent from fat and 14 per cent from protein. During the experiment each of the four control and four experimental menus was homogenized. Freeze-dried aliquots of this homogenate were analyzed for moisture,[14] gross energy,[22] crude protein,[5] total fat,[15] carbohydrate,[1] fiber,[7] ash[27] and calcium[13] content. The control and experimental diets were prepared and/or reconstituted with room temperature water (24±3°C) and both diets were served at room temperature.

All food fed to the subjects was accurately weighed (± 0.1 gram) and the subjects were required to consume all of the daily ration. They were permitted no additional food or condiments. Water was consumed *ad libitum* but individual intake was accurately measured. Evaluation forms were completed by each subject after every meal for all foods to determine the organoleptic quality of the menu. Acceptability was assessed by utilization of a graduated scale ranging from 1-9 Table II. These ratings were compared with food

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Dehydrated diet composed mainly of freeze dehydrated foods.

*Analysis of precooked, dehydrated and bite-size compressed foods were supplied by Food Division, U. S. Army Natick Laboratories, Natick, Mass.

preference questionnaire ratings completed by each subject prior to the experiment and with the ratings of the same subjects during the earlier portion of the experiment to assess the influence of time on the individual acceptability of food.

Individual daily stool samples were pooled into four-day collection periods. Carmine markers were used to indicate the limits of each period. The stools were weighed, homogenized and freeze dried. Duplicate aliquots from each collection period were analyzed. The volumes of twenty-four hour urine collections were recorded. Aliquots from a 48-hour collection period were frozen and stored for analysis. Both the urine and feces were analyzed for moisture,[14] energy,[22] nitrogen,[5] calcium,[13] sodium,[18] chloride,[16] potassium,[18] and phosphorus[11] content. Additional analyses included fat[14] and fiber[7] for feces and specific gravity, creatinine[4] and creatine[4] for the urine.

The test subjects were between 21 and 25 years of age. All were in normal health according to history, physical examination and routine clinical laboratory tests. Their body weights ranged from 60 to 85 kilograms (mean 74 Kg). Four men were confined in the experimental metabolic facility* during the experiment. Each subject was required to maintain an activity schedule designed to provide work, excercise, relaxation and sleep. The subjects were monitored continuously and individual tasks were carefully super-

TABLE II. ACCEPTABILITY RATING CATEGORIES

9	Like Extremely
8	Like Very Much
7	Like Moderately
6	Like Slightly
5	Neither Like Nor Dislike
4	Dislike Slightly
3	Dislike Moderately
2	Dislike Very Much
1	Dislike Extremely

*Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio.

TABLE I. AVERAGE ITEMIZED ACCEPTABILITY RATING OF FOUR-DAY CYCLE MENU OF FOUR SUBJECTS

	Dehydrated Diet	*Fresh Diet*
MENU I		
Meal A		
Grapefruit Juice	7.5	7.5
Apricot Cereal Cubes*	6.4	7.7
Toast	7.5	8.0
Beef/Vegetables	7.5	7.0
Banana Cube*	6.0	5.5
Meal B		
Corn Chowder	4.8	6.0
Peanut Butter Sandwich	8.5	8.0
Beef Bites	7.0	8.0
Potato Chip Blocks*	6.5	7.0
Pound Cake*	8.0	9.0
Meal C		
Chicken Sandwich	7.5	8.0
Bacon Squares	9.0	9.0
T. Bread Cubes*	7.5	8.0
Chocolate Pudding	8.0	7.0
Meal D		
Roast Beef	8.5	8.0
Toast	7.5	8.0
Pineapple Fruitcake*	8.5	8.5
Fruit Cocktail	8.5	8.5
Tea	8.0	7.5
MENU II		
Meal A		
Orange-Grapefruit Juice	8.0	8.0
Sugar Frosted Flakes	7.5	7.5
Chicken Bites	7.0	7.0
Cheese Sandwich	7.5	7.5
Brownies*	8.0	9.0
Tea	8.0	7.5
Meal B		
Beef/Gravy	8.5	7.0
Potato Salad	7.5	8.0
Cinnamon Toast	8.5	7.5
Apricot Pudding	8.0	7.7
Meal C		
Orange Juice	8.5	8.0
Tuna Salad	8.0	7.5
Mushroom Soup	3.5	5.0
Toast	7.5	8.0
Applesauce	8.0	8.0
Meal D		
All Star Cereal	7.5	7.5
Beef Sandwich	7.5	8.0
T. Bread Cubes*	7.5	8.0
Carrot in Cr. Sauce	3.0	4.5
Cocoa	8.0	7.5

*Bite-size compressed food items.

	Dehydrated Diet	*Fresh Diet*
MENU III		
Meal A		
Grape Juice	7.5	8.0
Strawberry Cereal Cubes*	6.7	8.0
Toast	7.5	8.0
Salmon Salad	6.5	6.0
Peaches	8.0	8.0
Tea	8.0	7.5
Meal B		
Orange-Pineapple Juice	8.0	8.0
Spaghetti/Meat	8.5	8.5
Beef Sandwich	7.5	8.0
Date Fruitcake*	8.5	8.0
Meal C		
Grapefruit Juice	7.5	7.5
Bacon & Egg Bites	8.0	8.2
Chicken/Vegetables	8.0	7.0
Butterscotch Pudding	8.5	8.5
Meal D		
Potato Soup	6.0	6.5
Shrimp Cocktail	7.8	5.9
Pineapple Cubes*	7.5	6.5
Gingerbread*	8.5	8.5
MENU IV		
Meal A		
Grape Juice	7.5	8.0
Sausage	7.2	7.2
T. Bread Cubes*	7.5	8.0
Cocoa	8.0	7.5
Meal B		
Chicken Salad	7.5	8.5
Green Beans-Creamed	5.0	6.0
Banana Pudding	8.5	7.0
Tea	8.0	7.5
Meal C		
Pineapple Juice } Apple Juice } Mix	8.0	7.5
Ham & Applesauce	7.5	8.2
Peanut Butter Sandwich	8.5	8.0
Potato Salad	7.5	8.0
Meal D		
Grape Juice	7.5	8.0
Pea Soup	5.0	3.7
Chicken/Gravy	7.0	5.5
Apricot Cubes*	7.0	8.0

*Bite-size compressed food items.

TABLE III. EXPERIMENTAL DESIGN

Subject No.	4 Days	16 Days	4 Days	16 Days	2 Days
9	Control Diet No Suit	Control Diet Suit	Experimental Diet No Suit	Experimental Diet No Suit	Control Diet No Suit
10	Control Diet No Suit	Control Diet No Suit	Experimental Diet No Suit	Experimental Diet Suit	Control Diet No Suit
11	Experimental Diet No Suit	Experimental Diet Suit	Control Diet No Suit	Control Diet No Suit	Control Diet No Suit
12	Experimental Diet No Suit	Experimental Diet No Suit	Control Diet No Suit	Control Diet Suit	Control Diet No Suit

vised so as to maintain a regulated schedule of activity throughout the experiment.

The study was divided into five periods in accordance with the experimental design shown in Table III. Each subject was fed a control diet for 20 days and an experimental diet for 20 days and was in an unpressurized space suit (MA-10) for 16 days during one of the dietary periods. The torso and boots were worn continuously during the 16-day period. In addition to the torso and boots the gloves and a helmet were worn for a minimum of four hours per day.

RESULTS

The average nutrient analyses of the control and experimental diets are reported in Table IV. The diets contained 4 percent more digestible calories than calculated. Of particular interest was the difference in weight of the experimental diet before rehydration when compared to the weight of the control diet. Based on these figures the total weight required per man for food for various mission durations has been calculated in Table V.

TABLE IV. AVERAGE DAILY NUTRIENT ANALYSES OF DIETS

	Dehydrated Diet	*Fresh Diet*
Total Weight (gm)	539	2055
Moisture (gm)	1231	1506
Gross Energy (Kcal)	2696	2760
Crude Protein (gm)	90	87
Total Fat (gm)	88	99
Carbohydrate (gm)	330	336
Fiber (gm)	10	7
Ash (gm)	21	20
Calcium (gm)	0.80	0.79

TABLE V. WEIGHT REQUIREMENTS FOR MAN FOR FRESH AND DEHYDRATED FOODS

	Dehydrated Diet	*Fresh Diet*
30 Days	16.2 Kg (35.6 lb)	61.7 Kg (135.6 lb)
60 Days	32.3 Kg (71.1 lb)	123.3 Kg (271.3 lb)
90 Days	48.5 Kg (106.7 lb)	185.0 Kg (406.9 lb)
120 Days	64.7 Kg (142.3 lb)	246.6 Kg (542.5 lb)
365 Days	196.7 Kg (432.7 lb)	750.1 Kg (1650.2 lb)

The availability of nutrients to the body as measured by the average coefficients of apparent digestibility[17] of nutrients in the control and experimental diets are reported in Table VI. Significant differences ($P<0.05$) were not found between the two diets in the digestibility of protein, fat or total energy.

TABLE VI. COEFFICIENT OF APPARENT DIGESTIBILITY

	Dehydrated Diet	*Fresh Diet*
Energy	94.9	96.5
Crude Protein	91.9	91.8
Fat	97.0	98.3

The average daily nitrogen balance data are reported in Table VII. A comparison of the control and experimental diets indicates that the subjects were essentially in nitrogen balance. The subjects experienced an average weight loss of 0.55 Kilogram (1.21 pounds) over the entire experiment, which was not attributed to differences in the diets.

TABLE VII. AVERAGE DAILY NITROGEN BALANCE

Nitrogen (mg/kg Bwt)	*Dehydrated Diet*	*Fresh Diet*
Intake	195	188
Fecal Excretion	15	16
Urinary Excretion	172	186
Balance	+7	—14

The average acceptability rating of each experimental and control food by all four subjects on the four-day cycle menu is also reported in Table I.

According to the experimental design each food item in the control and experimental diets was served and rated at least 20 times by the subjects. In general most of these items were rated 7-9 (well-liked) throughout the experiment. The average rating of all foods on the control diet was 7.5 while those foods on the experimental diet also received an average rating of 7.5. There was no indication of monotony of individual foods during the 20-day feeding experiment.

Although the foods were generally well-accepted it is interesting to consider those foods that tended to be unacceptable. Food items rated 4 and below (disliked) 10 per cent or more of the time by the subjects are reported in Table VIII. Foods such as corn chowder, creamed green beans, creamed carrots and mushroom soup demonstrated lower acceptability when dehydrated than when served fresh. In comparison, however, the dehydrated pea soup was better accepted than its fresh counterpart. Several items such as salmon salad or potato soup were disliked with similar frequency in both control and experimental diets revealing individual variation in taste.

The results of a debriefing at the completion of the experiment revealed that the dehydrated foods disliked most often by the subjects were vegetables (carrots or green beans with cream sauce and the potato chip block), soups (mushroom, pea, potato and corn chowder) and banana cubes. The dehydrated foods that were liked most by the subjects were toast, potato salad, bacon squares, beef/gravy and the cakes. The

TABLE VIII. FOOD ITEMS DISLIKED (4 AND BELOW) 10 PER CENT OR MORE OF THE TIME

DEHYDRATED DIET			FRESH DIET		
Item	No Times Rated	Percentage Disliked	Item	No. Times Rated	Percentage Disliked
Corn Chowder	22	36	Corn Chowder	22	18
Cm Green Beans	20	35	Cm Green Beans	20	20
Cm Carrots	22	73	Cm Carrots	22	38
Mushroom Soup	22	64	Mushroom Soup	22	33
Pea Soup	20	45	Pea Soup	20	65
Potato Soup	20	10	Potato Soup	20	10
Salmon Salad	20	20	Salmon Salad	20	20
Banana Cubes	44	18	Banana Pudding	20	10
Potato Chip Block	22	14	Beef/Vegetables	22	14
			Tuna Salad	21	10
			Shrimp	20	25
			Chicken/Gravy	20	40
			Vanilla Pudding	21	14
Average Rating of all 60 Items: 7.48			Average Rating of all 60 Items: 7.51		

bite-size compressed foods were very well accepted. The subjects verbally expressed an overall preference for the experimental diet; however, this fact was not reflected in their acceptability ratings.

DISCUSSION

The close agreement between digestibility of the experimental diet as compared to the control diet when fed to human volunteers is in agreement with Nunes, et al. (1961). A comparison of the analyzed diet gross energy and analyzed digestible gross energy indicates a high digestibility for both the experimental and control diets. Using the values proposed by Consolazio, et al. (1963) a very close agreement was found between calculated and analyzed digestible energy for the two diets. The ingestion of 2728 Kilocalories daily by the subjects without significant changes in body weight indicate that this daily caloric intake is sufficient for these subjects under the aforementioned conditions. The suggestion that lower daily energy intakes are sufficient to maintain body weight under simulated space conditions have been advanced by Page, et al. (1964) and Welch (1964).

The wearing of the pressure suits, under these experimental conditions, did not alter nitrogen requirements[24] and the subjects consumed daily at least the protein recommended for 95 per cent of the U. S. population.[9] It is, therefore, not surprising that nitrogen balance was maintained in these subjects. Nitrogen losses in the sweat, however, were not measured.

The general high acceptance of the precooked dehydrated foods is in agreement with data previously reported by others.[20,23,25] In the studies reported by Nunes, et al. (1961), Senter (1963) and Welch (1964), however, the precooked dehydrated foods were well accepted, though slightly less than comparable fresh foods. This difference was not evident in the study reported herein. It is quite possible that higher quality precooked, dehydrated foods were utilized in the Wright-Patterson AFB Experiment than in the studies previously cited.

The formulation of fresh foods of the control diet to nutritionally match the dehydrated items of the experimental diet under these constraints sometimes resulted in products that were low in quality regarding texture, flavor and consistency. The preparation and serving of all food items at room temperature (24°C±3°C) may also have decreased the acceptability of the control ration inasmuch as certain foods are ordinarily consumed at hot or cold temperatures.

It is of interest to note the study reported by Page, et al. (1964). In this experiment a four-day cycle menu with four meals per day and consisting mainly of precooked freeze-dehydrated and bite-size compressed foods was served at a temperature of 27-38°C (80-100°F) to five subjects for 12 days. The foods disliked in the study reported herein as well as in the study reported by Page, et al. (1964) were creamed carrots, banana cubes, corn chowder and creamed green beans. Many of the foods receiving borderline acceptability ratings (5.0-6.0) as well as many of the foods that were disliked (below 5.0) in the study reported by Page, et al. (1964) were well accepted by the subjects in the Wright-Patterson AFB Experiment. In general the prototype Gemini menu reported by Page, et al. (1964) was not as acceptable (5.28) as a very similar prototype Gemini menu (7.48) utilized for the Wright-Patterson AFB Experiment. The storage of foods for the prototype Gemini menu reported by Page, et al. (1964) may have influenced the organoleptic quality of this menu. The short feeding period (12 days) may not have allowed the subjects sufficient time to adapt to these foods. In the Wright-Patterson AFB Experiment several items became more acceptable with time.

It is obvious from the food weight differences reported for the control and experimental diets in Table V that the use of dehydrated foods, to be reconstituted with recycled water, during prolonged aerospace missions affords a considerable saving of weight (381 per cent). Utilizing a Titan 2 launch vehicle to thrust a Gemini spacecraft to rendezvous with the USAF Manned Orbiting Laboratory at a 300-mile orbit would require a launch vehicle weight (structure, engine and fuel) to payload weight of 37:1.[2] To acquire escape velocity as required in the Apollo spacecraft for lunar exploration and utilizing the Saturn 5 launch vehicle for thrust would require a launch vehicle weight to payload weight of 110:1.[10] These examples further magnify the importance of utilizing precooked dehydrated foods in reducing payload weight.

Although the men used in this experiment were not professional taste panelists it is believed that their ratings reflected the average response of men to this particular dietary regimen. The high organoleptic quality and nutritive value of selected precooked dehydrated and bite-size compressed foods in addition to the weight and volume saved by the removal of water suggest that this method of processing be utilized for foods considered for use in prolonged aerospace missions. The reader must be cautioned, however, that the data in this manuscript are the result of only one study utilizing four men and that precognitive conclusions drawn from these data may not be reflected by additional data accumulation.

SUMMARY

A review of the data of this study indicates that a four-day cycle menu with four meals per day and consisting only of precooked dehydrated and bite-size compressed food items was highly acceptable and rated equally with a matched diet consisting of fresh, frozen and heat-processed foods. No evidence of monotony in either the dehydrated food diet or the fresh food diet could be ascertained during the 20-day feeding trial. The subjects did not notice an increased gas production on either the control or experimental diet nor did they encounter gastrointestinal distress at any time.

Both diets were highly digestible when fed to human volunteers. Subjects fed both control and experimental diets were maintained in nitrogen and energy balance.

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