Food Composition Databanks: Important Considerations in Designing Metabolic Research Diets

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Metabolic nutrition research is a method of investigating the metabolism of chemical elements or food constituents by determining the loss, retention, or utilization of these substances in the human body (1-3). In designing a diet for metabolic nutrition research, the fundamental principle involved is absolute control by the metabolic kitchen staff over the food and fluid intake of participants in the study (2,3). Thus, the success of a human metabolic study depends greatly upon the design and delivery of a well controlled research diet. Whether the study protocol requires the feeding of a liquid formula diet, a 24-hour food plan, a cycle menu, or a combination of these diets, it is paramount that an accurate food composition data bank be used to compute the research diet's nutrient profile. Although modern day computers have greatly simplified the manipulation of metabolic diets to meet changing research needs, they are only tools used to perform an array of calculations. A complete and accurate nutrient data bank is the preliminary determinant of the usefulness of a calculated diet's nutrient profile and thereby can influence the meaningfulness of the metabolic study's results. This paper is written to address the application of food composition data banks to designing research diets in metabolic research facilities that are not clinically oriented. To cover this focus, examples and explanations using experimental diets designed for the Western Human Nutrition Research Center's human nutrition metabolic research studies will be given.

Briefly, the Western Human Nutrition Research Center (WHNRC) was established in 1980 via a congressional mandate and is located in San Francisco, California. The mission of WHNRC is to conduct research on human nutritional requirements and on methodology to improve nutritional status surveillance, intervention, and monitoring of individuals and population groups. Subsequently, research conducted in the Metabolic Research Unit (MRU) at WHNRC pertains primarily to: nutritional requirements of healthy people, nutritional status evaluation methodology, and nutrient intake and bioavailability methodology. The MRU at WHNRC is capable of supporting 12 volunteers in a residential status plus a variable number of volunteers in a free-living status. Diets for each study are designed and prepared to provide culinary and quantitative control, as well as preparation and storage control, using the theoretical concepts of metabolic research. To achieve accuracy in measuring, preparing, and serving the daily allowance of food and fluid to the study participants, specific and detailed procedures are defined and implemented. Each procedure established is directed at eliminating loss of food or fluid until it is consumed by the participant. The basic means of control used for the WHNRC metabolic diets are summarized in Table 1.

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Food Composition Data Bank

At WHNRC, research conducted in the MRU is primarily directed towards investigation of nutrient metabolism and requirements of healthy people in the United States, and therefore, the food composition data bank selected needed to contain nutrient composition of a variety of commonly consumed American foods. One criterion in selecting sources of information for the WHNRC food composition data bank was that the nutrient composition information in the data bank come from a reliable source where analytical techniques are accurate and up-to-date, where information on new food products would be made available, and where sampling and quality controls are assured. Another criterion was that the data bank selected contain a wide variety of foods with nutrient values for proximate content, fiber, water and fat soluble vitamins, major and trace minerals, amino acids, and fatty acids. Two other criteria were that the food data bank be inexpensive to acquire and that it would not require a separate staff to maintain. To satisfy these criteria, the food composition data bank at WHNRC is derived from the USDA Nutrient Database for Standard Reference.

Missing Values

When foods with missing nutrient values are used in calculating a metabolic research diet, an underestimation of true dietary nutrient level will occur. At WHNRC, the number one rule in calculating a research diet is that the key nutrient variable(s) under investigation should be free of missing values. For the nutrients which are not under investigation, but are included in the Recommended Dietary Allowances (RDA) or Estimated Safe and Adequate Daily Dietary (ESADD) intake tables, an accounting of the frequency of missing values and whether the missing values are in a major food source must be determined for each menu. In the case of the RDA or ESADD nutrients, an imputed value could be used, if available, in order to evaluate if nutrient supplements are necessary to assure nutritional adequacy. If imputed values are used in metabolic diet calculations, a method of identifying their contribution should be incorporated in the nutrient summation program. For example, a report on the percentage of the calculated intake from imputed values for each nutrient in the diet would be useful. This percentage would be especially helpful for determining the confidence of those nutrients not analyzed.

Currently, nine nutrients specified in the National Research Council's Recommended Dietary Allowances (4) are not contained on the WHNRC data bank. These nutrients are vitamin D, vitamin K, biotin, chloride, chromium, fluoride, iodine, molybdenum, and selenium. When one of these nutrients is studied, the WHNRC research dietitians utilize the following approach in order to acquire values for use in dietary calculations: (a) contact either the USDA's Nutrient Composition Laboratory at Beltsville or the USDA's Human Nutrition Information Service to obtain preliminary nutrient data, if available; (b) contact other investigators or research facilities conducting research on that nutrient; (c) conduct a literature search of foods analyzed for the nutrient; (d) obtain chemical analysis on as many foods included in the proposed menu as possible. For these reasons, when one of these nutrients is studied, the usual outcome is that only a limited number of foods can be served in the diet. Additionally, it should be noted that if literature values are used in preliminary diet calculation, it is critical that chemical analysis be done to validate the accuracy of the calculation. For older literature values, depending on the nutrient in focus, the analysis methods used may be less accurate thereby making the calculated values erroneous or out of the intended range for the study. Thus, it is best to obtain consultation from nutrient composition experts about the reliability of such literature values before using the values in a diet calculation.

Using Linear Programming to Design a Research Diet

Advancements in computer technology are allowing research dietitians to become much more creative in designing metabolic research diets. Traditionally, a research diet is formulated by first defining a list of foods to use in the metabolic diet and then calculating the nutrient composition of the proposed diet. If the total nutrient values exceed or fall below required values, food quantities are altered or exchanged and the diet recalculated. Calculations are repeated as often as necessary until a suitable diet meeting all nutrient levels is obtained. One way to simplify this tedious task is to allow the computer to calculate the metabolic research diet. At WHNRC, linear programming techniques have been used to calculate formula diets. Table 2 is a simplified flow diagram showing how linear programming can assist in formula diet calculation.

Table 3 shows an example of the final ingredients of the formula diet used to study the vitamin C requirement of healthy adult premenopausal women (5). In calculating this formula diet, linear programming was used to estimate the level of ingredients needed to prepare a formula which would provide 0.8 g protein per kg body wt per day. In preparing the linear program, calculation sequences, ratios and limits were set so that the computer would calculate the amount of cornstarch, dextri-maltose, and sucrose needed for the carbohydrate source first. Egg Albumin as a protein source would be calculated next followed by the fat ingredients. The minerals would be calculated last to meet the required mineral levels. The function of the linear program was to find estimates by fitting the linear equations with various iterations until all given conditions were satisfied or met.

While linear programming can free the dietitian from detailed, arithmetical tasks of calculating a research diet, it may also produce a very unpalatable diet for humans. In the above example, several combinations of different ratios of chemical sources were formulated to produce several different formulas. Then, the most palatable formula was selected based on a taste test. For the preliminary calculations, nutrient composition for carbohydrate, protein, and fat sources were taken from the food composition data bank. Molecular weights of chemical compounds were added as new records to the nutrient data bank under a temporary data file. After the best tasting formula was selected, lot ingredients were purchased and were chemically analyzed for energy, fat, nitrogen and other mineral contents. The nutrient composition of each ingredient was then entered as an up-dated record in the temporary data file on the nutrient data bank. The linear program was again used to calculate the final amounts of each ingredient for the diet.

While linear programming can be easily used to calculate a formula diet, using linear programming to formulate conventional food diets is a much more complicated task. First, the computer should be used to eliminate or select foods based on the study nutrient criteria. Then, linear equations must be set for each study nutrient variable for the foods selected. A logical definition for frequency of use of foods and serving limits also must be set. A final list of foods must be developed to be used in the linear program to help adjust the nutrient requirement levels. Once a conventional diet is produced by the linear program, sample meals must be prepared and evaluated for serving size and palatability. Dariel and Sklan[1] (6) have successfully developed a computerized model planning human diets using a mixed integer linear programming algorithm.

Chemical Analysis of the Research Diet

For both the formula or conventional food diet, nutrient intake information calculated from food composition data banks is not sufficiently accurate for metabolic research study interpretation. Calculated nutrient information should only be used as a preliminary guide to determine the level of the nutrient being studied in the research diet. Bomb calorimetry and chemical analysis are the only ways to assure that the differences between the actual intakes and the calculated estimates are minimal. The cost of nutrient analysis is insignificant when compared to the cost of a wasted MRU study or to the cost of operating a metabolic study. Prior to the start of the human study and throughout the study, composites of the cycle menu and individual food samples must be collected and chemically analyzed, not only for the primary nutrients being investigated, but also for selected major nutrients in order to verify that the calculated values are correct. If discrepancies are found between the calculated and analyzed diets, the dietitian should identify the source of discrepancy and redesign the diet. Ideally, at least three samples of each diet should be collected and analyzed. If cost prohibits multiple sampling of cycle diets, at a minimum a duplicate set of each diet cycle must be analyzed for the nutrient(s) under investigation. For problem

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nutrients that yield higher variation from composite to composite (such as vitamin B6 or folacin), as many as six samples of each menu day might be collected and analyzed. To determine the number of diet composites needed to accurately represent the nutrient content in the metabolic diets used, it is best to consult the advice of a statistician.

Recycling Foods in Research Diets

When a selected menu shows consistency in analyzed values or minimal error between analyzed samples, the foods in the menu would then be consistently used from study to study or from diet to diet when the same nutrients are examined. Even though interpretation of data is based on laboratory analyses of diet composites, consistent use of foods helps target the nutrient level requested by the investigator. This principle is best illustrated by a folate study (7) conducted by Dr. Sauberlich and colleagues at WHNRC.

This folate study was conducted to obtain information on the requirement of folate for premenopausal adult females when these women were fed a conventional food diet (Table 4). The study had both folate depletion and repletion phases. A formula diet was served during depletion period and diet menus prepared from ordinary food items were served during the folate repletion periods. Folate composition information from the data bank was used for preliminary calculations. Next, individual items (Table 5) were analyzed by microbiological assay method (L casei assay) and the diet was recalculated to provide 20, 50, 100, 150, 200, and 300 mcg of natural folate per day. The breakfast, lunch, and dinner menus for the six levels of folate intakes were derived from the following major items: apricot nectar, apple juice, yogurt (low-fat), green beans, carrots, potatoes, cheddar cheese, ground beef, cream of mushroom soup, and chicken breast meat. A number of these foods were selected for use because they had been successfully used in other low folate intake studies (8). Two types of extra protein pancakes were fed throughout the conventional food periods to provide protein intake at 1.2g/kg body weight per day. Margarine, sucrose, and Polycose all devoid of folate, were used throughout the repletion periods to supplement energy needs to maintain individual body weights, and a vitamin/mineral supplement devoid of folate was provided daily.

Participants in the "low" and "marginal" repletion periods received the same foods, except some food quantities were decreased to provide lower amounts of folate. During the "adequate" repletion period in addition to the foods provided during the "low" and "marginal" periods, other foods, such as, tomato sauce, white bread, dehydrated onion, cooked frozen spinach, and a banana-frozen orange juice concentrate puree were added to increase folate content in the diets. However, the differences between the 200 and 300 mcg "adequate" folate diets were in the amounts of tomato sauce, cooked frozen spinach, and orange juice concentrate provided in the diets. For this study, use of the same major foods for the different levels of natural folate yielded consistency in meeting the level of folate required by the study protocol.

Recipe Calculation

Though most WHNRC metabolic cycle diets have been limited to 3 to 4 day rotational plans, some diet plans have used 5 to 10 day rotational menus. To help control intake variability, the usage of fresh produce and pre-packaged mixed entree dishes should be minimized in a metabolic study. Mixed dishes served in a metabolic diet should be dishes created from a recipe using the foods that have been analyzed. In preparing a mixed entree dish the rule is that foods in the mixed dish must be weighed and cooked for each participant individually. Whenever possible, the participant's food should be weighed into, cooked and/or served in the same container.

At WHNRC, the research dietitians have coded individual foods for use in a recipe as cooked items and then run nutrient calculations using the cooked food values. However, the ideal computerized food composition data bank system used to design a cycle menu should have an algorithm to compute nutrient cooking yields/losses and to transform the data into nutrient values for the prepared item. This means that for every raw food in a food composition data bank there needs to be cooking yields/losses factors associated with the food. In addition, ideally, for water soluble nutrients there should be nutrient retention factors associated with those nutrients for different cooking methods. Nutrient values from calculated recipes must be verified by analyses before the dish is used in a cycle menu. Recipes where yields/cooking losses could vary greatly should be avoided.

Sometimes, for design purposes, research dietitians will use nutrient loss or retention information to create the control necessary for a research diet. An example may better explain this statement. A study (9) was conducted at WHNRC to assess the effect of animal or plant protein sources on the vitamin B-6 requirement of young women (Table 6). A strictly controlled, conventional food, 3 day cycle diet with protein from animal or from plant sources during the four repletion periods was fed (Table 7). Both repletion diets were calculated to provide a 0.5 mg per day level of vitamin B-6, and a multiple vitamin and mineral supplement devoid of vitamin B6 was fed daily to the volunteers. Composites of both sets of repletion diets were analyzed for vitamin B-6 by microbiological assay using Saccharomyces uvarum and for nitrogen before and during the research study.

The difficulty in using the version of the food composition data bank available to design this repletion diet was that many foods in the data bank at that time had missing vitamin B-6 information and that cooking yields and retention factors were also unavailable. Although only foods with existing vitamin B-6 values were used, vitamin B-6 content in those foods were higher then could be allowed for in the protocol. Through information found in the literature about yield and retention factors for vitamin B-6, special cooking procedures were devised to lower the vitamin B-6 content of the foods. All poultry, beans and vegetables were boiled and drained three times before serving. Poultry was skinned and boiled prior to the three time cooking treatment. As confirmed by analysis, the boiling procedure did reduce the vitamin B-6 content in the foods tested. Thus, in this study, cooking loss and nutrient yield information helped reduce the level of vitamin B-6 in the protein products served.

Areas of Need

It is becoming more apparent to the dietitians at WHNRC that the food composition data bank needed to design research diets at WHNRC need not be as large as the current version. However, it should contain all of the commonly consumed foods needed for a well balanced and nutritionally adequate diet. In such a data bank, energy and every known nutrient or needed dietary component should be represented by complete, accurate chemical values. Unlike Survey data banks or dietary assessment data banks, such a metabolic research data bank should be as free of imputed values as possible. If imputed values are included, they must be flagged. If imputed values or temporary records are used in calculating a cycle menu, a method of identifying their contribution must be incorporated into the nutrient summation report. In addition, attached to such a metabolic research data bank should be user friendly, menu driven programs to maintain the data bank, to append to the data bank nutrient composition of specialty items or dietetic products, to calculate research diet profiles, and to produce recipes calculations.

The challenge here is to provide a complete and accurate food composition data bank for human nutrition metabolic research studies. This challenge can best be met by a collaborative effort between different MRUs and food composition analyses laboratories. A consortium could be developed between these groups so that diet design ideas and valuable nutrient composition information can be exchanged. Perhaps the five USDA Human Nutrition Research Centers can serve as the leaders in developing such a consortium for metabolic research groups.

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Table 1
Basic Means of Control Used by the WHNRC Metabolic Dietetic Service

- Presentation of an appealing and accurately calculated diet plan.
- Controlled selection and sources of food.
- Establishment and enforcement of standardized procedures in food preparation and service.
- Usage of distilled or de-ionized water in food preparation or presentation.
- Strict supervision of personnel assigned to food preparation, measurement, and service tasks.
- Employment of a variety of backup systems and check points within dietetic service unit.
- Implementation of quality assurance plan via laboratory analysis of diets served.

Table 2: Flow Diagram of Linear Programming Process

Hypothetical Conditions:

1. 1600 kcal diet: 55% Carbohydrate, 15% Protein, and 30% Fat
2. use Cornstarch nutrient composition for Carbohydrate source
3. use Egg Albumin nutrient composition for Protein source
4. use Cottonseed Oil nutrient composition for Fat source

Hypothetical Equations:

(X g cornstarch)(0.88 g CHO/g cornstarch) + (Y g Egg Albumin)(0.06 g CHO/g Egg Albumin) + (Z g Oil)(0.00 g CHO/g Oil) = (55%)(1600kcal)(g CHO/ 4 kcal)

(X g cornstarch)(.002 g Protein/g cornstarch) + (Y g Egg Albumin)(0.80 g Protein/g Egg Albumin) + (Z g Oil)(0.0 g Protein/g Oil) = (15%)(1600kcal)(g Protein/ 4 kcal)

(X g cornstarch)(0.0g Fat/g cornstarch) + (Y g Egg Albumin)(0.0g Fat/g Egg Albumin) + (Z g Oil)(1.0 g Fat/g Oil) = (30%)(1600kcal)(g fat/ 9 kcal)

Flow of Programming Process:

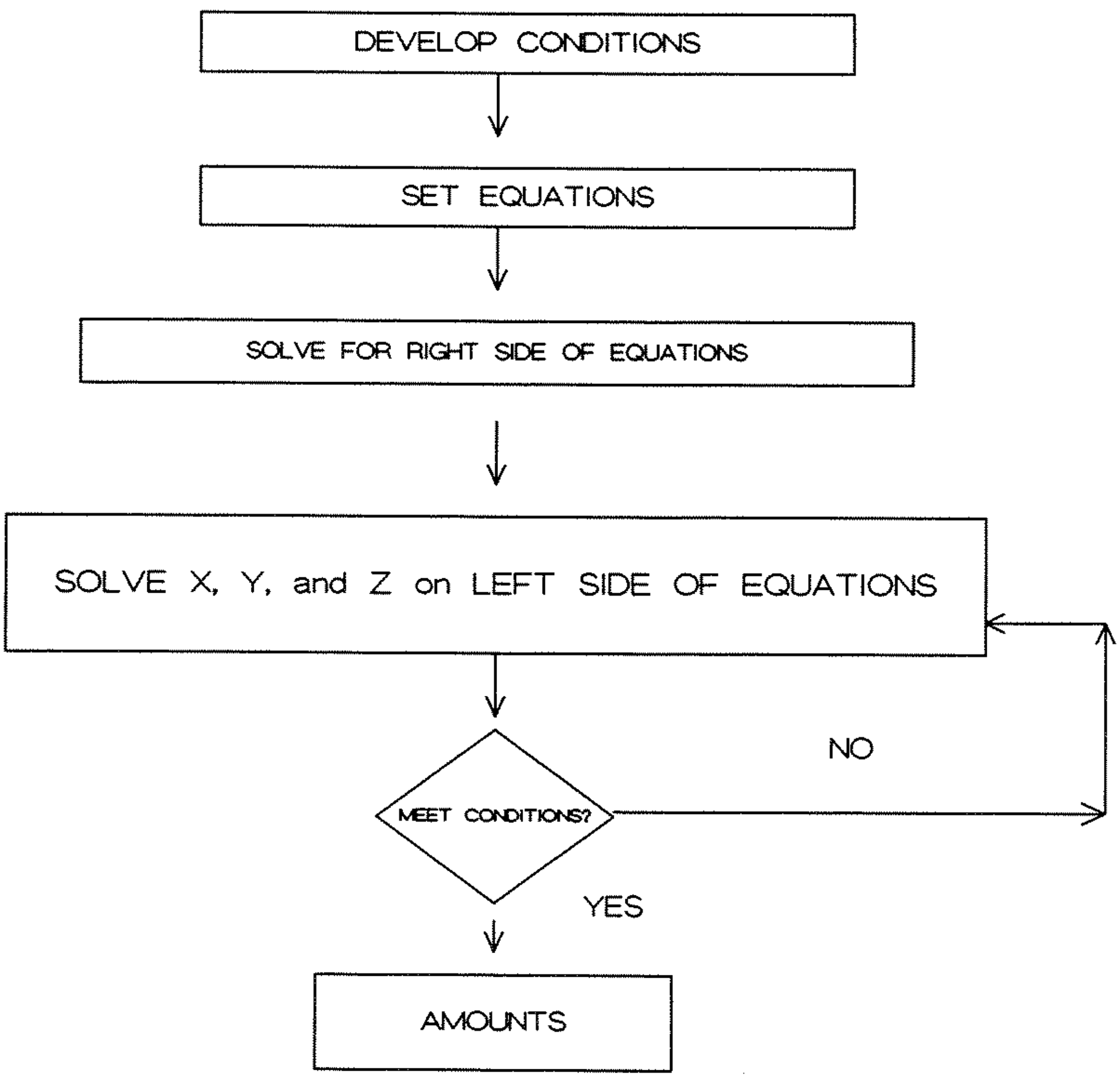

Table 3

Basic Formula*

Ingredients	g/d
Egg White, Sprayed Dry	44.05
Dextri-Maltose	78.7
Cornstarch	172.9
Sucrose	21.7
Oil, Cottonseed	40.7
Butterfat, Anhydrous	18.1
NaCl	0.26
$NaHCO_3$	8.12
KCL	2.65
KH_2PO_4	3.02
$CaCO_3$	1.87
MgO	0.40
Alpha Cellulose	6.0
Biotin	2×10^{-3}

* From Sauberlich et al. in Am. J. Clin Nutr. 50:1039, 1989. Carbohydrate intake is 60% of kilocalories; protein intake is 10% of kilocalories; fat intake is 30% of kilocalories; P/S = ~1.

Table 4

Experimental Design of Folate Study*

Period	Duration	Groups	Diets	Natural Folate (mcg/d)	Synthetic Folic acid (mcg/d)
Orientation	3 days	A	ad libitum	400	0
		B	ad libitum	400	0
		C	ad libitum	400	0
Depletion	4 weeks	A	formula	0	0
		B	formula	0	0
		C	formula	0	0
Low Repletion	3 weeks	A	Menus A-1	20	5
		B	Menus B-1	50	0
		C	Menus C-1	100	0
Marginal repletion	3 weeks	A	Menus A-2	20	30
		B	Menus B-2	100	0
		C	Menus C-2	150	0
Adequate repletion	3 weeks	A	Menus A-3	20	80
		B	Menus B-3	200	0
		C	Menus C-3	300	0

* From Sauberlich et. al. in Am. J. Clin. Nutr. 46:1016, 1987.

Table 5

Folate Content of Foods as Prepared for Consumption (mcg/100 g of food)*

Food Item	Total Folate
Apple Juice, bottled	0.12
Apricot Nectar, canned	0.14
Banana-Frozen Orange Juice Puree	20.4
Bean, green †	7.6
Carrots,	5.6
Cheese (cheddar)	34.6
Chicken (white portions) †	4.8
Ground Beef †	4.1
Onion, dehydrated	34.5
Potatoes, Canned †	4.4
Soup: cream of mushroom	3.0
Spinach (Frozen, cooked)	133.9
Tomato sauce, canned	22.5
Yogurt, low-fat	3.2

* Foods were analyzed at WHNRC, ARS, USDA.

† Food item boiled three times before serving to reduce folate content.

Table 6

Experimental Design of Vitamin B-6 Study*

Period	Duration (days)	Total B-6 Intake	Diet Type
Control	4	variable	Ad Libitum
Control	3	2.00	Formula
Depletion	Variable	<0.05	Formula
Repletion	14	0.5	APD or PPD[a]
Repletion	14	1.00	APD or PPD
Repletion	21	1.50	APD or PPD
Repletion	14	2.00	APD or PPD

* Adapted from Kretsch et. al.in Am. J. Clin. Nutr. 53:1266, 1991.

[a] APD=Animal Protein Diet; PPD=Plant Protein Diet.

Table 7

Day 1 Menus used in the Vitamin B-6 Study*

Plant Protein Diet	Animal Protein Diet
Food	Food
Breakfast	Breakfast
Orange juice, conc.	Orange juice, conc.
Bagel, plain	Bagel, plain
Margarine	Cream cheese
Garbanzo beans	Dietetic muffin †
Fruit cocktail, canned	Butter
Lunch	Lunch
Fruit cocktail, canned	Fruit cocktail, canned
Grape juice, conc.	Grape juice, conc.
Bread, white	Bread, white
Garbanzo beans	Plain lowfat yogurt
Cottonseed oil	Milk, dry powder
Iceberg lettuce	
Supper	Supper
Pears, canned	Pears, canned
French bread	French bread
Black beans	Chicken breast, skinless
Tofu, compressed	Mayonnaise
Cottonseed oil	Oyster soup
Iceberg lettuce	Iceberg lettuce

* Kretsch et. al. (manuscript in preparation). Energy and Protein intakes were adjusted in the plant protein diet using soy-protein, cottonseed oil, margarine, and Polycose powder; energy and protein intakes were adjusted in the animal protein diet using Na-caseinate, cottonseed oil, butter, Polycose powder, and Kool-Aid beverage.

† Specially prepared to meet individual protein and energy needs.