ACCEPTANCE

This thesis, Dietary variety in relation to BMI and energy intake of individuals with black African ancestry in two countries of different economic development, by Gitta Adiviana was prepared under the direction of the Master's Thesis Advisory Committee. It is accepted by the Committee members in partial fulfillment of the requirements for the degree Master of Science in the Byrdine F. Lewis School of Nursing and Health Professions, Georgia State University. The Master's Thesis Advisory Committee, as representatives of the faculty, certify that this thesis has met all standards of excellence and scholarship as determined by the faculty.

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ABSTRACT

Objective: To conduct a secondary analysis of dietary variety consumed by individuals of African-origin in two countries with differing stages of economic development. Our overall aim is to determine the relationships of two different dietary variety scores developed previously in our laboratory with reported energy intake (rEI), ER (which will be a more accurate reflection of true EI) and BMI in the total sample and the plausibly reporting subsample.

Methods: Data for this analysis were collected as part of METS between January 2010 to September 2011, whose purpose was to elucidate the associations of physical activity and diet with body weight, diabetes, and risk of cardiovascular disease. Five communities of African-origin and in different countries were selected based on their different levels of economic development, as measured using the UN Human Development Index**.** A subsample of 141 (Ghana, n=70 and U.S., n=71) men and women with an average age of 35.1±0.5 years and an average BMI of 27.5±0.6 kg/m^2 were randomly selected to have their total energy expenditure (TEE) measured by the doubly labeled water (DLW) method. Participants were interviewed using the multiple-pass method designed by the Medical Research Council of South Africa to estimate their dietary intake the day after consumption. Data was transferred to Nutrient Data System for Research (NDSR) ver. 2011 and dietary variety scores (DVS) were calculated for combination and ingredient varieties. Combination variety was defined as the total number of unique foods and beverages consumed in a day. Ingredient variety was the total number of unique ingredients consumed in a day. Implausibility of rEI was controlled for by calculating rEI as a percentage of TEE. Associations of dietary variety scores with total energy intake and BMI were assessed for both the total sample and plausible subsample using SPSS version 22 through univariate analyses of variance and correlations.

Results: Both combination and ingredient variety were positively associated with rEI in both countries when implausible reporting was not controlled, but no significant association was observed in both countries when implausible reporting was controlled. Ingredient variety was negatively associated with TEE when implausible reporting was both controlled and uncontrolled in the U.S. (p= 0.029), but no association was observed in Ghana. Ingredient and combination variety were also negatively associated with log BMI, percent body fat, and weight in U.S. when implausible reporting was not controlled but not in Ghana’s. However, in Ghana, combination variety was positively associated with percent body fat (p=0.041) and log BMI (p= 0.027) when plausible reporting was controlled but was not significant when implausible reporting was uncontrolled.

Conclusion: Dietary variety was positively associated with rEI in both countries when implausible reporting was not controlled and with obesity markers in Ghana when plausible reporting was controlled.

Dietary Variety in Relation to BMI and Energy Intake of Individuals with Black African Ancestry in Two Countries of Different Economic Development

Georgia State University

In partial fulfillment of the requirement for the degree of Master of Science in Nutrition (DPD)

By

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Abbreviations

BMI Body mass index

CHO Carbohydrate

d Day

DV Dietary variety

DLW Doubly-labeled water method

EI Energy intake

F Female

FAO Food and Agriculture Organization

FFQ Food frequency questionnaire

G Group

HV High variety

LV Low variety

m Months

M Male

METS Modeling the Epidemiologic Transition Study

N Number of participants

NA Data not available

NFCS Nationwide food consumption survey

No Number

NR Not reported

NS Non-significant observed

NW	Normal weight subjects
OB	Obese subjects
OW	Overweight
PAL	Physical activity level
Q	Quartile
r	Pearson's correlation coefficient
rEI	Reported energy intake
RV	Reduced variety
SD	Standard deviation
T	Tertile
TEE	Total energy expenditure
US	United States
w	Week
y	Year
Y	Yes

Chapter I

Introduction

Obesity is a global epidemic and results in numerous health problems; thus, effective preventive measures are needed to halt the epidemic (1). At an individual level, maintaining zero energy balance is necessary to maintain body weight while correspondingly, weight gain is the product of positive energy balance (2). Both low energy expenditure and excess energy intake could contribute to positive energy balance. One potential dietary factor that can contribute to energy intake is dietary variety (3). In general, dietary variety may be defined as the number of unique foods consumed either in a meal or a day (4). Dietary variety could either increase or decrease energy intake depending on the type of variety consumed. A greater variety of energy-dense foods has been associated with higher energy intake, and great variety of micronutrient-dense foods has been associated with lower energy intake (5). The Modeling the Epidemiologic Transition Study (METS) was designed to explore the associations of physical activity (energy expenditure) and diet with body weight and cardio metabolic risk. As a result of the significant implausible reporting, captured using the doubly-labeled water (DLW) method, the focus of much of the analyses to date has been on energy expenditure. Dietary variety may be less affected by implausible reporting than energy intake as it accounts for the number of foods consumed rather than the exact portion or quantity of food ingested. For the purposes of the current study, dietary variety was defined as number of individual foods consumed over a single day. Consequently, in this cross-sectional cohort study in adults of African-origin from two diverse countries, we assessed dietary variety and determine its association with total energy intake and body mass index (BMI). We explored whether dietary variety was a significant determinant of energy intake and BMI of participants in differing economic development.

In this secondary analysis of data from METS, we calculated two dietary variety scores for a single day and their associations with energy intake and BMI. The purpose of this study was to determine the associations of these variety scores with energy intake and BMI. Implausible reporting of energy intake was assessed and accounted for in the analysis as implausible reporting was observed in both countries (6), which may result in systematic error and inaccurate associations (7). We achieved this goal by addressing the following aim and hypotheses:

Aim and Hypotheses

Aim: To conduct a secondary analysis of dietary variety consumed by individuals of African-origin in two countries with differing stages of economic development. A subsample of participants had their total energy expenditure (TEE), or energy requirements, determined using the gold standard DLW method. Our overall aim was to determine the relationships of two different dietary variety scores developed previously in our laboratory (5, 8) with reported energy intake (rEI), TEE (which will be a more accurate reflection of true EI) and BMI when implausibility was both controlled and uncontrolled.

Hypotheses:

1. Combination variety and ingredient variety are positively associated with rEI, TEE, and BMI when implausible reporting was both controlled and uncontrolled, with stronger associations when implausible reporting was controlled.

2. Individuals from United States (country with higher economic development) have higher total and ingredient variety scores than those from Ghana.

Chapter II

Literature Review

A. Obesity: a global problem

Obesity is a global epidemic and results in numerous health problems such as diabetes, hypertension, heart disease, and cancer; thus, effective preventive measures are needed to halt the epidemic (1). At an individual level, maintaining zero energy balance is necessary to maintain body weight while correspondingly, weight gain is the product of positive energy balance (2). Both low energy expenditure and excess energy intake could contribute to positive energy balance. Since the 1970s, there has been a shift towards consumption of processed foods, dining away from home, and consumption of oils and sweet beverages across all economic levels globally. Paired with decreased physical activity, these shifts contribute to the rise in obesity (9). Another possible cause of obesity is the increase of the availability and affordability of ready-to-eat or packaged foods and the decrease in fresh vegetable and fruit availability (10). These readily available packaged foods tend to be high in fat and calories and thus increase the risk for overconsumption and persistent positive energy balance.

Another potential dietary factor that can contribute to energy intake is dietary variety (3). In general, dietary variety may be defined as the number of unique foods consumed either in a meal or a day (4). In the remainder of this review recommendations for dietary variety consumption, different definitions of dietary variety used in previous studies, and the results of studies on the role of dietary variety in weight control, with an emphasis on human studies will be covered. I will also touch on the role of a country's economic development in obesity, and how both may relate to the availability and consumption of variety in the diet.

B. Dietary variety as a foundation of good nutrition

The best way to control a disease is to prevent it from occurring in the first place. The human body needs a variety of nutrients in order to maintain its function at an optimal level and prevent diseases. These nutrients are divided into two major categories: macronutrients and micronutrients. The macronutrients - carbohydrate, protein, and fat - are nutrients which render energy; energy is needed in large amounts for cell growth and function (11). Micronutrients are needed in much smaller amounts and consist of vitamins and minerals. Deficiencies in micronutrients have been shown to lead to a range of morbidities from reduced immune system function to malnutrition which also leads to various diseases such as metabolic disease and cardiovascular disease (12). Although higher amounts of some micronutrients could lead to malabsorption of other micronutrients and toxicity, a balanced diet is highly unlikely to reach such toxic levels. Therefore the US Dietary Guidelines usually encourage consumption of a variety of foods to meet daily needs of micronutrients (13).

The Food and Agriculture Organization of the United Nations (FAO) and its member countries developed strategies to improve food quality and safety to control diseases, by promoting appropriate diets and healthy lifestyles through the dietary guidelines specific to each country. Eighty-one countries in five different continents have published their dietary guidelines on the FAO's website (14). Out of these countries, 21 did not include dietary variety as part of their guidelines (Benin, Japan, South Korea, Vietnam, Austria, Belgium, Croatia, Cyprus, Finland, Greece, Hungary, Italy, Malta, Sweden, Switzerland, Chile, Guyana, Honduras, Mexico, Saint Lucia, and Qatar). The populations of interest for this project are derived from the Modeling the Epidemiologic Transition Study (METS) study which consists of participants from two communities with the same ancestral ethnicity in two different countries (the United States and Ghana) (15). Dietary guidelines for Ghana have not been published. Below are the recommendations concerning dietary variety in dietary guidelines for the United States.

> In the US, the 2015-2020 Dietary Guidelines for Americans tell Americans to "Follow a healthy eating pattern across the life span" and to "Focus on variety, nutrient density, and amount." It then specifies that "a healthy eating pattern" includes: (a) A variety of vegetables from all of the subgroups—dark green, red and orange, legumes (beans and peas), starchy, and (b) A variety of protein foods, including seafood, lean meats and poultry, eggs, legumes (beans and peas), and nuts, seeds, and soy products" (16).

Dietary variety is a primary part of the dietary guidelines in many different countries, but not all countries specify from which food groups a variety of foods should be consumed. The United States regard dietary variety as part of a good diet or a healthy lifestyle. However, a section will be covered later in this review which will show that not all variety play a positive role in one's well-being because consuming a variety of starchy and energy-dense foods could result in adverse health effects due to their effects on increasing caloric intake. Studies which have been done on dietary variety and their results on adults will be reviewed in a later section. Only studies on adults will be included because children and infants have a gradual increase in weight and energy intake related to their growth regardless of dietary variety and their dietary variety choices are limited to parents' provision for foods and beverages. Therefore, the role of dietary variety in weight control for adults and children could differ.

C. Definition of dietary variety

There is no standard definition of dietary variety that has been agreed upon by all researchers who study dietary variety. Many types of dietary variety and definitions for each have been used, as shown in Table 1. Depending on the definition of dietary variety used, the same set of data could yield different results. Therefore, when comparing results across studies, the particular definition(s) used in each study needs to be kept in mind. However, all the different definitions for dietary variety account for unique food and beverage items regardless of how much or how many times they are consumed within a specified period of time. Thus, the basic concept of dietary variety remains consistent across studies regardless of the specific type and definition of variety examined.

Table 1. Definitions of dietary variety used in published studies in humans

Type of Variety	Description	References
Total	Total number of unique food and beverage items consumed.	McCrory et al. (4), Bernstein et al. (18), Roberts et al. (5), Saibul et al. (19)
Food group or MyPlate	The number of unique fruits, vegetables, dairy, protein/meat, and grains consumed	Roberts et al. (5), Azadbakht et al. (20), Jayawardena et al. (21)
Micronutrient dense	The number of unique foods consumed which are important sources micronutrients	McCrory et al. (4), Huang et al. (7)
Energy dense	Total number of unique foods consumed which have a high amount of calories per gram	McCrory et al (4), Huang et al. (7)

Micronutrient weak	Total number of unique food and beverage items consumed from foods that are poor sources of micronutrients	Roberts et al. (5)
Energy weak	Total number of unique food items consumed from foods low in energy density	Roberts et al. (5)
Ratio	Percentage of food items consumed in vegetables compared with sweets, snacks, condiments, entrées, and carbohydrates	Sea et al. (22), McCrory et al. (23)
Macronutrient	Total number of unique foods in macronutrient category	Lyles et al. (24)
Ingredient	Total number of recipe ingredients	Yao et al.(25)
Fruits and vegetables	Total number of uniquefruits and vegetables	Bernstein et al. (18)
NFCS (Nationwide Food Consumption Survey)	Total number of unique foods characterized by distinct code numbers	Krebs-Smith et al. (26)
Palatable food variety with similar macronutrient composition	Total number of unique foods with similar composition of protein, fat, and carbohydrate	Stubbs et al. (27)
High or low glycemic index food variety	Total number of unique foods with high or low glycemic index	Alfenas et al. (28)
Snack food variety	Total number of unique snack foods	Raynor et al. (29)
Non-nutrient dense, energy dense variety	Total number of unique foods which are poor sources of nutrients but has a high amount of calories per gram	Raynor et al. (30)
High calorie	Total number of good tasting high-calorie foods available	Thomas et al. (31)

D. Dietary variety studies

a. Animal model studies

As reviewed by McCrory et al. (3), studies in animal models showed that meal fed animals presented with a variety of chow flavors and textures had a 25% increase in energy intake compared to animals with only one choice of chow. Dietary variety not only increases energy intake within a meal, it also has longer term effects on body weight and body fat. Studies reviewed showed a positive relationship between dietary variety and weight gain. In addition, variety was also positively associated with weight gain. One study in the review observed significant fat gains only in rats fed with simultaneous variety but not in rats fed with successive variety. Rats fed with successive variety were presented with a different palatable food for each meal. Those fed with simultaneous variety had three palatable foods presented together in each meal. Thus rats in simultaneous variety had more variety in each meal which caused increased weight and fat gain. The availability of a variety of foods is an important factor in the amount eaten in the meal and in the etiology of obesity. After the review, a study (17) on consumption of dietary variety in rhesus monkeys was published which showed results consistent with those from the studies in the smaller animal models. They found that during two two-week study phases the monkeys ate more frequently and consumed more calories when two varieties of chows were available compared to when only one chow was available. Therefore, dietary variety in animal studies consistently showed dietary variety causing increase in energy intake, weight gain, and body fat gain.

b. Human studies single meals

Single meal experimental studies in humans yield the same results as do the animal model studies described above, also reviewed by McCrory et al. (3) In particular, variety in single meal studies lead to increased food intake when more than one sensory property (color, texture, or flavor) differed among the foods with an increase of 22% in energy intake of within-subject designs. Different flavor or shape of foods had more impact in increased energy intake than foods which differed only in color with a higher increase of 29% in both within and between-subject designs. More single meal studies on dietary variety in human were published after the review (Table 2). These studies were consistent with findings of the review (3) and showed increased energy consumption when participants were in experimental condition. All of the foods used in the experimental conditions were varied in flavor, color, and texture. In a study by Brondel et al. (32), there were three conditions: monotonous (fries and brownies alone), simultaneous (condiments with fries and brownies), or successive (condiments were presented afterwards). Calorie consumption in simultaneous and successive conditions were significantly higher than in monotonous condition, with successive condition associated with the highest calorie consumption as participants increased food intake after the introduction of condiments. Three other studies (33-35) specifically focused on vegetable variety in adults and found that variety could be used to increase appetite and vegetable consumption in adults as intake of vegetables increased when more than one variety was available.

An additional study (37) which focused on fruit variety also confirmed the same positive relationship of dietary variety with energy intake. Overall, variety caused an average of 39% increase in energy intake for within-subject study designs published since the review (3) that was almost twice more than the mean of single-meal variety effect in the review (22%). However, variety effect was exactly the same as the review (53%) (3) for between-subject design (33). In summary, the single meal studies in humans have shown significantly higher energy intakes in variety conditions and that energy intake is even higher when more than one sensory property differed among the foods. Consequently, variety with more than one differing sensory property should be used to increase fruit and vegetable consumption in adults but should be limited to decrease consumption of energy-dense and nutrient-weak foods such as fries and brownies.

c. Hypothesized physiologic basis for the role of dietary variety in increasing energy intake at a meal

The physiological basis hypothesized for dietary variety's role in increasing energy intake has to do with a phenomenon called sensory specific satiety (38). Sensory specific satiety means that satiety is specific to foods which have been eaten. Satiety is then reset for foods which have not been eaten. In other words, the pleasantness of taste of food previously consumed declines, but pleasantness of taste of food not yet consumed stays high. The degree of sensory specific satiety is affected by the texture, flavor, and color of the food (39). Because satiety is specific to foods eaten, this could lead to overeating or increased energy intake when a variety of food is available because satiety does not set in for unconsumed foods.

Table 2. Single meal experimental studies on of the effects of DV on EI in adults

First author year [reference]	Subjects	Control treatment (no. of foods/ vegetables/ fruits)	Experimental treatment (no. of foods/vegetables/ fruits)	Food types	Energy intake of control treatment (mean kcal±SD)	Energy intake of experimental treatment (mean kcal±SD)	Increase of energy intake (%)	Significant difference between treatment and control
Within- subject designs								
Brondel, 2009 (32)	N = 21 M Age 22±3 y BMI 22.4±0.9 kg/m^2	1	3	French fries, brownies, and condiments	1195±552	1485±582	24	Y
Meengs, 2012 (34)	N = 32 M Age 27.4±1.2 y BMI 25.5±0.6 kg/m2 N = 34 Age 26.5±1.3 y BMI 23.3±0.6 kg/m2	1	3	Vegetables	116±12 (broccoli) 55±6 (carrots) 111±11 (peas) 109±8 (broccoli) 58±4 (carrots) 114±8 (peas)	119±10 123±8	2 116 7 13 112 8	Y
Levitsky, 2012 (36)	Study 1 N = 27 Age 18-21 y BMI NR	2	3	Chicken, potatoes, rice, green beans, and peas	NR	NR	18	Y
	Study 2 N = 24 Age 19-21 y BMI 18-25 kg/m^2	1	5	Pasta and vegetables	NR	NR	NR	Y

Raynor, 2012 (37)	N = 20 M, F Age 26.5±8.1 y BMI 22.9±3.0 kg/m^2	1	4	Fruits	21±23	34±24	62	Y
Wijnhoven, 2015 (35)	N = 19 F Age 76 – 92 y BMI 24.8±4.9 kg/m^2	4	10	Vegetables, meats, and starch with focus on vegetables	341±115	427±119	25	Y
Mean							39	
Between- subject design								
Bucher, 2011 (33)	N= 98 M, F Age 22.8±2.25 y BMI 21.98±2.51 kg/m^2	1	2	Vegetables	20±8 (beans) 25±8 (carrots)	34±10	70 36	Y
Mean							53	

BMI, body mass index; d, day; F, female; G, group; M, male; N, number of participants; No, number; SD, standard deviation; Y, yes; y, years

E. Studies in humans lasting beyond a single meal

a. Cross-sectional studies

i. Energy intake

Animal model and single meal human studies showed consistent results on energy intake, however, single meal studies could not be generalized to day to day living as they were short-term and difficult to replicate or translate to normal daily living. Cross-sectional studies, though they do not demonstrate causality, help to determine the potential longer-term influences of dietary variety on energy intake and adiposity and portray normal daily intake. These studies are summarized in Table 3. In more than half of the studies (21, 23, 24, 26, 40, 41) which assessed the association of variety on energy intake, variety was positively associated with energy intake, especially a greater variety of energy-dense foods was associated with higher overall energy intake. However, greater variety of micronutrient-dense foods has been associated with lower overall energy intake (5, 22-24). In one study (22), negative (grains variety) as well as null relationships (fruits and meats variety) were observed with energy intake in obese and normal weight adults in Hong Kong because greater consumption of micronutrient-dense foods were associated with less consumption of energy-dense foods. Schebendach et al. (40) studied dietary variety as part of a treatment for anorexia nervosa patients and found that patients who consumed more variety of energy-dense foods had increased overall energy intake and were considered to have successful treatment. Almost all kinds of food variety were positively related to increased energy intake except for micronutrient-dense food variety which was related to decreased overall energy intake. Therefore, dietary variety was successfully used as part of a treatment for patients who needed help maintaining or gaining weight.

ii. Adiposity

As shown in Table 3, dietary variety was positively (18, 23-25) and negatively (5, 20, 22-24) associated with BMI in cross-sectional studies. Dietary variety was positively associated with BMI independent of other factors such as frequency of restaurant food consumption and physical activity (25). A study previously covered by Schebendach et al. (40) showed patients with anorexia nervosa were able to maintain desirable body weight because they consumed higher variety of foods compared to those who were considered to have poor outcome. However, in another study (22), only snacks variety was positively associated with BMI while grains and meats variety were negatively associated with BMI (22). Similarly interesting, older (age 60 +) and younger (age 21 – 60) adults with healthy BMI (22 – 24.99) consumed higher number of energy-weak variety foods than those with low BMI, overweight, and obese adults (5).Thus effect of dietary variety on adiposity varied depending on the type of variety used in the study.

Table 3. Cross-sectional studies on associations of DV with EI and adiposity in adults

First author year (reference)	Subjects	Definition of DV used	Dietary assessment method	Duration over which DV was quantified	DV Scores, mean ± SD	DV vs EI relation	DV vs adiposity relation
Krebs-Smith, 1987 **(26)**	N = 3701 MF Age >1 y BMI NR	Total # of unique food items characterized by distinct NFCS code # and total # of foods in MyPlate groups	24 h recall	3 d	Total: 42.7±13.5	+	NR
McCrory, 1999 **(23)**	N = 13 M Age 55±15 y BMI 25.5±3.3 kg/m^2 N = 58 F Age 52±15 y BMI 24.2±4.0 kg/m^2	% of different food types consumed from 10 different food groups initially then collapsed into 2 food groups.[a]	FFQ	6 m	NR	+ in all food groups	% body fat Vegetable - Other variety type [a] +
Bernstein, 2002 **(18)**	N = 36 M Age 88.1±5.4 y BMI 25.6±2.7 kg/m^2 N = 62 F Age 86.6±5.5 y BMI 24.8±3.6 kg/m^2	# of different foods and FV consumed	Weighed food record	3 d	M: Total: 36±5 FV: 11±3 F: Total: 35±4 FV: 11±3	+ in total and FV in M and F	BMI Total and FV in F +

Yao, 2003 **(25)**	N = 63 M Age 42.8±0.5 y BMI 25.4±0.4 kg/m^2 N = 67 F Age 42.3±0.5 BMI 24.9±0.5 kg/m^2	Total # of recipe ingredients	Weighed food record (by researcher) supplemented with recall as needed	3 d	M: 32±1 F: 34±1	NR	Ingredient variety in combined M and F analysis +
Sea, 2004 **(22)**	N = 60 (OB) MF Age 33.8±9.27 y BMI 35.5±5.5 kg/m^2 N = 60 (NW) MF Age 33.9±6.8 BMI 20.9±1.4 kg/m^2	Percentage (%) of different food types consumed in each of 6 food groups [b]	FFQ	1 w	OB Beverages: 15.3±7.2 Fruits: 13.8±8.9 Grains: 22.3±8.6 Meats: 16.2±5.4 Snacks: 16.0±10.7 Vegetables: 23.7±10.0 NW Beverages: 14.7±9.3 Fruits: 13.7±7.1 Grains:35.2±10.7 Meats: 20.1±7.9 Snacks: 7.4±4.7 Vegetables: 22.3±9.2	+ in beverages, snacks, and vegetables - in grains NS in fruits and meats	- in grains and meats + in snacks NS in beverages and fruits
Roberts, 2005 **(5)**	N = 892 (younger) MF Age 39.7±10.9 y BMI 25.0±3.9 kg/m^2 N = 282 (older) MF Age 71.1±7.5 y BMI 21.2±3.7 kg/m^2	Total, food group, energy-dense, energy-weak, micronutrient-dense, and micronutrient-weak	1 x 24 h recall	1 d	NR	NR	Total NS Food group NS Energy-dense+ Energy-weak- Micronutrient-dense NS Micronutrient-weak NS

Lyles, 2006 **(24)**	N = 13 M Age 58.3±11.7 y BMI 36.0±11.5 kg/m^2 N = 61 F Age 50.1±12.7 y BMI 31.5±7.0 kg/m^2	Total # of unique foods in macronutrient category: CHO, protein, and fat	Estimated food records for 2 weekdays and 2 weekend days	4 d	CHO: 25.8 ± 9.5 Protein: 10.1 ± 2.8 Fat: 14.9 ± 5.8 CHO: 22.2 ± 6.0 Protein: 8.7 ± 2.9 Fat: 12.5 ± 4.6	+ in all types of variety	+ in all food groups except CHO in F - in CHO in F
Schebendach, 2008 **(40)**	N = 41 F Age 18-45 y BMI NR	Total # of foods and beverages consumed from 17 food groups[c]	Estimated food records	4 d during 2 to 4 weeks	Success group[d]: 12.8±1.6 Failure group[e]: 11.1±2.4	+	+
Saibul, 2009 **(19)**	N = 182 F Age 30.8±7.8 y BMI 25.9±5.2 kg/m^2	Total # of food items consumed	3 x 24 h recalls	3 d	T1: 0 – 6 T2: 7 – 8 T3: > 9	+	NR
Thomas, 2011 **(31)**	N = 39 F Age 20.1±2.0 y BMI 21.6±1.8 kg/m^2	Total # of good tasting high-calorie foods available	24 h recalls	7 d	NR	+ in those with moderate and high BMI[h]	NR
Azadbakht, 2011 **(20)**	N = 289 F Age 18-28 y BMI 25.9±5.1 kg/m^2	Total # of foods in 5 different food groups[f]	FFQ	Daily, weekly, and monthly basis from past year	Total Q1: < 3 Q2: 3 – 5.4 Q3: 5.5 – 8.4 Q4: ≥ 8.5	NR	- In all food groups

Jayawardena, 2013 **(21)**	N = 481 MF Age >18 y BMI NR	Total # of foods in 12 different food groups[g]	1 x 24 h recall	1 d	Total T1: 2 – 5 T2: 6 – 7 T3: 8 – 11	+ in all variety types	+ in all variety types

[a] Two types of variety: 1) vegetables and 2) sweets, snacks, condiments, entrées, and carbohydrates
[b] Six types of variety: beverages, fruits, grains, meats, snacks, and vegetables
[c] Seventeen food groups: total complex carbohydrate and three carbohydrate subgroups (breads, cereals, starches); total protein and two protein subgroups (animal, vegetable); casseroles and mixed entrees; fruits; vegetables; yogurt and cheese; desserts and sweet snacks; savory snacks; added fats; added sugars; miscellaneous foods; and caloric beverages
[d] Success group: Morgan-Russell categorization of a full, good, or fair outcome; BMI ≥18.5
e Failure group: Morgan-Russell categorization of a poor outcome; BMI < 18.5
[f] Five groups: bread-grains, vegetables, fruits, meats, and dairy
[g] Twelve groups: starch (cereals, tubers, roots and starchy vegetables such as jackfruits), vegetables, green leafy vegetables (green salads and 'Mallum'), fruits, fish (including dried fish and seafood) meat (including poultry, egg), legumes (including nuts and seeds except coconut), milk (including all dairy products), beverages (tea, coffee and fizzy drinks), oils and fats (coconut products were included), sweets and miscellaneous (e.g. Alcohol)
[h] Moderate BMI = 25th–75th percentile of the sample BMI distribution, high BMI = upper 25th percentile of the sample BMI distributionBMI, body mass index; CHO, carbohydrate; d, day; DV, dietary variety; EI, energy intake; F, female; FFQ, food frequency questionnaire; G, group; M, male; m, months; N, number of participants; NFCS, nationwide food consumption survey; NS, non-significant observed; NR, not reported; NW, normal weight subjects; OB, obese; OW, overweight; Q, quartile; SD, standard deviation; T, tertile; w, week; y, year

b. Longitudinal studies

i. Energy intake and adiposity

There have been only two longitudinal studies published to date on effect of dietary variety on energy intake and adiposity in adults which were follow-up studies for up to 1 year on weight-restored females with anorexia nervosa (41, 42). In the first study (42), forty-one patients were categorized as treatment success (BMI≥18.5, n=29) or treatment failure (BMI<18.5, n=12) and had a substantial between-group difference in BMI at follow-up (19.6±1.3 vs 16.1±1.1). Those considered to be treatment success also differed significantly in total dietary variety consumed (50.7±6.75 vs 43.1±8.7) though there was no significant difference in energy intake (2,416±532vs 2,175±356). Similar results were found in the second study (41) of 19 female patients with anorexia nervosa. Patients who had poor outcome (BMI<18.5) had significantly lower diet energy density score (DEDS) compared to patients with full, good, or fair outcome (BMI≥18.5). Although not significant, patients who had full, good, and fair outcome had higher dietary variety score (15.7 ± 1.8) compared to those with poor outcome (13.9 ± 2.0). Therefore, longitudinal studies in patients with anorexia confirmed that higher dietary variety caused increased energy intake and BMI which were desirable for these patients.

Table 4. Experimental Intervention Studies on Effects of DV on EI in adults

First author year [reference]	Subjects	Treatment Duration	Control treatment (no. of foods)	Experimental treatment (no. of foods)	Type of variety	Energy intake of control treatment (mean kcal)	Energy intake of experimental treatment (mean kcal)	Significant
Controlled variety studies								
Stubbs, 2001 (27)	N = 6 (lean) M Age 27±2.9 y BMI 23.6±1.1 kg/m^2 N = 6 (overweight) M Age 39.7±2.9 y BMI 28.1±0.5 kg/m^2	3 x 9 d	NA	LV: 5 MV: 10 HV: 15	Palatable food variety with similar macronutrient composition	NA	Lean LV: 2560 MV: 2854 HV: 3196 Overweight LV: 2283 MV: 2404 HV: 2488	Y in lean men in all treatment conditions
Alfenas, 2005 (28)	N = 39 MF Age 24.9±0.8 y BMI 22.9±0.5 kg/m^2	2 x 8 d	1	3	Low glycemic vs. high glycemic foods	NR	NR	N
Reduced variety behavioral studies								
Raynor, 2006 (29)	N = 15 (control) MF Age 48.2±11.4 y BMI 32.3±3.8 kg/m^2 N = 15 (RV) MF Age 50.9±8.4 y BMI 32.2±2.8 kg/m^2	8 w	8.1±2.9	9.2±3.3	Snack food variety	2866±1044	2802±1418	N
Raynor, 2012 (30)	N = 202 F Age 51.3±9.5 y BMI 34.9±4.3 kg/m^2	18 m	2	NR	Non-nutrient dense and energy-dense variety	0 m: 2082±645 6 m: 1351±424 12 m: 1462±426 18 m: 1529±537	0 m: 1934±579 6 m: 1395±416 12 m: 1477±450 18m: 1547±499	N

BMI, body mass index; d, days; F, female; HV, high variety; LV, low variety; MV, medium variety; M, male; m, months; N, number of participants; NA, data not available; RV, reduced variety

c. Experimental studies

i. Energy intake

Observational studies might be the closest setting to normal daily living but there could be many variables which affected results in cross-sectional studies. Such confounding variables could be controlled in experimental studies and longer-term experimental studies may show more generalizable results. Intervention studies were conducted to test effect of dietary variety on energy intake for an extended amount of time. These studies are summarized in Table 4. Stubbs et al. (27) and Alfenas et al. (28) designed studies with matched or similar macronutrient contents for all treatment conditions to eliminate difference in energy intake caused by different macronutrient compositions. Only one (27) of the two studies found significant results: there was significant increase in energy intake in medium variety condition compared to the low variety condition as well as increase in energy intake in high variety condition compared to the medium variety condition. Another study (43) also found significant results in their intervention as participants consumed less variety of higher-energy-dense food groups and more variety in nutrient-dense, lower-energy-dense food groups by the end of the intervention which was associated with less energy intake. Although not all intervention studies found significant results, some showed that limiting variety could be an important factor in a successful program which limits energy consumption for weight loss. Intervention studies which did not find significant results might be caused by participants' lack of adherence to the reduced variety diet prescription.

F. <u>Factors affecting results</u>

a. Reporting implausibility

There was some variability in the results of the cross-sectional studies and this may be due to participants' underreporting of actual energy intakes (EI). Many cross-sectional studies depend on the participants' memory and honesty in collecting data through food frequency questionnaires (FFQ) or 24-hour dietary recalls. There may also be unclear instruction as to portion sizes and what is considered a serving in different studies. In the U.S., the prevalence of under-reporting is 25.7% based on EI : EER (estimated energy requirement) and is associated with being female, older age, non-Hispanic blacks, lower income, lower education, overweight, and obesity (44). Under-reporting also exists in other countries besides the US, and has been reported in Korea

(45), across six European countries (46), and in five diverse communities with African ancestry (6). Under-reporting could be controlled for in studies by excluding those reports which are implausible. Another way to control underreporting is by treating it as a cofounding factor in analyses. It is important to control for implausible reporting because when it is not controlled, it could mask associations between dietary variety with energy intake and adiposity and cause the associations to seem weaker than they actually are.

b. Methodology

Another factor that could affect the results is the study methods. Studies vary in how data are collected (including anthropometrics data) – FFQ (20, 22, 23), 24-hour recall (5, 19, 21, 26), measured (18, 25) vs estimated food intake (24, 40-42), frequency of data collection, and variables considered as markers of obesity. Difference in methods of analyses also affect how results are generated. In combination with the study design, the definition of variety used in each study varies and thus complicates generalization of results. For example, studies which use measured food intake may yield higher amount of energy intake than those which use estimated food intake and may lead to a stronger positive association between dietary variety and energy intake. Despite of all the differences in the amount of energy intake associated with dietary variety, we can still generate the same positive result between dietary variety and energy intake using different ways of data collection.

c. Definition of variety

Another factor which could affect results is the definition of variety used in the study as seen on Table 1. Different definitions of variety were used as there is no standard definition for variety. For example, one study (26) had more variety groups based on food codes which resulted in higher variety scores while another (24) condensed similar food items into a couple of major variety groups which yield lower variety scores. Thus variety scores might have been overestimated or underestimated when compared to other studies but still could be valuable when comparing variables within the study, such as energy intake and BMI.

G. Definition of METS study and role of dietary variety in the study with economic development and obesity in different countries

The Modeling the Epidemiologic Transition Study (METS) was designed to explore the associations of physical activity (energy expenditure) and diet with body weight and cardio metabolic risk (47). As a result of the significant under-reporting, captured using the doubly-labeled water (DLW) method, the focus of much of the analyses to date has been on energy expenditure in relation to obesity (6). However, data on energy intake was also collected and had not been used to determine if there was an association between energy intake, obesity, and dietary variety in this population. Data showed that prevalence of obesity increased with increase in income. Prevalence of obesity in these two African origin communities (the United States and Ghana) differed from 1.4% for men in Ghana to 63.8% for women in the US. It could be that developed countries had much higher obesity compared to developing countries due to economic well-being which means higher variety of foods available. As dietary variety increases, energy intake and BMI increase which result in obesity.

H. Summary and conclusion

As seen in the studies reviewed, different types of dietary variety resulted in either increased or decreased energy intake and adiposity. For the general population, increased energy intake was associated with weight gain and obesity, but it was not so for the elderly and patients with anorexia nervosa. Thus, higher variety in fruits and vegetables could mean better nutritional status especially in frail elderly people (5, 18), and higher variety in energy-dense foods was related to positive energy balance or increase in energy consumption which could lead to higher BMI and obesity. The purpose of the study which will be conducted is to analyze the effects of total and ingredient variety on energy intake, BMI, and adiposity in two different countries with different economic development. We hypothesize that higher total and ingredient variety would be associated with higher energy intake, BMI, and adiposity.

Chapter III

Methods

Study Design

Data for this analysis were collected as part of METS between January 2010 to September 2011, whose purpose was to elucidate the associations of physical activity and diet with body weight, diabetes, and risk of cardiovascular disease (6, 47). Energy expenditure, dietary intake, and body weight and composition were measured in the METS. From the dietary data, we calculated two dietary variety scores and determined their associations with rEI, TEE, and BMI. Follow-up measurements were completed after one year from baseline which included body weight and height.

Participants

Five communities of African-origin and in different countries were selected for the METS study based on their different levels of economic development, as measured using the UN Human Development Index (HDI, World Bank). Two of the five communities were selected for this thesis: a rural village, Nkwantakese in Ghana with a low to middle economic development and a suburb of Chicago, Maywood in Illinois, USA with a very high level of economic development. Five hundred participants aged 25-45 years from each community were recruited through a random door-to-door sampling, giving a total of 1,000 participants. A subsample of 141 (Ghana, n=70 and U.S., n=71) men and women were randomly selected to have their usual energy expenditure measured by the DLW method. Participants who were diagnosed with infectious disease such as malaria, HIV, or who were pregnant were excluded.

Protocol

Measurements were collected over 7-10-day period for each subject at baseline (the morning after an overnight fast) at each site-specific clinic by trained study-staff, which included TEE by the DLW method, body weight and height, dietary intake by the multiple pass 24 h recall method, and physical activity by accelerometer. Age and years of education were obtained through an interview. A second body weight measurement was obtained 7 d later at the end of DLW period. Another 24 h recall was also obtained 6-9 d after the first visit.

Anthropometrics

Height was measured using a stadiometer and recorded to the nearest 0-1 cm. Body weight was measured in light clothing without shoes and recorded to the nearest 0-1 kg. BMI was calculated as weight (kg) / height^2 (m^2). Weight was also measured at the end of the 7 d DLW period to determine if there was any change in body energy stores.

Total Energy Expenditure

Energy requirements over a 7-day period were measured by DLW as described by Luke et al (47). Briefly, after an overnight fast, a baseline urine sample was collected and a mixed oral dose of DLW (H_2O and H_2O^{18}) was administered. Urine samples were then collected at 1, 3, and 4h after ingesting the loading dose. After 7 d, two final urine samples were collected at a 1 h interval.

Urine samples were chilled and stored frozen until shipped to the analysis laboratory at the University of Wisconsin. Production of CO_2 was converted to total energy expenditure (TEE) using the modified Weir equation (48) and dietary balance of macronutrients.

Dietary Intake

Trained study staff used the multiple-pass method designed by the Medical Research Council of South Africa to estimate each participant's dietary intake (49). Specific foods and the amount consumed were reported by each participant the day after their consumption. Interviewers guided participants to quickly list foods ingested and then asked for details of portion size and preparation methods through a meal-by-meal listing. Participants determined portion size based on representative pictured foods (small, medium, or large) along with spoon, cup, bowl, or plate used. The pictures were available for all commonly observed local foods with different portion sizes (half, typical, and one-and-a-half) obtained by a dietetic consultant prior to the study. They were also used to determine local measuring tools, recipes, and foods that are commonly unreported.

All recalls were written on standardized paper forms which were structured. These were then digitized, sent to the Coordinating Center at Loyola University Chicago, and analyzed using the Nutrient Data System for Research ver. 2011 (NDSR; University of Minneapolis, MN, USA) by the study dietitian. For each day, total reported Energy Intake (rEI), macronutrient intakes (carbohydrate, protein, and fat) and fiber intake were calculated. Dietary variety scores were calculated as described below. For all dietary variables, the 2-day averages were used in the analyses.

Dietary Variety Scoring

Dietary variety scores were calculated for combination and ingredient variety. Combination variety was defined as the total number of unique foods and beverages consumed together in a day. For an example, milk and cereal within the same meal were assumed to be consumed as cereal with milk and therefore counted as one item. Ingredient variety was the total number of unique ingredients consumed in a day. Ingredients of baked goods such as baking soda, sugar, etc. were not counted as well seasoning such as salt and pepper. Thus, the same example of milk and cereal within the same meal counted as two items in ingredient variety score. For another example, a cheese pizza had dough, cheese, and tomato sauce as ingredients and counted as one item in combination variety and as three items in ingredient variety. SPSS (version 22) was used to calculate all variety scores.

Plausibility of reported energy intake

Plausibility of reported energy intake (rEI) was determined by calculating rEI as a percentage of TEE, i.e. rEI/TEE*100%.

Calculations and statistical analyses

In addition to the dietary variety scores, these variables were also calculated: percentage of energy from carbohydrate, percentage of energy from protein, percentage of energy from fat, percentage of energy from alcohol, fiber density, basal metabolic rate (BMR) using Mifflin St. Jeor's formula (50), and physical activity level (PAL) as TEE measured by DLW divided by BMR. Weight change was also calculated as the difference between weight at follow-up and at baseline. Some participants did not complete these follow-up appointments and thus some weight change values were unable to be generated, causing the number of participants for weight change to be less than other variables.

Data were analyzed using SPSS version 22 (Armonk, N.Y.). Variables were examined for their distribution through the use of scatterplots. Normality of distribution was tested by using the Shapiro-Wilk test. Variables not normally distributed were transformed prior to analysis. BMI was the only variable not normally distributed and was log transformed. Descriptive statistics were calculated and are expressed as means ± SD unless otherwise noted. Crosstabs and chi-square test were used to determine if the distribution of weight status differed by country and gender. Univariate analysis of variance (ANOVA) was used to test whether subject characteristics, energy expenditure, and dietary intake differed by gender and country as well as to test whether variety differed by gender, country, and weight status.

Scatterplots were also used to examine potential associations between variables and Pearson correlations were calculated. Analysis of covariance (ANCOVA) of dietary variety scores in relation to the primary outcomes of rEI and log BMI as well as other outcomes: TEE, % body fat, weight, and weight change. The independent variables were the two dietary variety scores and the dependent variables were total energy intake and BMI. In all models, confounding variables controlled for were: physical activity level, gender, and age. In addition, when weight was the outcome, height was also included as a confounder, and when weight change was the outcome, both weight and height were included. We conducted all analyses with both implausible reporting uncontrolled and controlled by considering kcal as a percentage of TEE as a covariate in the analyses of variance. Independent t-tests were conducted on variables in which a significant interaction effect between country and gender was observed. Within each country, we tested if men differed from women. Within each gender, we tested if Ghana was different from U.S. A p-value of 0.05 was accepted as significant for all analyses.

Chapter IV

Results

There were 141 participants, 70 from Ghana and 71 from the U.S. Of these, 67 were male and 74 were female. The entire group was about 35.1±6.0 years old (mean±SD) and moderately overweight (BMI 27.5±7.7 kg/m^2). Table 5 shows that participants from the two countries differed significantly in age, height, weight, percent body fat mass, and PAL. Specifically, participants in the U.S. were younger, taller, weighed more with more % body fat, and were less physically active than subjects in Ghana. In the U.S., most female subjects were obese and almost half of the subjects were considered of normal weight, whereas in Ghana most male and almost half of the female were considered of normal weight. This weight status distribution differed significantly by country and gender. As would be expected, men in both countries had significantly less body fat, were taller, more active, and had higher energy expenditure than women.

Table 5. Subject characteristics by country and gender

	Mean±SD			
	Ghana (n = 70)		U.S. (n = 71)	
	Male (n = 31)	Female (n = 39)	Male (n = 36)	Female (n = 35)
Age (y) [a]	35.6±6.1	37.5±5.9	33.3±5.7	33.8±5.7
Height (cm) [a, b]	168.8±6.2 [d]	157.8±5.2 [c, d]	178.9±5.8 [d]	164.0±5.6 [c, d]
Weight status (n, %) [e]				
Underweight (<18.5 kg/m^2)	1, 3.2	2, 5.1	0, 0	1, 2.9
Normal weight (18.5–24.9 kg/m^2)	27, 87.1	19, 48.7	17, 47.2	3, 8.6
Overweight (24.9–29.9 kg/m^2)	3, 9.7	11, 28.2	6, 16.7	8, 22.9
Obese (>30 kg/m^2)	0, 0	7, 17.9	13, 36.1	23, 65.7
Weight (kg) [a]	62.4±7.1	63.5±15.8	91.9±24.3	89.4±19.1
Weight change (kg)*	0.15±2.43	1.06±2.75	-0.37±4.39	0.11±3.88
Percent body fat mass (%) [a, b]	18.8±6.0	35.1±8.1	33.8±8.3	46.0±7.4
TEE (kcal) [b]	2885±448	2355±451	3132±684	2314±399
PAL [a, b]	1.92±0.28	1.86±0.31	1.68±0.34	1.46±0.23

Abbreviations: PAL, physical activity level; TEE, total energy expenditure.

*Total n = 103 since only a subset of participants completed follow-up measurements, Ghana male, n = 25, female, n = 30; U.S. male, n = 27 due to exclusion of an extreme value in addition to incomplete measurements, female, n = 21.

a Significant difference between countries.

b Significant difference between genders.

c Females significantly different from males within country.

d Ghana significantly different from U.S. within genders

e Chi-squared tests significant between countries and genders

Dietary intake data are shown in Table 6. Participants from the two countries differed significantly in energy intake, reporting plausibility, % energy from carbohydrate, protein, fat, and alcohol, fiber density, and ingredient variety. Participants in Ghana consumed significantly lower energy, and % energy from protein, fat, and alcohol than those in U.S. However, participants from Ghana consumed significantly higher % energy from carbohydrate and had higher fiber density than participants in the U.S. In addition, participants in U.S. consumed more ingredient variety than those in Ghana. There was no significant difference in consumption of combination variety between countries, but within the U.S., women consumed significantly higher combination variety than men. Ingredient variety scores, due to its definition was always higher than combination variety scores in both countries.

Table 6. Dietary intake by country and gender

	Mean ± SD			
	Ghana (n = 70)		U.S. (n = 71)	
	Male (n = 31)	Female (n = 39)	Male (n = 36)	Female (n = 35)
Energy intake (kcal) [a, b]	2168±93	1831±425	2680±1239	2169±1088
Energy intake as a % of TEE [a]	77.7±21.8	80.5±22.5	84.4±37.0	99.0±54.3
% Energy from carbohydrate [a]	61.3±8.5	62.4±8.0	43.9±9.3	47.7±6.9
% Energy from protein [a]	13.7±3.9	13.4±3.1	15.7±3.6	14.0±2.7
% Energy from fat [a]	25.8±8.2	26.1±9.5	36.8±7.4	37.8±6.4
% Energy from alcohol [a, b]	1.1±2.5	0.0±0.0	4.3±7.4	1.5±3.8
Fiber density (g/1000 kcal) [a]	13.5±4.8	13.2±3.0	6.3±3.9	6.9±2.3
Ingredient variety (no.) [a]	10.8±1.8	10.7±2.1	12.4±4.7	14.2±4.8
Combination variety (no.)	7.3±1.4	7.1±1.7 [d]	7.0±2.8	8.5±2.8 [c, d]

Abbreviation: TEE, total energy expenditure.
a Significant difference between countries.
b Significant difference between genders.
c Females significant different from males within country.
d Ghana significantly different from U.S. within genders

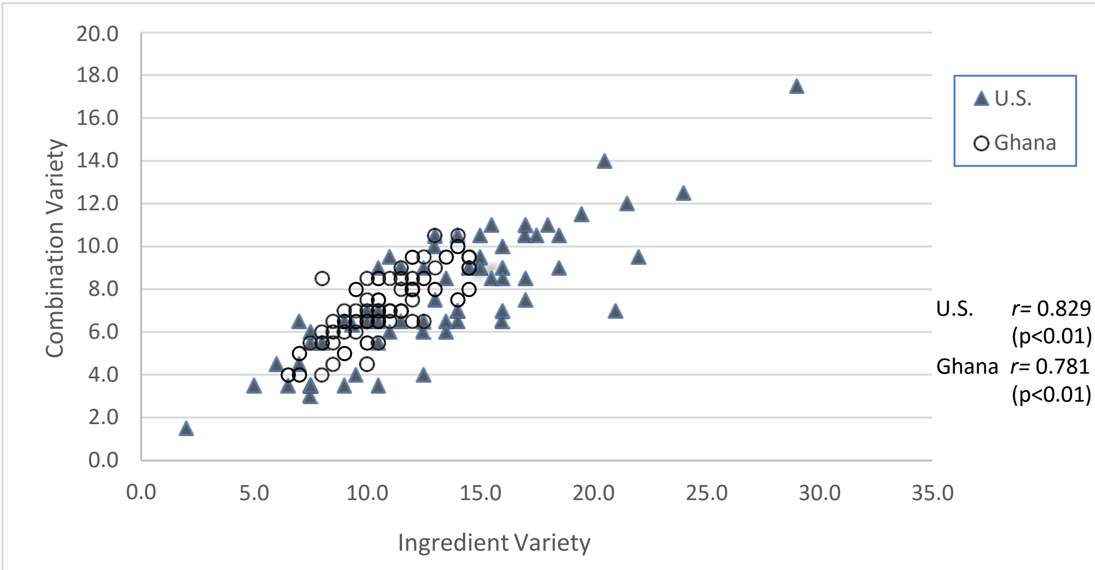

Figure 1. Scatterplot of combination and ingredient variety scores of Ghana and the U.S.

As shown in Figure 1, regardless of the country, combination variety was strongly correlated with ingredient variety. The correlation was lower in Ghana than in the U.S. However, combination variety was not perfectly correlated with ingredient variety which means these two varieties were not exactly the same and were measuring two different kinds of variety. Tables 7 and 8 show Pearson correlations of the two variety scores with macronutrient composition and fiber density. There was a significant positive correlation (Table 7) between both types of variety and energy intake, energy intake reporting plausibility, and % energy from protein. in participants from Ghana. No additional significant correlation was observed in participants from Ghana. Similarly, there was a significant positive correlation between both types of variety and energy intake and kcal % TEE in U.S. participants (Table 8). However, in the US, there were no significant correlations between either type of variety and dietary macronutrient or fiber composition.

Table 7. Pearson correlations of variety with dietary variables of Ghana participants

Pearson Correlation	Combination Variety	Ingredient Variety
Energy intake	0.381**	0.339**
TEE	0.019	0.041
Energy intake as a % of TEE	0.287*	0.237*
% Energy from carbohydrate	0.042	0.073
% Energy from protein	0.402**	0.326**
% Energy from fat	-0.210	-0.215
% Energy from alcohol	0.156	0.234
Fiber Density	-0.028	-0.010

Abbreviation: TEE, total energy expenditure.
**Correlation was significant at the 0.01 level (2-tailed). N= 70.
*Correlation was significant at the 0.05 level (2-tailed).

Table 8. Pearson correlations of variety with dietary variables of U.S. participants

	Combination Variety	Ingredient Variety
Energy intake	0.544**	0.543**
TEE	-0.214	-0.199
Energy intake as a % of TEE	0.591**	0.511**
% Energy from carbohydrate	0.080	-0.067
% Energy from protein	-0.193	-0.021
% Energy from fat	-0.011	0.107
% Energy from alcohol	0.044	0.000
Fiber Density	-0.053	-0.091

Abbreviation: TEE, total energy expenditure.
**Correlation was significant at the 0.01 level (2-tailed). N= 71.

Associations of ingredient variety without and with implausible reporting controlled are shown in Table 9. Ingredient variety was positively associated with rEI in both countries when implausible reporting was not controlled, but there was a positive nonsignificant association in Ghana when implausible reporting was controlled. Ingredient variety was negatively associated with TEE in the U.S., regardless of whether reporting plausibility was controlled, but there was a positive nonsignificant association observed in Ghana. There was a negative association between ingredient variety with log BMI, percent body fat, and weight in U.S. when implausible reporting was not controlled but there was a positive nonsignificant association with log BMI and weight in Ghana when implausible reporting was controlled.

Table 9. Associations of ingredient variety with dependent variables before and after controlling for energy intake reporting plausibility [a]

	Ghana (n=69)		U.S. (n=71)	
Energy intake	β±SE	p	β±SE	p
Implausible reporting not controlled	71.679 ±25.822 kcal	0.007	124.678 ±24.172 kcal	0.000
Implausible reporting controlled	20.535 ±11.770 kcal	0.086	12.054 ±12.612 kcal	0.343
TEE				
Implausible reporting not controlled	7.640 ±15.761 kcal	0.630	-31.304 ±8.478 kcal	0.000
Implausible reporting controlled	26.254 ±13.903 kcal	0.064	-22.263 ±9.985 kcal	0.029
Log BMI				
Implausible reporting not controlled	0.003 ±0.005	0.529	-0.007 ±0.003	0.004
Implausible reporting controlled	0.009 ±0.005	0.078	-0.005 ±0.003	0.083
% Body fat				
Implausible reporting not controlled	0.162 ±0.450 %	0.720	-0.592 ±0.192 %	0.003
Implausible reporting controlled	0.406 ±0.456 %	0.376	-0.430 ±0.228 %	0.064
Weight [b]				
Implausible reporting not controlled	0.479 ±0.818 kg	0.560	-1.718 ±0.548 kg	0.003
Implausible reporting controlled	1.438 ±0.720 kg	0.050	-1.147 ±0.645 kg	0.080
Weight change [c*]				
Implausible reporting not controlled	0.346 ±0.183 kg	0.065	0.130 ±0.137 kg	0.349
Implausible reporting controlled	0.353 ±0.200 kg	0.084	0.146 ±0.159 kg	0.365

Abbreviations: TEE, total energy expenditure; BMI, Body mass index.

[a] All models controlled for age, sex, and physical activity

[b] Model additionally controlled for height

[c] Model additionally controlled for baseline weight and height

[*] n = 54 in Ghana and n=48 in the U.S. since only a subset of participants completed follow-up measurements

Similar results were observed for associations of combination variety (Table 10) as it was positively associated with rEI in both countries when implausible reporting was not controlled, but no significant association was observed in both countries when implausible reporting was controlled. Combination variety was also negatively associated with TEE in U.S. when implausible reporting was not controlled, but not when it was controlled. As with ingredient variety, combination variety was positively associated with log BMI, percent body fat, and weight in the U.S. when implausible reporting was not controlled, but not in Ghana. In addition, in Ghana, no association was found for combination variety when implausible reporting was not controlled, but it was positively associated with percent body fat, log BMI, and weight when implausible reporting was controlled. Reporting plausibility was negatively correlated with weight (*r*= -0.397, p<0.01), log BMI (*r*= -0.294, p<0.05), and TEE (*r*= -0.523, p<0.01) in Ghana. Reporting plausibility was also negatively correlated with weight (*r*= -0.302, p<0.05) and TEE (*r*= -0.363, p<0.01) in U.S.

Table 10. Associations of combination variety with dependent variables before and after controlling for energy intake reporting plausibility [a]

	Ghana (n=69)		U.S. (n=71)	
Energy intake	β±SE	p	β±SE	p
Implausible reporting not controlled	103.127 ±32.34	0.002	250.801 ±38.115	0.000
Implausible reporting controlled	24.304 ±15.333	0.118	27.834 ±23.476	0.240
TEE				
Implausible reporting not controlled	-2.142 ±20.113	0.916	-50.754 ±14.717	0.001
Implausible reporting controlled	26.547 ±18.237	0.150	-31.660 ±18.959	0.100
Log BMI				
Implausible reporting not controlled	0.005 ±0.007	0.435	-0.011 ±0.004	0.019
Implausible reporting controlled	0.015 ±0.006	0.027	-0.005 ±0.006	0.394

% Body fat				
Implausible reporting not controlled	0.743 ±0.567	0.194	-0.690 ±0.342	0.048
Implausible reporting controlled	1.201 ±0.576	0.041	-0.169 ±0.438	0.700
Weight [b]				
Implausible reporting not controlled	0.452 ±1.058	0.671	-2.710 ±0.960	0.006
Implausible reporting controlled	1.891 ±0.941	0.049	-1.421 ±1.222	0.249
Weight change [c*]				
Implausible reporting not controlled	0.385 ±0.235	0.108	0.174 ±0.235	0.464
Implausible reporting controlled	0.399 ±0.265	0.139	0.219 ±0.298	0.468

Abbreviations: TEE, total energy expenditure; BMI, Body mass index.

[a] All models controlled for age, sex, and physical activity

[b] Model additionally controlled for height

[c] Model additionally controlled for baseline weight and height

[*] n = 54 in Ghana and n=48 in the U.S. since only a subset of participants completed follow-up measurements

Chapter V

Discussion

Our analysis showed that, as may be expected, participants from Ghana had lower energy intake and adiposity than those from the U. S. In both countries, both types of variety were positively associated with reported energy intake; however, none of these associations were significant after implausible reporting was controlled, although the positive association between ingredient variety and energy intake in Ghana became only marginally nonsignificant. Furthermore, in Ghana, several adiposity measures were positively associated with combination variety and marginally non-significantly positively associated with ingredient variety when implausible reporting was controlled. Finally, in the U.S., both variety scores were negatively associated with TEE, a biomarker of energy intake (whereas a positive association would be expected), and with obesity markers, and when implausible reporting was controlled these associations were attenuated with ingredient variety and disappeared with combination variety. These results indicate that both ingredient variety and combination variety may be important determinants of energy intake in both countries, and that combination variety may especially be associated with adiposity in Ghana. In addition, the high degree of implausible reporting in this dataset may have partially masked the associations between dietary variety and adiposity, since when implausible reporting was controlled, associations in Ghana became stronger and associations in the US which were previously negative were attenuated.

Our participants in Ghana had lower energy intake and adiposity than those in U.S. These data are consistent with data from the FAO (51) in 2015 that shows energy intake in Sub- Saharan Africa was 2360 kcal/d and 3440 kcal/d for industrialized countries. Concerning energy intake, we had hypothesized that both types of variety would be positively associated with reported energy intake. Our results confirmed our hypothesis when implausible reporting was not controlled and the relationship was only marginally nonsignificant for Ghana once implausible reporting was controlled. These findings are consistent with previous cross-sectional studies which did not control for implausible reporting (19, 21, 24, 26, 40), and another cross-sectional study that used weighed food records (18) . Short-term experimental (32-37), longitudinal (41), and longer-term intervention (27) studies also found a positive relationship between variety and overall energy intake. We also hypothesized that the U.S. would have higher combination and ingredient variety scores than Ghana. But results only confirmed higher ingredient variety scores for participants in the U.S. To our knowledge, no other study has been published in which dietary variety consumption in countries with differing economic development has been compared. Thus, we compared results from Ghana to that of an ingredient variety study with participants in China (25) and found very similar ingredient variety scores per day to our Ghana participants. Another study (52) on variety with Chinese immigrants in the U.S. found that those who were more acculturated had higher variety scores than those who were less acculturated. Compared to some total variety scores in different studies for U.S. participants (18, 26), our participants had a lower score than in previous studies. This may be caused by the different dietary variety definitions used in the studies. Total variety is not calculated exactly the same way as combination or ingredient variety, even though they were different ways of calculating total variety. Part of our finding on energy intake and variety was the significant positive correlation of % energy from protein with both types of variety observed in participants from Ghana. This suggested that higher variety was associated with higher sources of protein in Ghana, but not in the U.S. Hence, further studies are needed which compare dietary variety scores calculated in the same way in different countries with differing economic development to confirm or challenge our findings.

In addition to lower energy intake, participants in Ghana had lower adiposity measures than U.S. participants. We had hypothesized that both types of variety would be positively associated with adiposity and thus our findings were consistent with our hypothesis. These adiposity measures were positively associated with combination variety and had a positive marginally nonsignificant association with ingredient variety when implausible reporting was controlled. This result was also consistent with previous cross-sectional studies which found positive association between dietary variety and BMI through the use of either estimated food records (5, 21, 22, 24, 40), weighed food records (18, 25), or controlled for implausible reporting. In addition to a positive association, some studies also found a negative association between dietary variety and BMI when looking at types of dietary variety which were weak in energy density (5) such as vegetables (23), grains, and meats (22). The positive association of variety with adiposity suggested that higher variety was associated with higher body fatness especially when obesity prevalence is low. This result is especially consistent with controlled experimental studies on variety and weight gain which focused on energy density of foods consumed (27, 43, 53).

Our finding for both types of variety scores in relation to TEE was inconsistent with our hypothesis for U.S. participants, as both types of variety scores were negatively associated with TEE and adiposity when implausible reporting was not controlled. As mentioned above, TEE was a more reliable indication of actual energy intake than was reported energy intake. This finding of negative association was also inconsistent with previous studies which found positive association of dietary variety with energy intake (32, 35, 36). However, when implausible reporting was controlled, these associations were no longer significant with combination variety and was attenuated with ingredient variety. In other words, these associations became more positive (stronger) in Ghana as well as in the U. S. when implausible reporting was controlled. Therefore, our result suggested that association between dietary variety and adiposity in the U.S. might have been masked by implausible reporting and further studies with less implausible reporting are needed to reveal actual relationship. As further evidence of how implausible reporting might have masked the association, we found a negative correlation between reporting plausibility and weight, log BMI, and TEE in Ghana. Reporting plausibility was also negatively correlated with weight and TEE in U.S.

Our study had several strengths, including measurement of TEE measured by DLW, a biomarker of energy intake and an excellent variable available to control implausible reporting. Thus findings of the study were more reliable than if it was conducted without such control. In addition to reporting implausibility, all other possible confounding factors were controlled for in all analyses: physical activity, age, and gender. Finally, data for our study was collected through a 24-hour multiple pass recall method by trained staff, which was more reliable than food frequency questionnaires or food diaries. However, the dataset of this study was relatively small and there were only two different kinds of variety analyzed. Other types of variety which should be included in future studies: total variety, ratio variety, energy-dense variety, micronutrient-dense variety, and snack-food variety to analyze their relationships with adiposity, TEE, and across the different countries. I would also suggest % body fat be measured at follow-up to see if there was any change and its relationship with the different kinds of variety.

In conclusion, participants from the lower economic development level (Ghana) had lower variety scores, energy intake, and adiposity level than those from a higher economic development level (U. S.). However, dietary variety had stronger positive association with adiposity in those from lower economic development than those from higher economic development. These results may indicate that those in a more developed country might have access to more variety of foods than those in a less developed country. Furthermore, though more variety of foods were available in developed countries, they were not consumed individually. Rather, varieties of foods were prepared and consumed together.

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