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Precursors to overnutrition: The effects of household market food expenditures on measures of body composition among Tsimane' adults in lowland Bolivia

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ABSTRACT

Nutrition transitions are characterized by shifts in diet and activity levels that lead to changes in weight and body fatness over a relatively short time. Research has linked these nutritional shifts to socio-economic factors, including wealth and income. However, few studies have examined household spending patterns on market foods among subsistence populations, which may reveal food access, choice, and indicate household nutritional environment. This paper examines the relation between household monetary expenditures on "market" foods and measures of body composition among Tsimane', a forager–horticulturalist indigenous group in the Bolivian Amazon. Economic and anthropometric surveys were conducted for adults ($n = 1199$) 16 years or older in 563 households in 40 Tsimane' villages in 2008. Results indicate that overweight status (19% of men and 24% of women) is more common than obesity (1% of men and 4% of women). Sixty-one percent (61%) of households reported purchasing market foods during the previous week. Multiple linear and logistic regressions suggest that men living in households in the top third of monetary expenditures on market foods had significantly higher BMI (0.69 kg/m^2; $p = 0.027$), weight (1.80 kg; $p = 0.048$), percent body fat (1.06%; $p = 0.025$), and probability of being overweight/obese (Odds ratio = 1.83; $p = 0.042$) than men in households that reported not spending money on market foods in the previous week. We discuss the possibility that the division of labor may help explain the differences between men and women in this sample. This research suggests household expenditures on market foods may mediate the relation between wealth and body composition.

Introduction

In the last 30 years, a global epidemic of obesity has emerged in both industrialized and industrializing countries (Popkin, Adair, & Ng, 2012; Shaw & Braverman, 2012), and is expected to worsen in Latin America (Webber et al., 2012). This public health problem has received extensive attention because obesity is associated with increased risks for many non-communicable diseases (e.g., diabetes, cardiovascular disease) (Hubert, Feinleib, McNamara, & Castelli, 1983; Schulz et al., 2006). The rapid emergence of obesity is often associated with the process of a nutrition transition (Popkin, 1994) in which shifts from traditional, nutrient-rich foods to a "western" diet of energy-dense, fatty, sugary, and highly-processed foods and drinks are combined with reduced physical activity levels (Drewnowski & Popkin, 1997; Popkin, 2011). Evidence of nutrition transitions has been documented in most regions of the world, including the Americas, Eastern Europe, and Asia (Kuhnlein, Receveur, Soueida, & Egeland, 2004; Lourenco, Santos, Orellana, & Coimbra, 2008; Popkin et al., 2012; Ulijaszek & Koziel, 2007; Zhai et al., 2009).

Globally, research has demonstrated that individual wealth (savings and material assets), income (steady cash flows from labor and other earnings), socio-economic status (SES; a combination of income, material ownership, education, and occupation), gender, and diet composition are associated with obesity prevalence during nutrition transitions, but the associations vary by national income levels (Gerbens-Leenes, Nonhebel, & Krol, 2010; Popkin, 1994; Uauy, Albala, & Kain, 2001). In low-income countries, wealth is positively associated with weight and Body Mass Index (BMI) (Popkin, 1994; Welch et al., 2009). Conversely, in high-income countries, low-SES places an individual at greatest risk of obesity (Jolliffe, 2011). The trend is mixed in middle-income countries. For

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example, in Brazil, a high prevalence of overweight and obesity is seen among people in both low- and high-SES groups (Popkin, 1994). In Mexico, the highest rates of overnutrition occur among individuals in the lower quintiles of SES (Rivera, Barquera, Gonzalez-Cossio, Olaiz, & Sepulveda, 2004) while income is positively associated with BMI and weight among rural women (Colchero & Sosa-Rubi, 2012). In a survey of 68 countries, Wells, Marphatia, Cole, and McCoy (2012) found that gender and economic inequalities explain why obese women outnumber obese men three-to-two. This research suggests wealth is largely connected to body composition at a national, macro-scale but does not consistently address the importance of local dynamics, especially during rapid economic changes, such as those experienced by people in much of the Amazon.

Recently, studies have called attention to a trend of weight gain tied to increased reliance on market foods among rural and indigenous people in the Amazon basin where problems of overnutrition and non-communicable diseases have traditionally been rare (Lourenco et al., 2008; Welch et al., 2009). This study examines how household spending on market foods is related to adult body composition among Tsimane', an indigenous Amazonian population in Bolivia, who are in an early stage of a nutrition transition. In this study, we define market foods as foods purchased in a market and associated with nutrition transitions in terms of energy density, sugar, and amount of processing.

Lifestyle transitions in Amazonia

Populations in the Amazon basin have experienced rapid ecological and economic changes over the past 50 years. Research suggests increased participation in market economies parallels increased access to market-purchased foods and goods, medical care, and national culture (Baker, Hanna, & Baker, 1986; Blackwell, Pryor, Pozo, Tiwia, & Sugiyama, 2009; Godoy, 2001; Godoy et al., 2009; McDade & Nyberg, 2010). Although the relation between nutrition and market participation is not consistent across all studies, several scholars have linked economic factors and commodification of indigenous or rural economies to the nutrition transition in Amazonia (Lindegarde, Widen, Gebb, & Ahren, 2004; Lourenco et al., 2008; Nardoto et al., 2011; Piperata, Spence, Da-Gloria, & Hubbe, 2011; Welch et al., 2009). For example, in lowland Bolivia, Benefice, Lopez, Monroy, and Rodríguez (2007) found nearly 40% of women living in riverside communities were overweight or obese according to BMI. Overweight status among women was associated with a diet consisting of more market foods such as meat, bread, and rice than starchy foods like cassava roots and plantains.

Similarly, Lourenco et al. (2008) compared nutritional status among indigenous Surui in Brazil between the mid-1980s and 2005, finding dramatically higher rates of overweight (40%) and obesity (16%) as men and women gained an average of 11.3 kg and 8.6 kg, respectively. Lourenco et al. (2008) explain the increase in weight through lifestyle shifts, such as an increase in monetary power and socio-economic stratification leading to a diet that included more purchased market foods, like noodles, deep-fried foods, and soft drinks. Ethnographically, they allude to the importance of expenditures on market foods for subsistence populations in explaining the recent rise in overweight and obesity.

Food expenditures and body composition

Monetary expenditures on market foods may help explain the observed link between wealth and body weight posited by the nutrition transition because food expenditures reveal choices and access to different dietary items. However, research on food expenditures has primarily been conducted in industrialized settings, so we know little about food expenditures in populations where the majority of food is produced at the household level. For example, in Cyprus, Jacobson, Mavrikiou, and Minas (2010) found that expenditures on foods away from home (which were less nutritious) were related to age of the female household head, income, and household size, such that younger women spent more money on foods from take-away restaurants than older women. In the United States, expenditures on foods away from home have increased over time (Duffey, Gordon-Larsen, Jacobs, Williams, & Popkin, 2007). Compared with food cooked at home, foods eaten away from home are higher in total energy and saturated fat, lower in fiber, and associated with higher BMI (McCrory, Fuss, Saltzman, & Roberts, 2000; St-Onge, Keller, & Heymsfield, 2003). Aggarwal, Monsivais, Cook, and Drewnowski (2011) found the cost of diets in the US is associated with the quality and nutrient content of foods and varies with SES, such that people in lower income groups spend more money on cheaper, nutrient-poor foods than higher income groups.

In contrast, research among people relying heavily on subsistence agriculture suggests the relation between food expenditures and body composition is dependent on local context and the nutritional quality of purchased foods. For example, DeWalt (1983) indicated Mexican farmers who increased their income began to purchase animal source proteins instead of consuming staple foods produced in the household. Among cassava-producing agriculturalists in coastal Ecuador, Leonard, Dewalt, Uquillas, and Dewalt (1994) found a significant positive relationship between per capita food expenditures and adult caloric and protein adequacy. Recent research among Toba and Wichi, two indigenous Argentinean populations, suggests that household SES was strongly positively correlated with both overweight and reliance on market-purchased versus foraged foods (Valeggia, Burke, & Fernandez-Duque, 2010). While these studies suggest that market food expenditures may help explain the wealth–body composition relationship, the effects have not been quantitatively assessed.

This study examines how household monetary expenditures on market foods are related to weight and body composition, controlling for wealth, among a subsistence population undergoing rapid economic and sociocultural change. We focus on household-level expenditures on market foods as a measure of an individual's access to these foods because food sharing within households is the norm among Tsimane'. We stratify by gender because women have been shown to be more susceptible to weight gain during nutrition transitions (Piperata et al., 2011; Wells et al., 2012). We expect greater household food expenditures will be associated with increased body weight and fatness in both Tsimane' men and women.

Background

This research was conducted in the Department of Beni, in northeastern Bolivia, among Tsimane'. Traditionally a nomadic and hunting-gathering population, Tsimane' established villages in the 1970s and began to participate in market activities during this time (Byron, 2003). Currently, Tsimane' are one of the largest indigenous groups in lowland Bolivia with a population of approximately 15,000 in 100 villages. Research among Tsimane' has been ongoing for the last 30 years with a recent focus on the effects of markets on health and well-being (Gurven, Kaplan, & Zelada, 2007; Leonard & Godoy, 2008).

Nutrition transition among Tsimane'

Research has found that the majority of Tsimane' food is produced or foraged by the household and generally includes fish, wild

game, domestic animals such as chickens, and agricultural crops including plantains, manioc, maize, fruits, and rice (Byron, 2003). This diet is supplemented by purchased market foods (e.g., beef, sugar, pasta, salt, lard, vegetable oil, and white flour/bread). Over the past decade, research conducted by the Tsimane' Amazonian Panel Study (TAPS) has documented diet shifts as Tsimane' increasingly participate in market activities. Between 2002 and 2006, the value of foods consumed by all individuals in 13 communities increased by 6.35% per year (Godoy et al., 2009). Similarly, an increased focus on cash crops, such as rice and maize, influenced what was planted in horticultural fields (Vadez, Reyes-García, Huanca, & Leonard, 2008). Most recently, the introduction of electricity has created an added impetus for market transactions (Zycherman, 2011).

Tsimane' recognize individual ownership of income, property, and expenditures, but with the exception of small purchased items, food is generally consumed from a common pot in the household (Byron, 2003). Godoy et al. (2007) found that Tsimane' adult food consumption (measured through anthropometric indices of short-term nutritional status) was affected by income shocks (illness, theft, accidents), but effects differed by gender and were relatively small compared to those documented in other farming and industrial societies. One possible explanation they provide for the weak association is that crops such as manioc and plantains are readily available year-round and could buffer consumption from shocks.

Like other rural Amazonians, Tsimane' are susceptible to both overnutrition and high rates of stunting. Infectious diseases are common, historically accounting for approximately half of all deaths (Gurven et al., 2007). A 60–80% prevalence of parasitic infection exists among children and adults (Tanner et al., 2011; Vasunilashorn et al., 2010). Simultaneously, overnutrition is also increasing. Longitudinal studies have documented a small but steady increase in mean BMI per year among Tsimane' adults between 2002 and 2006 (Godoy et al., 2009). Additionally, Zeng et al. (2013) found that 8.9% of these adults who had a BMI considered normal (18.5–25) in 2002 became overweight (25–30) or obese (>30) by 2006. Therefore, while infectious diseases remain an important aspect of Tsimane' health, overnutrition may become an emerging issue.

Methods

Sample

This data comes from a randomized, controlled experiment investigating the effects of a one-time rice transfer on measures of well-being. Demographic, economic, and health surveys and anthropometric data were collected using exhaustive sampling on individuals from 40 randomly-selected Tsimane' communities in February–May 2008 and February–May 2009. Of a potential 100 Tsimane' communities, 65 met inclusion criteria related to size, relative accessibility, safety, and had not been extensively researched. From these 65, we used random selection to obtain the final sample of 40 villages (full description available in Saidi, Behrman, Undurraga, & Godoy, Working paper). Here we use only data from 2008 to avoid the possible confounding effects on household food expenditures and adult body composition of an experimental rice transfer that occurred between the two survey periods. Surveys were conducted by four Bolivian university students and four bilingual Tsimane' with experience working in the area. This paper focuses on adults, defined as individuals aged 16 years and older because that is when Tsimane' begin to establish independent households. The total number of adults in this study is 1199 (600 men) in 563 households after excluding 82 pregnant women from the analysis. Of the 563 households, 372 consisted of an adult male and female, 164 included male and female household heads in addition to at least one other adult (i.e. adult children, siblings, parents, or grandparents), and the remaining 27 were single male (10) or female-headed households. The study protocol was approved by the Tsimane' Grand Council and Northwestern University Institutional Review Board (IRB project approval # STU0007).

Dependent variables: weight, BMI, percent body fat

Weight, BMI, and body fatness are used as indicators of adult body composition. Anthropometric measurements were collected following procedures outlined in Lohman, Roche, and Martorell (1988). Weight was measured in kilograms (kg) in light clothing, without shoes or hats, using a Tanita scale (Model BF-680, Tanita Corporation of America Inc.). Height without shoes was measured with a standing stadiometer and rounded to the nearest tenth of a centimeter. BMI was calculated as kg/m^2. BMI can be a problematic measure of body composition because it overestimates body fatness among heavily muscled individuals and can be an unreliable predictor of body fatness among populations where stunting is common (Shaw & Braverman, 2012). To account for this, we also consider weight and percent body fat, which provide an assessment of fatness and are less likely to underestimate obesity. Body fat was measured using both bioelectrical impedance analysis (Tanita scale) and calipers to measure triceps, biceps, subscapular, and suprailiac skinfolds. Skinfold values were summed (SUM4) and converted to percent body fat using the sex-and age-specific equations of Durnin and Womersley (1974). In the main analysis, we focus on percentage body fat calculated from skinfold measurement.

Main explanatory variable: market food expenditures

To assess monetary expenditures on market foods, individuals were asked "What have you purchased with money in the last 7 days, and how much did you spend on each item?" The question was exhaustive with all purchases itemized using follow-up prompts. After deriving a list of items, expenditure was calculated by aggregating how much money, in Bolivianos (Bs) (1 USD = 7.01 Bs), an individual spent. During data analysis, we constructed the variable market food expenditures by summing the amount of money an individual reported spending on 5 categories of market foods related to nutrition transitions (i.e. refined and high energy density) (Drewnowski & Popkin, 1997). These categories include dairy, oils, market meats, refined carbohydrates, and sweets (see Results for additional discussion).

We summed the amount spent by all adults within a household because Tsimane' live in extended households and eat meals together (Byron, 2003). Household expenditure data was left skewed and approximately 40% of individuals lived in households reporting zero expenditures on market foods and were grouped as "none". We divided the remaining 60% of households into groups of varying participation in the market economy using data-driven tertiles. This resulted in a four-level categorical variable with three equally-sized categories of low, medium, and high expenditures and a no expenditures category. To model nonlinear relationships between expenditures and body composition, we converted these categories into dummy variables with the no expenditures category serving as reference.

Covariates

In all models, we control for age, age-squared, number of days spent in bed due to illness, wealth, education, adult equivalence, and village effects. Age was measured by asking individuals their

birth date and age, and verified with a birth certificate when possible. Age was squared to account for the nonlinear relationship with measures of nutritional status. The number of days spent in bed in the 7-day period before the interview was used to control for morbidity due to illnesses. To assess total wealth, we asked participants how many of 23 selected local, market, and animal assets they currently owned. Specifically, local assets included dugout canoes, mortars, hand-woven bags, grinding stones, and bows/arrows. Market assets included bicycles, shotguns, rifles, cooking pots, fishing nets, metal fishing hooks, machetes, axes, mosquito nets, radios, watches, grinding mills, and metal knives. Finally, domesticated animals included ducks, pigs, chickens, and cattle. We then aggregated the value in bolivianos based on survey responses to obtain the current price of each asset in the village or nearest town. For analysis, wealth was transformed using the natural logarithm ($n + 1$) to correct for a left skewed distribution. We use wealth as a covariate instead of income because income is a short-term measure of cash flows among Tsimane', whereas wealth is a cumulative measure of savings that better reflects economic standing. Education was measured as the total number of years of formal schooling completed by an individual. To control for differences in household composition and nutritional requirements, we rely on adult male equivalent scores (Claro, Levy, Bandoni, & Mondini, 2010; Zeng et al., 2013). Following Zeng et al. (2013), each person in the household was given an adult male equivalency score according to their age and gender. These scores were then summed at the household level to provide a proxy of household energy requirements. Finally, to control for unmeasured village-level fixed effects, such as distance or access to the market, we include dummy variables for all villages.

Statistical analysis

Data was analyzed using Stata 12 (StataCorp, 2011). Data analysis began with descriptive statistics and excluding outliers (9 observations [4 male]) with biologically implausible values. We used bivariate analyses to describe household spending patterns on market foods and BMI, weight, and percent body fat. We then used OLS multiple linear regression models to test our research question while controlling for covariates with the variance–covariance estimator (vce-cluster) to cluster-robust standard errors by household. The vce-cluster method relaxes the independence assumption of errors within designated group membership, allowing us to account for correlation within households.

Results

Descriptive statistics and diet composition

Household spending on market foods was relatively common in the sample, with 61% of households reporting purchases over the previous week (Table 1). These included cooking oils (~16 Bs/l), dairy products (cheese/milk cost ~5–20 Bs depending on item and amount purchased), meat products (dried, salted beef charqui, beef products, canned sardines with sauce, and pork cost ~10–30 Bs/kg), sweets (raw sugar, sodas and other sugar-sweetened drinks, candies, cookies, and ice-cream cost ~1–12 Bs), or processed carbohydrates (pasta noodles, refined white bread, and white flour cost ~5–15 Bs). The median spending level among those reporting purchases was 46.5 bolivianos (range: 3–622 Bs). Sweets were the most common food type purchased with over 75% of households in each spending tertile reporting these expenditures. The percentage of households reporting expenditures on processed carbohydrates increased steadily across expenditure categories. In contrast, the percentage of households purchasing meats did not increase as sharply. This finding suggests that although market meats are relatively expensive, they are a common purchase. Only a few households reported spending money on milk and cheese, which are generally not produced by households. A small number of households also bought rice (2.4%), citrus fruits (0.3%), tomatoes (0.2%), plantains (0.2%), and onions (4.8%). These foods were not included in the market foods variable because they are not refined or associated with nutrition transitions.

Table 1
Percentage of Tsimane' households that reported expenditures on market foods by household spending levels.

HH expenditure level	Number (%) households	Percent of households in spending category that purchased:				
		Dairy (%)	Cooking oils** (%)	Market meat** (%)	Noodles /bread** (%)	Sweets** (%)
None (0 Bs)	219 (38.9%)	0	0	0	0	0
Low (0.1–29.9 Bs)	117 (20.8%)	0	18	33	38	77
Medium (30.0–68.9 Bs)	115 (20.4%)	1	38	44	67	86
High (>69.0 Bs)	112 (19.9%)	2	54	54	84	89
Total	563	0.5	22	27	39	51

p-values reflect one-way ANOVA for differences in percent of households spending money on food groups between expenditure categories.
$^{**}p < 0.01$, $^{*}p < 0.05$, $+p < 0.1$.

Men's total expenditures comprise the majority (84%) of household expenditures (See Table 2) as more men (47.9%) reported spending money on market foods than women (19.5%) (Data not shown). This is consistent with the fact that men are more involved in market food purchases. Individual wealth was positively correlated with household expenditures (Pearson's $r = 0.06$, $p = 0.03$), suggesting that individuals with more wealth lived in households that purchased more market foods.

Adults in the sample show little evidence of undernutrition. As shown in Table 2, mean BMIs for men and women fall in the upper end of the WHO normal/healthy category (23.5 and 23.7 kg/m^2, respectively). Consistent with other studies in the region (Godoy et al., 2009; Zeng et al., 2013), this sample has a moderate number of overweight and obese adults. Here 19.2% and 1% of men and

Table 2
Descriptive statistics for Tsimane' adults (mean and SD for continuous variables).

Variable	Men ($n = 600$)	Women ($n = 599$)
Age (years)	36.6 ± 15.8	35.3 ± 16.8
Weight (kg)	62.2 ± 7.2	53.8 ± 8.2**
Height (cm)	162.4 ± 5.0	150.4 ± 4.5**
BMI (kg/m^2)	23.5 ± 2.2	23.7 ± 3.2
SUM4 (mm)	35.9 ± 11.9	60.9 ± 19.6**
Body fat (%)	17.3 ± 4.8	30.7 ± 5.1**
Overweight (%)	19.2	24.2*
Obese (%)	1.0	3.8**
HH expenditure on market foods (Bs)	49.1 ± 86.4	44.5 ± 80.1
Percent of HH spending on market foods (%)	84.0	16.0**
Wealth (Bs)	2578.9 ± 2549.9	836.3 ± 806.3**
No. of days spent in bed last 7 days (#)	0.4 ± 1.1	0.5 ± 1.4*
HH adult equivalence (#)	4.6 ± 2.1	4.7 ± 2.1
Education (years)	2.8 ± 3.2	1.5 ± 2.3**

Notes: BMI: body mass index; SUM4: sum of 4 skinfolds (triceps, biceps, subscapular, and suprailiac); kg: kilograms; HH: household; Wealth measured in bolivianos; No.: Number; Overweight: between 25 and 30 BMI; Obese: greater than 30 BMI. *p*-values refer to *t*-tests between men and women.
$^{**}p < 0.01$, $^{*}p < 0.05$, $+p < 0.1$.

Table 3
Anthropometric indicators of nutritional status for Tsimane' adult men and women disaggregated by their reported household market food expenditure levels.

HH market food expenditure category	Number[a] (%) individuals	BMI mean ± SD	Weight (kg) mean ± SD	Percent body fat (%) mean ± SD
Men ($n = 600$)				
None (0 Bs)	229 (38.2)	23.4 ± 2.2	61.9 ± 7.2	17.0 ± 4.8
Low (0.1–29.9 Bs)	118 (19.7)	23.5 ± 2.1	62.2 ± 6.2	17.3 ± 5.0
Medium (30.0–68.9 Bs)	123 (20.5)	23.4 ± 2.4	61.6 ± 8.1	17.4 ± 4.9
High (>69.0 Bs)	130 (21.7)	23.9 ± 2.3	63.2 ± 7.0	17.5 ± 4.6
Women ($n = 599$)				
None (0 Bs)	242 (40.4)	23.3 ± 3.0+	53.0 ± 7.8	30.4 ± 5.1
Low (0.1–29.9 Bs)	115 (19.2)	24.1 ± 3.4+	54.4 ± 8.2	30.7 ± 5.2
Medium (30.0–68.9 Bs)	123 (20.5)	23.9 ± 3.4+	54.0 ± 8.7	31.0 ± 4.9
High (>69.0 Bs)	119 (19.9)	24.0 ± 3.3+	54.6 ± 8.7	31.2 ± 5.2

**$p < 0.01$, *$p < 0.05$, +$p < 0.1$.
[a] Number of individuals per category vary slightly because of differences in household composition. p-values reflect one-way ANOVA for differences between expenditure categories for men and women separately.

24.2% and 3.8% of women were overweight or obese, respectively. As seen in Table 3, both women and men show a small increase in BMI, weight, and percent body fat across categories of increased household market food expenditures although the differences are not statistically significant using one-way ANOVA without controlling for confounders ($p > 0.05$).

OLS multiple regression analysis

We find mixed support for our prediction that household expenditures on market foods are positively associated with nutritional status among Tsimane' adults. In all three models for men, body composition was significantly greater among the category of high levels of reported expenditures compared to the reference category of no expenditures (Table 4). Men in households that spent 69 or more bolivianos a week (~$10 US) on market foods had 0.69 higher BMI (Model 1a, $p = 0.027$), 1.80 kg greater body weight (Model 2a, $p = 0.048$), and 1.06% higher body fat (Model 3a, $p = 0.025$) when compared to men in households that did not spend money on market foods adjusted for covariates. This pattern suggests that, for men, living in a household with high, but not low or medium, spending rates on market foods is associated with increased body fatness. Among women, increased household expenditures on market foods are positively associated with measures of body composition, but the results are not statistically significant (Table 4).

It is important to note that individual wealth also has an independent and significant positive association with BMI and weight among men and women. In this study, a 10% increase in individual wealth is associated with a 0.02 higher BMI among men (Model 1a, $\beta = 0.17$; $p = 0.06$) and 0.06 higher BMI among women (Model 1b, $\beta = 0.57$; $p = 0.001$) adjusting for covariates, including household expenditures. These findings indicate it may be important to consider both wealth and household food expenditures when examining body composition among adults.

Robustness

We conducted two additional tests of robustness. First, to evaluate if household food expenditures were associated with increased probability of being overweight/obese (BMI $\geq$ 25.0), we dichotomize BMI to estimate models using multiple logistic regression with cluster-robust standard errors and the same covariates (full results not shown). Consistent with results presented in Table 4, men in the high category are 1.83 times more likely to be overweight (OR = 1.83, $p = 0.042$, 95% CI: 1.02–3.27) than men in households that spent no money on market foods. Among women, the associations failed to achieve statistical significance (results not shown). We use the predicted mean values from these regressions models to illustrate how household food expenditure categories relate to probability of overweight/obesity (See Fig. 1a and b). Men in the none category have the lowest probability of being overweight at slightly less than 15%, whereas men in the high category have a 24% probability of being overweight. For women, the rates of overweight are ~25% in the none category, and this increases slightly in the low category to 31%, before attenuating in the medium and high categories.

Next, we re-estimated the models from Table 4 with a continuous, log-transformed ($n + 1$) market foods variable to examine if categorizing the variable affected the relations with our measures of body composition (full results not shown). Among men, a 10% increase in household market food expenditures was associated with an increase in BMI of 0.05% ($p = 0.052$), an increase in weight of 0.05% ($p = 0.087$), and an increase in body fat of 0.12% ($p = 0.015$). For women, the results were similar to the main findings and did not reach statistical significance. Finally, we re-estimated the models for body fatness using percent body fat calculated through

Table 4
OLS multiple linear regression of covariates of body composition for Tsimane' adults.

Independent variables[a]	Dependent variables					
	BMI		Weight		% Body fat	
	Men (1a)	Women (1b)	Men (2a)	Women (2b)	Men (3a)	Women (3b)
HH Market food expenditures (Reference category: None)						
Low (0.1–29.9 Bs)	0.199 (0.261)	0.437 (0.405)	0.455 (0.804)	0.522 (1.043)	0.459 (0.483)	0.550 (0.563)
Medium (30.0–68.9 Bs)	0.185 (0.293)	0.370 (0.433)	0.212 (0.957)	0.426 (1.155)	0.850+ (0.484)	0.270 (0.587)
High (69.0+ Bs)	0.694* (0.313)	0.313 (0.430)	1.798* (0.908)	0.497 (1.160)	1.060* (0.473)	0.622 (0.570)
Age (years)	0.129** (0.030)	0.163** (0.038)	0.435** (0.091)	0.450** (0.098)	0.525** (0.057)	0.374** (0.062)
Age^2	−0.001** (0.000)	−0.002** (0.000)	−0.005** (0.001)	−0.005** (0.001)	−0.004** (0.000)	−0.003** (0.001)
No. of Bed-days last 7 days (#)	−0.095 (0.069)	−0.090 (0.080)	−0.101 (0.231)	−0.093 (0.226)	−0.210 (0.154)	−0.011 (0.148)
Wealth (natural log Bs)[b]	0.174+ (0.094)	0.574** (0.176)	0.724* (0.327)	1.293* (0.561)	0.069 (0.162)	0.585* (0.290)
Education (years of schooling)	0.130** (0.039)	−0.028 (0.069)	0.453** (0.120)	0.0812 (0.187)	0.109* (0.062)	0.059 (0.111)
Adult equivalent in household	−0.042 (0.048)	0.135* (0.058)	−0.163 (0.150)	0.385* (0.160)	0.054 (0.078)	0.318** (0.092)
Constant	18.110** (1.048)	16.436** (1.144)	45.000** (3.624)	35.447** (3.454)	0.190 (1.711)	13.899** (1.925)
Observations[c]	575	579	577	581	556	570
R-squared	0.193	0.203	0.202	0.196	0.443	0.359

**$p < 0.01$, *$p < 0.05$, +$p < 0.1$, Cluster-robust standard errors in parentheses.
[a] Models also contain a full set of village dummy variables ($n - 1 = 39$).
[b] Natural log-transformed value in bolivianos.
[c] Observations in models vary because of differences in missing values.

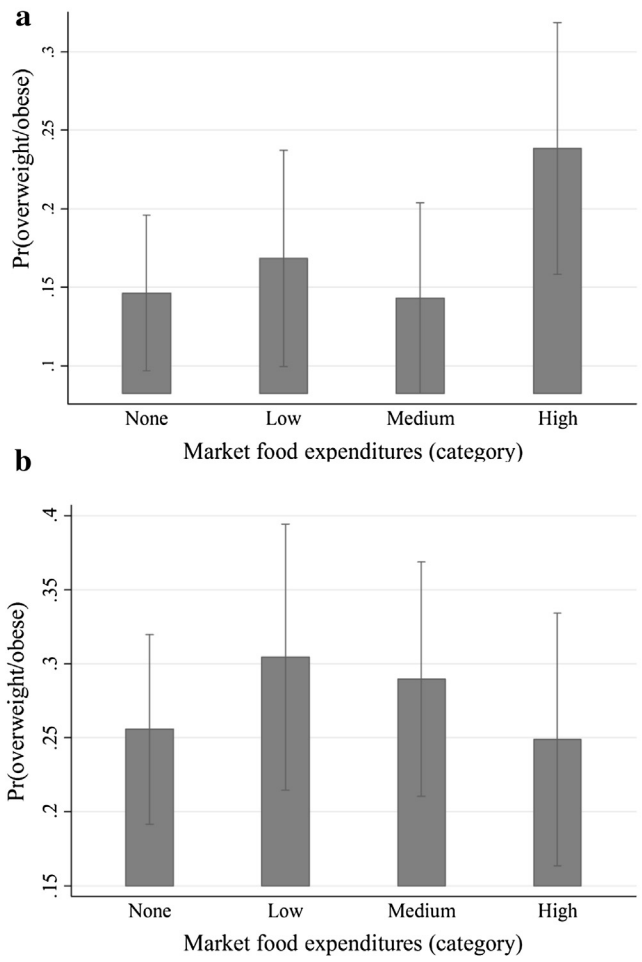

Fig. 1. a. Association between household market food expenditures and probability of being overweight (point estimate ± 95% CI.) for Tsimane' men (based on coefficients in robustness analysis). b. Association between household market food expenditures and probability of being overweight (point estimate ± 95% CI.) for Tsimane' women (based on coefficients in robustness analysis).

bioelectrical impedance analysis instead of skinfold-based estimates and found similar but slightly attenuated results (results not shown).

Discussion

This study finds that for subsistence populations, in addition to wealth, household expenditures on market foods provide insight into local dynamics of dietary changes. In this large survey of Tsimane' adult food expenditures, sugar, refined pasta, cooking oils, dried meats, sodas, and refined white bread were the most common market food items purchased. This pattern is consistent with the overall framework of nutrition transitions (Popkin, 1994), in which economic and sociocultural factors provide context to how locally-produced foods are replaced by market foods. For example, research in rural Brazil by Piperata, Ivanova et al. (2011) found that women who had abandoned household gardens and food production relied more on market foods than women with gardens. Similar studies have illustrated the importance of links between wealth and access to market foods (Valeggia et al., 2010; Welch et al., 2009). This study adds to this literature by considering household purchasing decisions in relation to adult body composition.

A second important finding is that household expenditures on market foods relate to body composition among men who live in households that rely most heavily on market foods. Although overweight and obesity rates are relatively low in this study (~20%) compared with recent research documenting rates closer to 30–40% in Bolivia (Benefice et al., 2007) and ~60% in Brazil (Lourenco et al., 2008), we found that increased household expenditures were associated with increased BMI, weight, body fatness, and likelihood of being overweight. Previous research examining the health effects of integration into market economies in Amazonia have tied wealth, income, distance to market, and subsistence strategies to changes in diet and body composition (Lourenco et al., 2008; Nardoto et al., 2011; Piperata, Spence et al., 2011). Here, household expenditures on market foods may provide insight into the dynamics of household nutritional ecology in subsistence populations that wealth assessments may overlook.

While the effect sizes found in this study are modest (0.7 BMI and 1.8 kg differences between men in the high versus none categories), the nutritional significance of these effects depends on whether the increases in BMI and weight shift an individual into the overweight or obese categories. Our analysis shows that this is 83% more likely for men in the high category. Additionally, if individuals continue to purchase market foods to replace traditional subsistence foods, these nutritional effects could be cumulative over time and weight could continue to increase similar to other parts of Amazonia (Welch et al., 2009).

Finally, we did not find an association between increased household food expenditures and body composition for women. Much literature examining nutrition transitions suggests women are more likely to gain weight and fat than men (Piperata, Ivanova et al., 2011; Wells et al., 2012). While significantly more Tsimane' women than men in this sample were overweight or obese and wealth was positively associated with body composition, associations between household food expenditures and body composition, while positive, were not statistically significant among women.

A potential explanation for the stronger results among men could be due, in part, to gender differences in market participation, access to market foods, and division of labor that make men more sensitive to fat gain in the high expenditures category. In a panel study conducted in the same region as the current study, Godoy et al. (2007) note that Tsimane' men participate in local markets more than women. Men are more likely to make the majority of market purchases, which may lead to increased access to market foods, such as soda, bread, etc., particularly among those in the high category. If purchased foods replace foods that were previously produced in household fields, this may also decrease men's activity levels tied to food production. While the majority of men has horticultural fields, they are also more likely to earn money through other jobs that vary in physical demand, like working for cattle ranchers and loggers, planting cash crops, or gathering jatata, a thatch palm. Women, on the other hand participate in markets less then men. They are more likely to spend time in domestic activities, such as laundry, cleaning, childcare, getting water, and providing some basic daily foods from household gardens (e.g., plantains). Therefore, women's activity levels tied to food production may not be reduced in the same way as men's when buying market foods.

Social status may present a second possible connection between high market food expenditure and body composition among men. Reyes-García et al. (2008) found that Tsimane' men with high social status and prestige, measured by peer-ranking, had higher indices of nutritional status, including BMI. They suggest one possible explanation might be that strenuous work obligations are lifted because of their position in the community thereby reducing total energy expenditure. Men in households that spend "high" amounts could have more prestige, regular access to energy-dense foods,

and slightly lower energy obligations, leading to weight and fat gain, whereas women may not have the same energy obligations lifted due to lower status. This is consistent with research indicating indigenous Argentinean men with high degrees of social connections and SES had higher BMI and body fat than men with fewer connections (Valeggia et al., 2010).

Research among farmers in both Bolivia (Kashiwazaki et al., 2009) and globally (Doufor & Piperata, 2008) indicates that both men and women are active in manual labor. Although relatively little research has focused on activity patterns associated with market expenditures (Doufor & Piperata, 2008), a larger body of literature has suggested gender differences in market participation are related to adult body composition among farming peoples. For example, both Lourenco et al. (2008) and Welch et al. (2009) found that men in Brazilian indigenous communities tended to travel to markets more frequently and that household wealth was related to gender divisions of labor, which may partially explain the associations between socio-economic differentiation and body fatness.

Limitations

It is important to note the limitations of this study. First, as a cross-sectional study, these results are associations and cannot be used to infer causality or change over time. The data we present is on food expenditures which does not equate to dietary intake; however, ethnographic evidence suggests Tsimane' generally consume market foods within households (Byron, 2003). Additionally, findings are subject to potential errors in reporting of expenditure data. A seven-day recall period is optimal for expenditure recalls (Neter, 1970) and has been used in other studies (Leonard et al., 1994), but may be subject to forward telescoping bias (Johnson & Schultz, 2005), in which individuals project expenditures from before the recall period into the recall period. Additionally, a seven-day recall period may not be generalizable to a full month's worth of food purchases and could miss data on individuals who had expenditures before the recall period. Both of these potential sources of information bias would result in misclassification of households in expenditure categories. This would likely underestimate the true effects and bias the effect toward the null hypothesis making the estimates in this paper conservative.

Additionally, this analysis may be subject to endogeneity of household market food expenditures that results from omitted variable bias and reverse causality. It is possible that a non-measured factor, like preference for market foods, is related to both household market food expenditures and body composition, and because it is uncontrolled for, is absorbed by the error term. While this omission could bias our results upward by overestimating the effect of market food expenditures on body composition, our results are consistent with research that found household expenditures on sugary beverages were significantly associated with increased BMI among rural Mexican women (Colchero & Sosa-Rubi, 2012). It is more likely that wealth, which we control for, is responsible for purchasing market foods as it provides the means to buy these foods instead of preferences, which may provide an impetus but not the means. The potential of reverse causality, such that increased weight is driving the purchases of market foods, is unlikely because Tsimane' produce surplus food (Ringhofer, 2010). Therefore, while heavier individuals require more calories, they can obtain extra energy from subsistence foods easier than from market foods. Finally, we do not have physical activity data to complement information on expenditure patterns (Ulijaszek, 2000). Additional research is needed to examine how activity levels are related to adult nutritional status and expenditures during nutrition transitions.

Conclusion

Evidence for the nutrition transition has extended into Amazonia recently (Welch et al., 2009). This paper examined the relation between household expenditures on market foods and body composition to better understand how intra-group differences in market participation are related to nutritional transitions. The findings from this paper suggest that household spending on market foods may be precursors to overnutrition among rural men in transitioning populations. For a population in a marginal environment with high prevalence of infectious diseases, market foods provide additional sources of fat and calories that may buffer against nutritional insults in the short-term but lead to chronic diseases in the long-term. Recognizing the interrelationships between wealth, income, and adult nutrition also requires understanding how households access market foods and if these supplement or replace foods produced by the household. Health interventions should consider such spending patterns when assessing weight gain risk factors.

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