# Maternal ethnobotanical knowledge is associated with multiple measures of child health in the Bolivian Amazon

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25 pages text (including references and figure legends)
1 figure
4 tables
Supporting text: 1 figure, 1 map, 1 table, 4 photos

Abstract: 240 words
Manuscript: 44,453 characters

Classification: BIOLOGICAL SCIENCES, Anthropology

Abbreviations: CRP, C-reactive protein; LEK, local ethnobotanical knowledge; ZSF, z-score sum of skinfold measurements; HAZ, height-for-age z-score

**Abstract**

Culture is a critical determinant of human behavior and health, and the intergenerational transmission of knowledge regarding the use of available plant resources has historically been an essential function of culture. Local ethnobotanical knowledge is important for health and nutrition, particularly in rural, low resource settings, but cultural and economic transitions associated with globalization threaten such knowledge. This prospective study investigates the association between parental ethnobotanical knowledge and child health among the Tsimane', a horticulturalist and foraging society in Amazonian Bolivia. Anthropometric data and capillary blood samples were collected from 330 Tsimane' 2-10 year-olds, and mothers and fathers were interviewed to assess ethnobotanical knowledge and skills. Comprehensive measures of parental schooling, acculturation, and economic activities were also collected. Dependent variables included three measures of child health: 1) C-reactive protein, assayed in whole blood spots as an indicator of immunostimulation; 2) skinfold thickness, to estimate subcutaneous fat stores necessary to fuel growth and immune function; and 3) height-for-age, to assess growth stunting. Each child health measure was associated with maternal ethnobotanical knowledge, independent of a wide range of potentially confounding variables. Each standard deviation of maternal ethnobotanical knowledge increased the likelihood of good child health by a factor of more than 1.5. Like many populations around the world, the Tsimane' are increasingly facing the challenges and opportunities of globalization. These results underscore the importance of local cultural factors to child health, and document a potential cost if ethnobotanical knowledge is lost.
Keywords: culture; child nutrition; acute phase reaction; infectious disease; growth and development; maternal behavior; C-reactive protein; Latin America

Cultural factors are critical, and widely recognized, determinants of human behavior and health (1). Culture—defined here as socially transmitted systems of shared knowledge, beliefs, and/or practices that vary systematically across groups—is a fundamental component of the human adaptive strategy, and a primary reason why our species has been able to exploit an impressive range of habitats (2). The intergenerational transmission of knowledge regarding the availability and potential utility of local plant resources has historically been an important adaptive function of culture (3).

Ethnobotanical knowledge—which in many ways resembles scientific knowledge accumulated through inductive methods (4)—serves as a guide for activities central to survival and well-being, including effective habitat management, strategies for subsistence and food procurement, and attempts to prevent and cure disease (5, 6). However, globalization currently poses a threat to such knowledge to the extent that formal schooling and integration into emerging market economies devalue folk knowledge, prioritize alternative sources of information, and provide access to substitute products not made from local resources (7).

The World Health Organization estimates that one in four children globally suffer from undernutrition, and that infectious diseases are responsible for 63% of all child deaths (8, 9). Poor nutrition and infection exert both independent and synergistic effects on growth and survival, and growth faltering early in life has negative effects on reproductive performance, work capacity, cognitive function, and health throughout the lifespan (10, 11). Measures of nutritional status and infectious disease in childhood can therefore serve as barometers for the current and future well-being of a population, and help identify individuals in suboptimal caregiving environments that may be at risk for adverse outcomes later in life (12).

The Tsimane'—an indigenous Amazonian population of lowland Bolivia—are increasingly facing the challenges and opportunities of globalization. Like other remote, rural populations around the world, they have limited access to commercial foods and medicines, and must rely on their ability to exploit local natural resources to maintain the health of their children. Tsimane' have wide knowledge of local plants, and use them daily for medicine, firewood, construction, tools, and food. Wild and domesticated plants account for more than 50 percent of the total value of household consumption, whereas purchased goods account for less than three percent (13). However, many Tsimane' are pursuing new economic opportunities that may undermine this aspect of their culture.

As a population in the early stages of market integration, the Tsimane' provide an excellent opportunity to evaluate the importance of local ethnobotanical knowledge to child health, and to consider the potential consequences of lost knowledge. In prior work we have shown that acculturation and certain forms of market participation are associated with lower ethnobotanical knowledge (7). In this paper we investigate the potential cost of lost knowledge to child health. Specifically, we address three questions. First, do parents with greater ethnobotanical knowledge have healthier children? Second, is this association independent of potentially confounding processes related to acculturation and market integration? And third, which matters more to child health, mother's knowledge or father's knowledge? In answering these questions we link culture and health at the level of the individual, and document an adaptive—but threatened—function of local knowledge.

A range of interview-based and observational methods were used to quantify individual variation in ethnobotanical knowledge and plant use among Tsimane' adults. We recognize that such knowledge has multiple theoretical and practical dimensions, and therefore constructed a

summary index of local ethnobotanical knowledge (LEK) based on five measures: agreement with local experts on plant uses, botanical knowledge, skills using plants, total number of plants used, and diversity of plants used. In prior work we have explored the theoretical significance of each of these measures and their associations with recent educational and economic changes (7, 14), and in this analysis we use a summary LEK variable to evaluate the degree to which an important component of Tsimane' culture predicts variation in child health.

We investigated LEK in relation to three objective measures of child health: concentrations of C-reactive protein (CRP), skinfold thickness, and stature. C-reactive protein is an central component of innate immunity that increases in concentration in response to a range of pathogenic agents, making it a potentially useful marker of infectious burden and the degree of immunostimulation (15). While much research on child health relies on caregiver reports of disease symptoms, the direct measurement of acute phase proteins such as CRP has the advantage of providing an objective assessment of morbidity that is not sensitive to recall or reporting bias, and that detects subclinical infectious processes that may not manifest as observable symptoms, but that nonetheless involve the activation of energetically costly anti-pathogen defenses (16).

Skinfold thickness provides an estimate of the size of subcutaneous fat stores, which is directly related to total body fat (17). Measures of body fatness are sensitive to fluctuations in energy balance on the order of weeks or months (18), and we use a standardized measure of skinfold thickness (ZSF) calculated against age- and sex-specific reference values. In nutritionally marginal environments, fat stores are a critical energy supply upon which the body can draw to fuel the high metabolic costs associated with growth or mounting immune responses to infectious disease (19). Height-for-age (HAZ) is a standardized measure of achieved linear

growth that is commonly used as an indicator of prior nutritional and/or health status. Stunting results from extended periods of inadequate dietary intake, frequent morbidity, or both (12).

These three measures of health were selected because they are well-validated indicators of current and future child well-being, and because they represent multiple pathways through which caregiving environments may affect health. Undernutrition and exposure to infectious disease are two primary—and inseparable—causes of child morbidity and mortality (10). Elevations in CRP capture short-term pathogenic challenges, while height-for-age reveals the cumulative, largely irreversible impact of infection and undernutrition endured over the long-term. Skinfold thickness is an intermediate measure that assesses the status of energetic resources that are critical to fueling normal growth, defenses against infectious disease, and catch-up growth following illness.

Our analyses were guided by a conceptual framework in which cultural and socioeconomic factors, as well as more proximate aspects of environmental quality, are all recognized as important determinants of child health (20, 21). We expected child health to be related to three sets of variables: 1) ethnobotanical knowledge of mothers and fathers; 2) individual child attributes (age, sex); and 3) parent-, household- and village-level variables associated with acculturation and market integration. The latter set of variables includes a wide range of commonly evaluated socioeconomic and environmental quality variables that may confound or mediate associations between ethnobotanical knowledge and child health. Statistical analyses proceeded in three stages. First, we explored the bivariate associations between parental ethnobotanical knowledge and each child health outcome. Second, we investigated the extent to which these associations were independent of potentially confounding variables by evaluating the association between LEK and child health in maximum likelihood

regression models that included a comprehensive set of parent-, household-, and village-level variables. Lastly, we compared the relative importance of maternal and paternal knowledge as predictors of child health.

## Results

The geometric mean CRP concentration for the entire sample (N=330) was 0.70 mg/L, indicating a relatively high level of immunostimulation (15). Anthropometric measures of nutritional status reveal substantial levels of growth stunting, but little evidence of wasting, a pattern similar to that found in other indigenous lowland Amerindian populations (22).

Mothers and fathers reported very similar levels of knowledge and utilization of local ethnobotanical resources, and on average they have lived in their current communities for nearly twenty years(data not shown). For the most part, we found similar patterns of correlation between various lifestyle and contextual variables and measures of maternal and paternal LEK (Table 1). Older individuals possess richer LEK, as do those who have lived in the same location for longer periods of time. Better knowledge is also associated with more positive evaluations of traditional Tsimane' lifestyles, as well as residence in more remote villages. Mothers and fathers with proficiency in spoken Spanish have lower LEK. Similarly, additional years of formal education are negatively associated with LEK, but only for fathers. Parental LEK is not associated with household wealth or size of agricultural plots, and the correlation between maternal and paternal LEK is 0.76 ($p<0.001$). All variables were inspected for covariation with LEK, and none approached significance except for those identified in Table 1.

### Ethnobotanical knowledge and CRP

Overall, 36.5 percent of the sample has concentrations of CRP≥1 mg/L, with equal distributions across boys and girls but a higher likelihood of CRP elevation among younger children. Children with elevated CRP have mothers and fathers who report significantly lower levels of LEK (see *Supporting information Figure 2* for the bivariate association between LEK and each of our child health measures). In a maximum likelihood model including child age and gender, overall maternal LEK was significantly associated with reduced risk of elevated CRP (Table 2, Model 1). This association was not altered by the addition of several maternal, household, and village covariates (Table 2, model 2). A one standard deviation decrease in a mother's ethnobotanical knowledge is associated with a 52% increase in the risk of a child having elevated CRP, controlling for a wide range of potentially confounding variables.

A similar, but weaker association is evident when paternal factors are considered separately from maternal knowledge. Controlling for child age and gender, paternal LEK is significantly associated with a lower likelihood of elevated CRP (Table 2, model 3). The addition of household and village covariates does not substantially alter this association (Table 2, model 4). Children whose fathers are one standard deviation below average on local ethnobotanical knowledge are 38% more likely to have elevated CRP.

Lastly, we considered a combined model to evaluate the relative importance of maternal and paternal LEK in predicting elevated CRP (Table 2, model 5). The association between child CRP and maternal LEK was strengthened with the addition of paternal variables, while the association with paternal LEK was entirely eliminated, suggesting that the association reported above is mediated primarily by maternal knowledge.

Other maternal predictors of elevated child CRP include frequency of travel to San Borja, ratings of the value of traditional Tsimane' lifestyles, and years of formal schooling, although the

latter is of marginal statistical significance. CRP is more likely to be elevated in children whose mothers travel more frequently to San Borja, have fewer years of formal education, and are more conservative in their orientation toward Tsimane' lifestyles. Frequency of travel to San Borja was the only significant predictor of child CRP for fathers: as with mothers, the likelihood of elevated CRP is higher for children whose fathers travel more often.

Additional predictors of child CRP include the distance of the household from its water source, and the presence of nurses and ethnomedical healers in the village. On average, each household is approximately eight minutes from its water source, and more distant sources are associated with reduced CRP, perhaps reflecting the quality of these sources. While options for health care are limited for the Tsimane', the presence of a village resident with basic health care training is associated with lower risk of elevated CRP, and the presence of ethnomedical healers is associated with higher risk.

To facilitate interpretation of the association between CRP and ethnobotanical knowledge, we calculated the predicted probability of elevated CRP based on regression coefficients from our final maximum likelihood model. We set ethnobotanical knowledge to one standard deviation above average and one standard deviation below average to represent high and low levels of knowledge, respectively, and retained individual values for other covariates. In effect, this procedure allows us to estimate the independent association between ethnobotanical knowledge and elevated CRP while controlling for potentially confounding factors. For children whose mothers have high LEK, approximately one in four will have CRP$\geq$1 mg/L. The likelihood of elevated CRP nearly doubles for children of mothers with low LEK (Figure 1).

**Ethnobotanical knowledge and skinfold thickness**

Approximately 15 percent of the sample was below one standard deviation for age- and sex-standardized skinfold thickness, with girls more likely to be below the cutoff (17.5%) than boys (11.9%). Younger children were also more likely to have lower skinfolds. LEK scores are significantly lower in mothers and fathers of children with low ZSF (see *SI Figure 2*). When considered in a model with child age and gender, higher maternal LEK is significantly associated with reduced likelihood of low child ZSF (Table 3, model 1). This association strengthens with the addition of maternal, household, and village covariates (Table 3, model 2). Controlling for a wide range of potentially confounding variables, children whose mothers are one standard deviation below average in maternal knowledge are 66% more likely to have low skinfold thickness.

We found a similar association between father's ethnobotanical knowledge and child ZSF, with higher LEK associated with reduced likelihood of low child ZSF, independent of child age and gender (Table 3, model 3). This association is weakened, but remains significant, with the addition of other paternal, household, and village variables (Table 3, model 4). Fathers who are one standard deviation below average in ethnobotanical knowledge are 48% more likely to have a child with low skinfold thickness, independent of potentially confounding variables.

As with CRP, the simultaneous consideration of mother's and father's LEK with significant covariates results in a model where mother's knowledge remains as a significant predictor of child skinfold thickness, while the association with father's knowledge is eliminated (Table 3, model 5). The only significant, independent paternal predictor of child ZSF was body mass index, with larger fathers less likely to have children with low skinfold thickness. Maternal duration of village residence, distance to water source, village size, and the number of traditional healers were also significant predictors of low ZSF.

Controlling for these covariates, one in ten children of mothers with high LEK will have low skinfold thickness. The predicted probability of low skinfolds increases to almost one in five for children of mothers with low LEK (Figure 1).

**Ethnobotanical knowledge and growth stunting**

Reflecting the high rates of growth faltering in this population, 44.9 percent of the sample can be considered growth stunted, with height-for-age z scores of less than -2. Measures of ethnobotanical knowledge did not predict growth stunting in maximum likelihood models, with or without the full range of parental, household, and village variables.

Since the impact of parental ethnobotanical knowledge may be greater at the lower end of the distribution of child growth, we evaluated a series of models predicting the likelihood of severe stunting (HAZ<-3). The prevalence of severe stunting was 12.2%, with higher prevalence among younger children. Severely stunted children have mothers and fathers with significantly poorer ethnobotanical knowledge (see *SI figure 2*). We first evaluated the association between maternal ethnobotanical knowledge and severe child stunting in a model including child age and gender, as well as maternal stature. In this model, higher maternal LEK is significantly associated with a lower probability of severe stunting (Table 4, model 1). This association is strengthened slightly by the addition of other maternal, household, and village covariates (Table 4, model 2). The likelihood of severe stunting increases by 76% for each standard deviation decrease in a mother's ethnobotanical knowledge.

For fathers, considered separately from mothers, higher LEK also predicts lower likelihood of severe child stunting independent of paternal stature and child age and gender (Table 4, model 3). This association strengthens with the consideration of additional paternal,

household, and village variables (Table 4, model 4). Controlling for potentially confounding variables, a one standard deviation decrease in a father's ethnobotanical knowledge is associated with a 57% increase in the likelihood of severe stunting.

As with CRP and skinfold thickness, significant associations between child stunting and father's level of ethnobotanical knowledge were eliminated in a full model including maternal knowledge (Table 4, model 5). Maternal knowledge remained as a significant predictor of severe stunting in children, independent of a wide range of parental, household, and village-level variables. As one might expect, growth faltering was less likely in children with taller mothers and fathers. In addition, severe stunting was less likely in children whose fathers are more proficient in Spanish. Higher interviewer ratings of household cleanliness were associated with reduced stunting.

Based on this model, less than one in ten children of mothers with high LEK will be severely stunted. The likelihood of severe stunting increases to nearly one in five for children of mothers with low LEK (Figure 1).

**Discussion**

Like many remote, rural populations around the world, the Tsimane' have limited resources and opportunities for acquiring food, medicine, or other processed goods. They rely heavily on local natural resources to meet their daily needs, and accumulated knowledge passed down across generations of Tsimane' serves as a guide for drawing on these resources. However, adults vary in the degree to which they possess ethnobotanical knowledge, and in this study we find that mothers with higher levels of plant knowledge and use have healthier children, independent of potentially confounding variables related to education, market participation, and

acculturation. Associations are similar across short-term measures of inflammation, and medium- and long-term measures of nutritional status, with each standard deviation of ethnobotanical knowledge increasing the likelihood of good child health by a factor of more than 1.5.

Bivariate associations between maternal knowledge and child health are strong, and are not attenuated by the addition of proxies for environmental quality. Absence of mediation, however, does not discount the importance of these well-established proximate determinants of child health, particularly since we find significant associations with child health for measures of household cleanliness and water quality. Rather, it suggests that LEK is operating through alternate pathways, and that in environments with high burdens of infectious disease like that currently inhabited by Tsimane' children, LEK may be more important in buffering children from the adverse health consequences of infection rather than preventing exposure. This underscores the importance of considering cultural factors such as LEK as key contributors to child health, even if the proximate mechanisms linking culture and health are not immediately evident.

The strong associations with maternal knowledge are consistent with prior research in other low income settings demonstrating the importance of maternal education to child health (23). Within Tsimane' families, women typically assume primary responsibility for childcare, and it is therefore reasonable to expect that maternal attributes will affect children more directly than paternal attributes. In addition, like formal schooling in other settings, maternal ethnobotanical knowledge may empower women to create a more salutary caregiving environment despite limited resources.

Alternatively, while mothers and fathers report similar levels of overall ethnobotanical knowledge, they may differ in their expertise regarding specific applications of this knowledge. For example, women may be expert in using plants to prevent and treat infectious disease, while men may possess more knowledge relevant to construction or habitat management. Evaluation of the potentially gendered nature of Tsimane' ethnobotanical knowledge will require more fine-grained, domain-specific analyses in future work.

There are several plausible mechanisms linking maternal LEK and child health. First, informed adults may be more efficient exploiters of local natural resources, allowing them to provide their children with diets that are superior in terms of quality as well as quantity. Better diets supply the macro- and micro-nutrients that build body fat stores, fuel linear growth, and bolster immune defenses against infectious disease (12, 24).

Second, local plants may have direct pharmacological properties that help prevent or treat common child ailments. Indeed, plants are a central part of the Tsimane' ethnomedical tradition (25), and they may play a particularly important role in protecting health since effective commercial medicines are expensive and difficult for the Tsimane' to procure. If remedies derived from local plants are effective in preventing or treating illness, this would contribute not only to lower levels of inflammation, but also to improved linear growth and body fat stores by reducing allocations of energy to fueling immunity and fighting infection (16, 26).

Third, while we infer a direct association between maternal knowledge and child health, it is possible that the associations are mediated in part by the child. Tsimane' children as young as four and five years spend much of their time away from the supervision of their parents, playing and foraging in small peer groups. We have observed instances where older children have used plants for medicinal purposes for themselves, or for younger children. It is therefore

feasible that adults transmit their ethnobotanical knowledge and skills to children at a relatively young age, and children who use this information are able to more effectively provision or medicate themselves, at least in part.

Lastly, it is possible that there is no direct causal association between maternal LEK and child health. We collected data on child health after assessing maternal attributes, and it is not likely that differences in child health are causing differences in parental knowledge. Of greater concern is omitted variable bias, in which LEK stands in for correlated, but unmeasured, attributes of children, parents, or their households. However, we considered a comprehensive set of variables that represent plausible alternative pathways linking LEK and child health. In most cases, adding these variables to multivariate models did not substantially change—and in fact strengthened—the association between maternal knowledge and child health. This stability stands in marked contrast to the pattern of results with fathers, and increases our confidence that the effect of mother's knowledge is not being driven by unmeasured variables or measurement error. In addition, we find consistent results across three distinct child health measures, further suggesting that a mother's ability to use local plant resources contributes directly to the well-being of her children. Additional research with more fine grained measures of LEK and the proximate mechanisms connecting it to child health will be required to verify this claim.

A strength of this study is the explicit attempt to link culture and health at the level of the individual. Culture is, by definition, an aggregate, shared property of a group that exists in the minds and actions of individuals, but that is given meaning collectively (27). This poses a significant challenge to measurement, particularly for quantitative, epidemiological analyses of biological outcomes that require an individual-level operationalization of "culture". While

culture matters to health on multiple levels, this challenge has limited our ability to document the importance of cultural factors, and to inform interventions and policy accordingly.

Culture is not a monolithic, homeostatic whole, but rather a set of dynamic models pertaining to different domains of beliefs and behaviors (27, 28). This conceptual foundation provides a basis for empirically defining a specific cultural model that may be relevant to health, and for locating an individual with respect to that model (29). We draw on this perspective to characterize the accumulated knowledge collectively possessed by the Tsimane', and then rank individuals with respect to this knowledge. In this way we are able to move from culture as a shared property of the group, to culture as an attribute of the individual that is predictive of child health in a multivariate framework.

The value of this approach is evident in the strength and consistency of the association between child health and a mother's ethnobotanical knowledge. In contrast, schooling and household wealth—two commonly investigated predictors of child health—accounted for little, if any, variation in three measures of child health in this population. There is no question that education and economic security are critical determinants of population health globally, but when levels of schooling are low and economic opportunities are limited—as they are currently for the Tsimane'—the loss of adaptive cultural resources for protecting health may come at a significant cost.

## MATERIALS AND METHODS

**Study site and data collection.** The Tsimane'[1] are an indigenous Amazonian population of approximately 8,000 in the Department of Beni in lowland Bolivia (30) (see *SI figure 3* for a map

[1] The Tsimane'—along with the neighboring Moseten—represent a distinct linguistic group in the Beni that is related to languages of the Macro-Pano family.

of the study site, and *SI figures 4-7* for photographs). Slash-and-burn farming is the primary means of subsistence, supplemented with hunting and gathering, with relatively new and increasingly available opportunities for wage labor in logging camps or cattle ranches, or the sale of crops and forest goods. At the time of our survey electricity and running water were not available to any household, and only half of the surveyed communities were accessible by road. Thirteen communities were selected that vary in distance from the town of San Borja, the regional commercial center (population ~19,000). Analyses focus primarily on data collected in the wet season (November-December 2002, January 2003), when comprehensive measures of ethnobotanical knowledge were first introduced to the survey. We limit our analyses to children between the ages of 2 and 10, inclusive, since it is during this period that our health measures are most sensitive, and when the well-being of children is most dependent upon their caregivers. An attempt was made to recruit every resident of the 13 villages over the age of 2 years into the study. Anthropometric measures and finger prick whole blood samples were collected in one or two days, and virtually everyone who was present was included in the sample. Health data were collected after assessing LEK and other explanatory variables. The study protocol was approved by the Northwestern University Institutional Review Board for research involving human subjects. The Tsimane' Grand Council also approved the study, and parental consent as well as child/adolescent assent was obtained prior to enrollment.

**Measures.** ***Ethnobotanical knowledge.*** Measures of ethnobotanical knowledge are based on prior work in this population (31). Cultural consensus methods (28) were used to evaluate the degree to which knowledge regarding the usefulness of local plant species was shared among the Tsimane', and to characterize this knowledge. First, a free listing exercise with 50 study

participants resulted in a list of 92 plants judged to be useful, from which 21 were randomly selected for further evaluation. All participants were then asked, in a multiple-choice format, to report on whether each plant could be used for the following: construction, firewood, food, medicine, and/or other. Multiple uses per plant were allowed. Analysis of the resulting plant by plant-use matrix indicated a high degree of agreement across individuals regarding the specific uses for each plant (31) (mean cultural competence = 0.58, SD = 0.20). In effect, this analysis produces an "answer key" that reveals the shared Tsimane' cultural model for how plants can be used, and that presumably guides exploitation of plant resources in their environment. By comparing individual responses against this collective wisdom, an individual-level measure of locally meaningful plant use knowledge can be obtained. Since elders are commonly recognized as repositories of local ecological knowledge, we derived a cultural model for plant use based on responses from individuals over 55 years of age. We then compared individual ratings of plant uses to this model to derive a quantitative measure of knowledge as defined by local experts.

We also used cultural consensus methods to characterize variation in local botanical knowledge by posing questions regarding the attributes of ten randomly selected plants. For example, we asked: "Which is the color of the mahogany flower? a) red, b) green, or c) white". We confirmed the existence of shared botanical knowledge among the Tsimane', and then assessed the degree to which an individual's responses were in agreement with the most frequent responses of the group to define an individual-level measure of botanical knowledge (mean cultural competence = 0.55, SD = 0.18).

To collect information on individual variation in practical skills using plants—in addition to knowledge regarding their uses and attributes—we asked participants to report whether they had ever made, on their own, 18 different plant-based objects. The list included nine objects that

are more commonly made by men and nine that are more commonly made by women, and six items that are considered easy to make, six items of medium difficulty, and six items considered difficult to make. A measure of plant skills for each individual was created by summing the number of objects made.

Two additional measures of plant usage were derived from household visits in which the number and diversity of plants brought into the household were observed. On a day chosen at random, each adult present in the household was asked to report all of the wild plants he/she had brought into the household during the previous 24 hours. A measure of total plant use was created by summing the total number of plants brought into the household. Diversity of plant use was defined as the total number of different plant species brought into the household.

Since these measures are correlated, and since we are interested in parental ethnobotanical knowledge and skills more broadly, we constructed a summary variable based on the above measures. Also, by evaluating a single summary variable as a predictor of child health rather than five related variables we reduce the chances of type I error. Separate, standardized variables were constructed for a child's mother (or primary female caregiver) and father (or primary male caregiver), with mean=0 and standard deviation=1. Chronbach's alpha was 0.68 for mother's LEK, and 0.60 for father's LEK (See *SI Table 5* for additional information on the association between each individual ethnobotanical knowledge/plant use measure and child health).

***Child health.*** Concentrations of CRP were measured in dried blood spot samples, collected by placing at least one drop of free flowing capillary whole blood on standardized filter paper (Whatman #903, Middlesex, UK), following a simple finger prick with a sterile, single-use

microlancet. Samples were analyzed using an enzyme-linked immunosorbent assay (ELISA) protocol previously validated for use with blood spots (32). Subscapular and tricep skinfold thicknesses were measured to the nearest 0.5 mm with precision Lange calipers, using standard procedures (33). The sum of triceps and subscapular skinfolds were standardized as z-scores (standard scores) relative to age- and sex-specific U.S. references (34). Linear growth measurements were taken with a portable stadiometer and recorded to the nearest millimeter according to standard protocols (33). Sex-specific standardized z-scores for height-for-age (HAZ) were calculated in EpiInfo (Version 3.2, CDC) using the CDC/WHO 1978 reference curves recommended for international use (35).

**Data analysis.** All statistical analyses were conducted with Stata for Windows, version 8.0 (StataCorp, College Station, TX). A series of maximum likelihood logistic regression models were used to predict the likelihood of: 1) CRP$\geq$1 mg/L; 2) ZSF<-1; 3) HAZ<-2; and 4) HAZ<-3. A cut-off of 1 mg/L was used for CRP because prior research in this population has shown that CRP concentrations above this threshold indicate significant activation of inflammatory pathways that are prospectively associated with deficits in height gain (26). A cut-off of -1 was chosen for ZSF to identify the group of children with low body fat stores, and therefore the highest risk for subsequent infection and/or growth faltering. Consistent with prior applications (17), z-scores of -2 and -3 on height-for-age were used to represent the presence of stunting and severe stunting, respectively.

We considered the following parent-level variables: age, duration of residence in current village, years of formal education, literacy, proficiency in spoken Spanish (an official language of Bolivia, and of growing importance to the Tsimane'), income from wages and barter over the

preceding two weeks, frequency of travel to the local town of San Borja, stature, and body mass index. We also evaluated attitudes toward "traditional" aspects of Tsimane' culture by asking respondents to rate their level of agreement with practices and beliefs historically common among the Tsimane' (10 likert-style questions; 3-point scale, higher scores indicate more conservative cultural attitudes, while lower scores indicate a preference for non-traditional western lifestyles). These variables provide proxies for education and market participation, orientation toward and experiences with acculturation, and health endowments that may confound associations between parental ethnobotanical knowledge and child health.

We considered the following household-level variables: household size (number of residents) and density (residents/$m^2$); wealth (summary of 18 physical assets); size of agricultural plots; presence of a latrine in the compound; water source (river, well); distance to water source (minutes walking); distance to nearest neighbor (minutes walking); and interviewer rating of household cleanliness. Village-level variables included: village size (number of households); distance from San Borja (measured in hours of travel time); number of teachers in residence; the presence of one or more residents with basic health care training provided by local missionaries, number of ethnomedical healers practicing in the village; and whether the village was accessible by road.

Variables were added separately to models, and evaluated for association with child health as well as impact on the odds ratio describing the association between LEK and child health. The "cluster" option in STATA was specified for all models, with village designated as the clustering variable. This option relaxes the assumption that individual observations are independent, and requires only that observations be independent across clusters. This procedure

adjusts for the fact that individuals were enrolled at the village level, and provides robust (and more conservative) estimates of variance around regression parameters.

**Acknowledgments**

This material is based upon work supported by the National Science Foundation under Grant Nos. (BCS-0134225; BCS-0078801; BCS-0200767). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. Support from the Physical Anthropology and Cultural Anthropology Programs at NSF is gratefully acknowledged, as is support from a Presidential Early Career Award for Scientists and Engineers (TWM).

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**Figure legends**

Figure 1. Predicted probability of a child having CRP≥1mg/L, ZSF<-1, or HAZ<-3 for mothers with high versus low levels of local ethnobotanical knowledge, controlling for covariates in Tables 2-4.