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Differences in nutritional status between rural and urban Yucatec Maya children: The importance of early life conditions

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Abstract

Early-life conditions shape childhood growth and are affected by urbanization and the nutritional transition. To investigate how early-life conditions (across the "first" and "second" 1000 days) are associated with rural and urban children's nutritional status, we analyzed anthropometric data from Maya children in Yucatan, Mexico. We collected weight, height and triceps skinfold measures, then computed body mass and fat mass indices (BMI/FMI), in a cross-sectional sample of 6-year-olds (urban $n = 72$, rural $n = 66$). Demographic, socioeconomic and early-life variables (birthweight/mode, rural/urban residence, household crowding) were collected by maternal interview. We statistically analyzed rural-urban differences in demographic, socioeconomic, early-life, and anthropometric variables, then created linear mixed models to evaluate associations between early-life variables and child anthropometric outcomes. Two-way interactions were tested between early-life variables and child sex, and between early-life variables and rural-urban residence. Results showed that rural children were shorter-statured, with lower overweight/obesity and cesarean delivery rates, compared to urban children. Household crowding was a negative predictor of anthropometric outcomes; the strongest effect was in boys and in urban children. Birthweight positively predicted anthropometric outcomes, especially weight/BMI. Birth mode was positively (not statistically) associated with any anthropometric outcome. Cesarean delivery was more common in boys than in girls, and predicted increased height in urban boys. In conclusion, urbanization and household crowding were the most powerful predictors of Maya 6-year-old anthropometry. The negative effects of crowding may disproportionately affect Maya boys versus girls and urban versus rural children. Early-life conditions shape Maya children's nutritional status both in the "first" and "second" 1000 days.

KEYWORDS

anthropometry, childhood, growth, urbanization, Yucatec Maya

1 | INTRODUCTION

Early-life conditions and exposures shape childhood growth, vary over space and time, and are affected by urbanization and the nutritional transition. Evidence from human and animal models show that adverse environmental influences during sensitive periods of early development can have significant and negative consequences for growth and health in both the short and long-term (Barker, 1993; Gluckman et al., 2006; Martorell, 2017; Matthews et al., 2017; Rutherford et al., 2021). In humans, this is particularly true from conception to the end of the second year of life ("the first 1000 days," http://thousanddays.org/),which represents a critical period for brain and body growth and immunologic and metabolic maturation (Cusick & Georgieff, 2016; Mayneris-Perxachs & Swann, 2019; Robertson et al., 2019; Wells et al., 2020). This concept has been integrated into global health research and prevention efforts to identify early-life factors that increase risk of childhood obesity and the "double burden of malnutrition" (DBM; here defined as the "coexistence of undernutrition, that is, micronutrient deficiencies, underweight, and childhood stunting and wasting and overweight, obesity, and diet-related noncommunicable diseases [Popkin et al., 2020])" (Doak et al., 2005; Hennessy et al., 2019; Pietrobelli & Agosti, 2017; Wells et al., 2020). However, some recent work has argued for a renewed focus on child development in the "second 1000 days" (the preschool period), a neglected but important period of physical and intellectual development (Black et al., 2021; Prado, 2021). Furthermore, children ages ~3–10 years undergo learning and development of lifelong dietary habits; poor diet quality in this time can increase obesity risk (Vinke et al., 2020).

Childhood obesity and DBM are rising in lower- and middle-income countries due to urbanization and widespread rural-to-urban migration (Corvalán et al., 2017; Danquah et al., 2020; Popkin et al., 2012). Rural-to-urban migrants experience a rapid "nutritional transition," which contributes to the anthropometric differentiation of rural and urban children. The nutrition transition is here defined as a process by which locally produced and "traditional" (low-fat and high-fiber) diets become displaced by "urbanized," non-local diets composed of highly refined market foods and beverages that are high in fat, salt and sugar and low in fiber (Moreno-Altamirano et al., 2014; Popkin et al., 2020; Rivera et al., 2002; Tzioumis et al., 2016; Varela-Silva et al., 2012; Vega Mejía et al., 2018; WHO, 2021). Upon exposure to the nutritional transition, urban children become taller and more obesity-prone than rural children, a pattern that persists when comparing rural versus urban children within the same country, region, and ethnic population (Dong et al., 2019; Paciorek et al., 2013; Van de Poel et al., 2007). However, socioeconomic and sex differences can cut across the rural–urban divide and may affect children's growth in more complex ways (Aris et al., 2017; Gatica-Domínguez et al., 2020; Paciorek et al., 2013). For example, negative health outcomes tend to be exacerbated in marginalized indigenous populations experiencing urbanization and the nutrition transition (Cockx et al., 2018; Goryakin et al., 2017; Gracey & King, 2009; Harris et al., 2019; King et al., 2009; Malik et al., 2013; Mora-García et al., 2020; Valeggia & Snodgrass, 2015; Varela-Silva et al., 2012). In addition, early-life factors may culminate in differential outcomes across rural and urban settings (Garraza et al., 2016; McDade et al., 2005; Mueller et al., 2015; Mushtaq et al., 2011; Opara et al., 2012; Ortiz et al., 2014; Veile, Faria, et al., 2019).

To investigate how early-life conditions influence childhood nutritional status across rural and urban settings, we analyze anthropometric data from 6-year-old Maya children in the Yucatan Peninsula, Mexico. Yucatec Maya children's growth has been extensively studied and published elsewhere and the data we present come from prolific and long-term field sites. We add to the existing literature by combining detailed demographic, socioeconomic and anthropometric datasets for rural and urban children. This combination of data offers an excellent opportunity for rural–urban comparison because the Yucatec Maya are genetically the same population and share many common cultural traits but inhabit different environments – both rural farming communities and highly urbanized ones. The Yucatan also provides a well-documented case study of postcolonial urbanization and the nutritional transition (Delfin Gurri, 2015; Dickinson et al., 1993; Leatherman & Goodman, 2005). The Yucatec Maya have farmed on the peninsula for at least 3000 years; many of their traditional agricultural and dietary practices are still thriving today (Díaz, 2012; Kramer, 2005; O'Connor & Anderson, 2016). Still the past 40 years have seen a dramatic acceleration of economically driven Maya migration from rural farming communities to dense urban settings where they experience negative health outcomes associated with the nutritional transition (Azcorra et al., 2020; Leatherman 2020; Bogin et al., 2020).

The main goals of this study were to: (a) compare rural and urban children's nutritional status; (b) test the association of early-life conditions and nutritional status in rural and urban children; and (c) test for sex and residence-based interactions with early-life proxy variables. We chose to compare 6-year-olds because this age indicates an end of early childhood and the "first" and "second" 1000 days; it is also a time (in the Maya) when some dietary independence (food choice) has begun. We use anthropometric measurements and derived indices to assess the nutritional status of Maya children because they provide a useful indicator of population-level nutritional conditions and health status (Schell, 1986; Tanner & Tanner, 1981; WHO Working Group, 1986). To assess early-life conditions, we utilize common proxy variables: child birthweight and birth mode (for prenatal and perinatal conditions, respectively; e.g., the "first 1000 days") and rural/urban residence (for nutritional conditions across the "first" and "second" 1000 days), and current household crowding (for epidemiologic conditions, e.g., the "second" 1000 days). Our models account for maternal/child individual factors and socioeconomic variation. We expected that that maternal, socioeconomic, perinatal, nutritional, epidemiologic and socioeconomic conditions would differ between rural and urban settings, with consequences for children's anthropometric status. We further expected that urban Maya children with urbanized diets would be more susceptible to overweight, obesity and DBM, compared to rural children consuming more traditional foods derived from long-established household subsistence food production practices.

2 | METHODS

2.1 | Study communities

The Yucatec Maya people have farmed on the peninsula for at least 3000 years, and many of their traditional agricultural and dietary practices persist today (Díaz, 2012; Kramer, 2005; O'Connor & Anderson, 2016). While ancient Maya developed technologically and politically sophisticated urban centers beginning ~2500 BCE, rural-to-urban migrations to Merida (the capital of Yucatan state) began under Spanish Colonial period (18th century) and continued after Mexican Independence (19th century) (Ramírez-Carrillo, 2020). The past 40 years have seen an acceleration of economically driven Yucatec Maya migration from rural farming communities to dense urban settings (Leatherman 2020). While tourism has become an important income source for many urban and rural coastal Maya communities, the data presented here are from communities that are not integrated into the tourist economy.

The rural Yucatec Maya study community is located in the Puuc region of Yucatan about 140 km southwest of Merida. The community consists of ~500 subsistence maize agriculturalists whose economy, demography and childcare practices have been studied extensively since 1992 (Kramer, 2005; Kramer, 2009; Kramer & Veile, 2018; Veile, Faria, et al., 2019; Veile & Kramer, 2018). The past 20 years have seen the introduction of electricity, running water, a paved road, motorized vehicles, mechanized farming, schools, and a health clinic, yet villagers maintain a largely traditional diet and agricultural practices. Fathers engage in agricultural tasks and community labor such as public building construction and road maintenance. Mothers engage in domestic tasks (e.g., cooking, laundry, and childcare) and some field work; some earn cash by participating in government-run craft cooperatives (Hackman & Kramer, 2021). The rural Maya are bilingual in Spanish and Maya, with Maya being the predominate language spoken within households and children's first language (Padilla-Iglesias & Kramer, 2021) Previous studies showed a median breastfeeding duration of 30.64 months (95% CI: 29.62–31.66, $n = 88$), with the introduction of complementary foods occurring at a median of 5.7 ($SD = 2.2$, range $= 2$–12, $n = 58$) months (Veile, Faria, et al., 2019; Veile & Kramer, 2015). Mothers completed on average 6.52 ($SD = 3.10$, $n = 73$) years of schooling (Kramer et al., 2021; Veile, Valeggia, & Kramer, 2019). The rural community is homogeneously Maya.

The urban sample was drawn from the cities of Merida and Motul in the State of Yucatán, Mexico. Merida is the capital of Yucatán and the most important economic center in the Mexican southeast. With a population of ~892,363 people (INEGI, 2016), Merida has a Maya population of ~11% (Lizama Quijano, 2012). The city of Motul, located in the north-central region of the state at approximately 40 km from Merida city, was inhabited in 2015 by 36,097 people; 25% of them were Maya speakers (INEGI, 2016). Nowadays, the economic activities in Motul consist of small-scale livestock production and agriculture, tourism, and maquiladoras (manufacturing operations). In Merida, most of the adult population works as employees and wage laborers in small businesses performing low-wage jobs. In both cities, participants were recruited through primary schools attended by children. Maya children were identified based on having both paternal and maternal Maya surnames. Previous studies from this population showed a median breastfeeding duration of 8 (range $= 0$–72) months, with introduction of complementary foods occurring at a median of 6 (range $= 2$–34) months. Mothers had on average 9 (range $= 0$–19) years of formal education, which corresponds to secondary education (Sanchez-Escobedo et al., 2020).

2.2 | Data considerations

Anthropometric and demographic data were originally collected in the rural and urban settings as part of separate projects with different aims. Importantly, the rural sample of children only includes children who were born and raised in rural areas, while the urban sample of children includes only children who were born and raised in urban areas. However, some other aspects of the sampling and data collection procedures vary from site to site.

The rural–urban sample schemes differed in three main ways: (a) In the rural setting, >90% of the community's school-aged children were measured. In contrast, urban participants were randomly selected and recruited from schools in low-income neighborhoods (Merida) or from all 12 public primary schools (Motul). (b) Rural children were measured longitudinally (once annually from 2010 to 2017, starting at 6 years old), whereas urban children 6–8 year-olds were measured cross-sectionally (in five annual rounds of cross-sectional data collection, 2011–2015, with no repeat measures). (c) Because the rural sample draws from the entire community, it includes siblings, so some rural mothers have more than one child in the dataset. In the urban setting, in contrast, all mothers are only represented once and there are no siblings in the dataset.

These different sampling schemes limit our ability to make comparisons. We opted to only compare 6-year-olds, effectively treating the rural sample like a cross-section, and then comparing it to the cross-section of urban 6-year-olds. Ultimately, compiling all 6-year-old children in the sample yielded a cross-section of 72 urban and 66 rural children ($n = 138$ total). Considering the sampling issues and small sample size, we pay special attention to data analysis and interpretation throughout this article. Following recommendations of Valeggia and Fernández-Duque (2021), we emphasize in plain language the effect sizes (rather than focusing exclusively on statistical significance) of the associations we find. For each model, we also provide a post-hoc power analysis for each tested main effect and interaction effect. When power statistics are low, we do not assume that a non-significant result implies no effect, but rather that the sample size may be too small to detect one. When we do find a significant result, we consider effect size and power along with our general predictions and contextual knowledge when drawing cautious conclusions.

2.3 | Data collection

The following demographic and socioeconomic information were collected at both sites via maternal interview and verified with official records when possible: maternal age, birthplace and parity (live births), child birthdate, birthweight, birth order and birth location and mode, breastfeeding duration, parental occupations and parental years of schooling. Family size (adults and children residing permanently in the home) and number of bedrooms were also collected by maternal interview, then used to create a household crowding index using family size divided by the # of rooms designated at least partially for sleeping.

Child anthropometric measures height and weight (standard indicators of long and short-term nutritional conditions, respectively), and triceps skinfold (and indicator of adiposity or subcutaneous body fat) (Bedogni et al., 2003), were collected at both sites by trained research personnel using standardized procedures (Lohman et al., 1988), regularly calibrated instruments, and as previously described (Azcorra, 2014; Kramer, 2005). At both sites, children were measured in bare feet, wearing shorts and sleeveless shirts, and after emptying pockets and removing jewelry, watches and hats. Maternal height was measured at both sites as well, using the same procedures (Lohman et al., 1988).

Different measuring equipment and measurement protocols were used at the rural and urban sites. Rural children were weighed using a Health-O-Meter digital scale (model BFM081-63, error of $+/-0.5\%$) whereas urban children were weighed using a SECA scale (model 881, error of $+/-0.25\%$). Rural children's height was measured using a portable Seca stadiometer; urban children's height was measured using a moveable Martin type anthropometer. Children's triceps skinfold were measured at each site using a Harpenden caliper. In the rural setting, anthropometric measurements were taken 2–3 times and an average recorded if values differed. In the urban setting, each anthropometric measurement was taken three times and the average used for calculations.

2.4 | Database construction

The main dataset consists of raw (weight, height, triceps skinfold) and derived (body mass index, fat mass index) 6-year-old anthropometric outcome variables (5 total); raw (birthweight, birth mode, residence) and derived (crowding index) early-life variables (4 total); and potential confounding variables (year of data collection, child age and sex, maternal age, education, parity and height, family size and birth order) (9 total). Other variables include World Health Organization (WHO) Z-scores (weight-for-age [WAZ], height-for-age [HAZ], and BMI-for-age [BMIZ]), and child growth stunting (low height-for-age), overweight, obesity and DBM rates (7 total). Body mass index (BMI) was computed using the standard equation (BMI = weight (kg)/height (m^2)), WHO Z-scores were computed using the igrowup package in R, and child stunting/overweight/obesity were assessed using standard WHO cut-off criteria (WHO, 2006). DBM was considered present if a child was simultaneously stunted and overweight or obese. Breastfeeding information (presence/absence and duration) and several socioeconomic variables (paternal education, parental occupation, maternal childhood residence, child's location of birth) were also analyzed for descriptive purposes but were not modeled due to having at least one of the following issues: (a) >3% of observations missing data, (b) low variability (<10%), or (c) non-comparability across sites.

We estimated child body fat mass for both settings using an anthropometric equation (FM, Equation 1). The equation was developed using the deuterium oxide dilution technique on a large, geographically and ethnically diverse sample of Mexican children (which included Maya individuals) and validated against the standard BIA formula (Ramírez et al., 2012). This value was then converted to fat mass index, a commonly used indicator of obesity and metabolic syndrome in adults and children, using the standard equation (FMI, Equation 2), (Alpízar et al., 2020; Liu et al., 2013). The anthropometric FM equation yields lower FM values compared to those obtained by BIA and reported by Azcorra et al. (2019) (BIA mean, $SD = 6.9$, 2.55 vs. anthropometric mean, $SD = 4.9$, 3.16, $n = 74$), however, they are highly correlated in the urban sample (Pearson correlation coefficient $= 0.86$, $p = <0.01$, $n = 72$).

$$\text{FM (kg)} = 1.067 \times \text{sex} + 0.458 \times \text{triceps skinfold} + 0.263 \times \text{Wt} - 5.407 \quad (1)$$

$$\text{FMI} = \text{FMI} = \text{fat mass [kg]}/\text{height [m]}^2) \quad (2)$$

2.5 | Data analysis

Calculation of derived variables, descriptive statistics and modeling were all conducted using the R programming environment (R Core Team, 2020). Anthropometric outcome variables were tested for normality. *T*-tests and chi-squared tests were used to compare the anthropometric outcomes and early-life variables, confounders and other variables, between rural and urban children. Children from the two cities did not differ significantly in any of these variables and are therefore combined to form the urban sample in all statistics and modeling. The same procedures were then used to compare the same variables between boys and girls within the rural and urban setting. Pearson coefficients were calculated to determine correlations between all continuous predictors and all anthropometric outcome variables.

The analytical approach was to create comparable linear mixed models (LMM) fit by maximum likelihood for each anthropometric outcome. We modeled raw anthropometric values (while accounting for child age) instead of Z-scores for two main reasons. First, we are modeling a cross section of children in one age group and not dealing with non-linear growth changes over time. Second, our previous work showed that the WHO Z-score distribution does not fit the distribution of anthropometric outcomes (especially height) for rural Maya children (Kramer et al., 2016).

Of the five outcome variables, only height had a normal distribution whereas weight, triceps skinfold, BMI and FMI all had a right-skewed gamma distribution. In height models, the distribution was specified as "normal" and "identity" used as the link function. For the gamma-distributed dependent variables, the distribution was specified as "gamma" and "identity" used as the link function. Some rural mothers ($n = 23$) had more than one child in the dataset, so child ID was nested within maternal ID. We used the pwr.lme function in a post-hoc power analysis to detect statistical power (1 - beta or probability of NOT making a type 2 error) for each main predictor variable and for each interaction term in each model, assuming a medium effect size and $\alpha = 0.05$ (Champley, 2020).

One child was missing data for the variable birthweight, and one was missing data for triceps skinfold. These missing values were imputed during the modeling process rather than eliminating observations because the percentage of imputed data was small (<3%) (Gelman & Hill, 2006). Family size, parity, birth order, and crowding index were significantly correlated, and crowding index was therefore used as a proxy for each to avoid collinearity in the models. There were no significant anthropometric trends across the data collection period, so year of data collection was excluded from the models.

LMM was used to model each anthropometric outcome variable as a function of the four early-life variables (main effects models), and then as a function of the four early-life variables and their two-way interactions with child sex and rural–urban residence. Each model included five potential confounding variables: maternal age, height and education, and child age and sex, plus the four early-life variables (treated simultaneously as a potential confounder and an individual predictor). For example, when modeling weight as a function of crowding index, the model accounted for maternal age/height/education, child age/sex, and birth weight, birth mode and rural/urban residence. In total, three sets of models were created:

1. Five main effects models: one per anthropometric outcome (9 total effects per model, 4 early-life variables plus 5 confounders), early life variables tested ($\alpha = 0.05$).
2. A total of 22-way sex interaction models: (10 total effects per model, 4 early-life variables plus 5 confounders, plus one interaction term), interaction tested ($\alpha = 0.05$).
3. A total of 15 two-way residence interaction models: (10 total effects per model, 4 early-life variables plus 5 confounders, plus one interaction term), interaction tested ($\alpha = 0.05$).

3 | RESULTS

3.1 | Descriptive statistics

Descriptive statistics and rural–urban comparisons for demographic and anthropometric variables are given in Table 1. Urban 6-year-old children had significantly higher anthropometric measurements, derived anthropometric indices, and WHO Z-scores compared to 6-year-old rural children. The mean BMI Z-score of urban children (0.93 ± 1.22) was nearly 1 *SD* above the WHO median, whereas rural children's mean BMI Z-score (0.05 ± 0.68) fell nearly at the WHO median. Nearly half (46%) of urban children were overweight or obese whereas no rural children were obese and few (7.6%) overweight. Urban children's mean HAZ-score (−0.70 ± 0.83) exceeded rural children's mean HAZ-score (−2.04 ± 0.84) and the WHO stunting rate was 5.6% (urban) versus 56% (rural). There were no cases of DBM (concurrently stunted + overweight nor concurrently stunted + obese) in the urban setting. There were three cases of DBM in the rural setting: three children were concurrently stunted and overweight; no children were concurrently stunted and obese.

Urban and rural mothers did not differ significantly in age, but urban mothers were significantly taller (~4 cm) and rural mothers significantly more parous (~2 more children). Family size did not differ significantly between the urban and rural households but rural households were significantly more crowded (with ~1.4 more residents per bedroom). Birthweight did not significantly differ with residence, nor did rates of macrosomia (birthweight >4000 g) or low birthweight (birthweight <2500 g). The urban cesarean delivery rate was >2 times higher compared to the rural rate (47.2% vs. 21.2%, respectively), likely due to the closer proximity of urban children to hospital facilities where cesareans are performed. All rural children ($n = 44$) and ~ 70% of urban children ($n = 50$) were "ever-breastfed;" there was also a dramatic difference in the mean breastfeeding duration (27 vs. 5 months, respectively).

There were no differences in predictor, outcome, or confounding variables between the two urban settings (S1). No sex differences were significant within the rural or urban setting with one exception: in both settings, girls had higher FMI compared to boys (S2, S3). While neither rural nor urban children's cesarean delivery rates differed significantly by sex, we note that for girls, the cesarean delivery rate was ≥10% lower in both settings (rural girls vs. boys = 13.8% vs. 27%, urban girls vs. boys = 42.1% vs. 52.9% (S2, S3). There were no major differences or trends in rural/urban mean anthropometric values across the study duration (S4). Children's five anthropometric indices were significantly correlated with each other; family size, parity, birth order, and crowding index were all significantly correlated as well (S5).

3.2 | Socioeconomic context

All clinic or hospital-born rural children ($n = 50$), and nearly all urban children (97%, $n = 70$), were born in government (rather than private) hospitals (S6). Cesarean deliveries in government hospitals were provided at little or no cost, because only the lowest income families qualified for government-subsidized medical care. A total of 16 rural mothers birthed in their home community under the care of a local midwife for personal rather than economic reasons (Veile & Kramer, 2018); all the home birthing mothers qualified for government-subsidized medical care. This collectively implies a lack of correlation between wealth and birth location and mode in this sample of children

All rural mothers ($n = 43$) were born and raised in rural communities whereas most urban mothers (79%, $n = 57$) came from relatively urban areas. A more detailed breakdown of maternal childhood residence is provided (S6). No rural mothers engaged in wage labor employment whereas 46% of urban mothers ($n = 33$) engaged in wage labor outside of the home. The predominate economic activity of rural fathers was cash cropping of maize. Urban fathers did not farm but instead engaged in a wide variety of wage

TABLE 1 Descriptive anthropometric, parental, and demographic statistics compared for 6-year-old rural and urban Maya children

	Numeric variables										
	Rural (n = 66)				Urban (n = 72)				Comparison		
Variables	Mean	*SD*	Minimum	Maximum	Mean	*SD*	Minimum	Maximum	*t*-value	*SE*	*p*-value
Child birth weight (g)[a]	3071.4	442.48	1800	4000.0	3084.4	504.09	1590	4300	0.16	81.29	0.87
Child weight (kg)	18.1	2.00	14.30	22.9	22.8	4.32	16.4	37.8	8.07	0.58	<0.01
Child WAZ	−1.3	0.80	−3.44	0.47	0.26	1.20	−2.29	3.32	9.02	0.18	<0.01
Child height (cm)	107.9	4.40	99.00	117.0	114.8	4.69	105.6	125.3	8.89	0.78	<0.01
Child HAZ	−2.0	0.84	−4.06	−0.09	−0.70	0.83	−2.42	1.20	9.53	0.14	<0.01
Child BMI	15.5	1.06	13.46	19.0	17.2	2.45	13.6	25.1	5.11	0.33	<0.01
Child BMIZ	0.1	0.68	−1.33	1.8	0.93	1.22	−1.42	4.46	5.19	0.17	<0.01
Child triceps skinfold (mm)[a]	7.7	1.85	4.00	13.5	10.9	4.47	4.9	23.8	5.41	0.59	<0.01
Child fat mass index[b]	1.9	2.14	0.001	9.6	3.8	2.23	0.3	10.0	5.85	0.29	<0.01
Maternal age (years)	32.9	7.10	23.25	53.2	31.5	5.48	22.4	49.9	−1.35	1.07	0.18
Maternal height (cm)[c]	143.4	4.26	135.8	151.6	147.5	5.16	132.5	147.5	−4.38	0.93	<0.01
Maternal education (years)	5.8	2.32	2	12	8.0	3.36	0	16	3.76	0.22	<0.01
Paternal education (years)[d]	6.8	2.90	0	12	9.2	3.00	3	16	3.88	0.54	<0.01
Breastfed duration (months)[e]	27.0	16.85	1.5	60	4.0	5.03	0	24	−10.79	2.13	<0.01
Family size	5.6	1.57	3.0	11	5.1	1.98	2	12	−1.81	0.31	0.07
Birth order	3.3	2.73	1.0	15	1.6	0.97	1	6	−4.81	0.34	<0.01
Parity	4.2	2.42	1.0	15	2.2	1.30	1	8	−5.94	0.33	<0.01
Crowd index	4.5	2.05	1.33	11.0	3.1	1.45	1.3	10	−4.64	0.30	<0.01

	Categorical variables					
Variable	Frequency	Percent	Frequency	Percent	Chi-square	*p*-value
Cesarean	14/66	21.2	34/72	47.2	10.52	<0.01
Stunted	37/66	56.1	4/72	5.6	42.06	<0.01
Overweight	5/66	7.6	19/72	26.4	8.48	<0.01
Obese	0/66	0.0	14/72	19.4	14.28	<0.01
Double burden malnutrition	3/66	5.6	0/72	0.0	N/A	N/A
Low birth weight	3/66	4.6	6/72	8.3	0.81	0.37
Macrosomia	0/66	0.0	2/72	3.8	1.86	0.17
Ever breastfed[f]	44/44	100	50/72	69.4	16.59	<0.01

[a] n = 71, 1 missing data point.
[b] One rural and one urban child had fat mass indices <0.00. Values were replaced with 0.001 to meet assumptions of the general linear model.
[c] Rural n = 43 because some mothers have more than one child in the sample.
[d] Urban n = 62, 10 missing data points, rural n = 42 because some fathers have more than one child in the sample, 1 missing data point.
[e] Rural n = 42, 24 missing data points.
[f] Rural n = 44, 22 missing data points.

labor activities. Rural fathers also engage in communal labor (e.g., community road maintenance) and occasional wage labor (e.g., visiting a neighboring farm to help harvest for pay). However, we lack quantitative measures of this type of income due to its inconsistency and informality. A detailed breakdown of parental employment status is provided (S6).

3.3 | Model results: Main effects

Adjusted parameter estimates from the main effects models are provided (Table 2) and the full models are shown in the supplemental materials with power statistics for each main predictor variable (S7). Urban residence was associated with substantially higher values for all five anthropometric outcomes, whereas crowding index was associated with substantially lower values for all anthropometric outcomes. Birthweight was associated with higher values for all anthropometric outcomes, though effect sizes varied, and associations were most pronounced for child weight and BMI. Cesarean delivery was positively associated with all anthropometric outcomes, though the effect sizes were small.

Birthweight and urban residence were positive, significant predictors in the weight model. Each 500 g-increase in birthweight was associated with a 1.0 kg-increase in 6-year-old weight. Compared to rural residence, urban residence was associated with a 3.5 kg-increase in 6-year-old weight. Crowding index was a negative, significant predictor in the weight model. Increasing the crowding index by 1 (e.g., increasing the number of household members without changing the number of bedrooms) was associated with a 0.5 kg-decrease in 6-year-old weight. Cesarean delivery was a positive, non-significant predictor in the weight model. Compared to vaginal delivery, cesarean delivery was associated with a 0.42 kg-increase in 6-year-old weight.

Urban residence was a positive and significant predictor, and crowd index a negative and marginally significant predictor, in the height model. Compared to rural residence, urban residence was associated with a 5 cm-increase in 6-year-old height. Increasing the crowding index by 1 was associated with a 0.6 cm-decrease in 6-year-old height. Birthweight and cesarean delivery were both positive, non-significant predictors in the height model. Each 500 g increase in birthweight was associated with a 0.15 cm-increase in 6-year-old height. Compared to vaginal delivery, cesarean delivery was associated with a 0.68 cm-increase in 6-year-old height.

Birthweight and urban residence were both positive and significant predictors in the BMI model. A 500 g-increase in birthweight was associated with a 0.5-unit increase in 6-year-old BMI. Compared to rural residence, urban residence was associated with a 1.3 unit-increase in 6-year-old BMI. Crowding index was a negative, significant predictor in the BMI model. Increasing the crowding index by 1 was associated with a 0.20 unit-decrease in 6-year-old BMI. Cesarean delivery was a positive, non-significant predictor in the BMI model. Compared to vaginal delivery, cesarean delivery was associated with a 0.12 unit-increase in 6-year-old BMI.

Urban residence was a positive and significant predictor, and crowding index a negative and near-significant predictor, in the triceps skinfold model. Compared to rural residence, urban residence was associated with a 2.4 mm-increase in 6-year-old triceps skinfold. Increasing the crowding index by 1 was associated with a 0.3 mm-decrease in children's triceps skinfold. Birthweight and cesarean delivery were both positive, non-significant predictors, in the triceps

TABLE 2 Adjusted parameter estimates and *p*-values for predictor variables in main effects models

Predictor	Outcome	Parameter estimate	*SE*	*p*-value
Birthweight (g)	Weight (kg)	0.002	0.001	0.006**
Birth mode = Cesarean	Weight (kg)	0.422	0.609	0.490
Residence = urban	Weight (kg)	3.535	0.642	<0.001
Crowding index	Weight (kg)	−0.523	0.159	0.001**
Birthweight (g)	Height (kg)	0.001	<0.001	0.063
Birth mode = Cesarean	Height (kg)	0.844	0.761	0.269
Residence = urban	Height (kg)	5.004	0.802	<0.001***
Crowding index	Height (kg)	−0.557	0.198	0.006**
Birthweight (g)	BMI	0.001	<0.001	0.017*
Birth mode = Cesarean	BMI	0.115	0.370	0.7586
Residence = urban	BMI	1.286	0.097	0.001**
Crowding index	BMI	−0.247	0.096	0.011*
Birthweight (g)	Triceps skinfold (mm)	0.001	0.001	0.226
Birth mode = Cesarean	Triceps skinfold (mm)	0.401	0.672	0.552
Residence = urban	Triceps skinfold (mm)	2.445	0.709	<0.001***
Crowding index	Triceps skinfold (mm)	−0.342	0.175	0.053
Birthweight (g)	Fat mass index	<0.001	<0.001	0.108
Birth mode = Cesarean	Fat mass index	−0.251	0.319	0.433
Residence = urban	Fat mass index	1.337	0.337	<0.001***
Crowding index	Fat mass index	−0.198	0.831	0.019*

Note: Significance codes: 0 "***" 0.001 "**" 0.01 "*" 0.05.

skinfold model. A 500 g increase in birthweight was associated with a 0.40 mm increase in 6-year-old triceps skinfold, and cesarean delivery was associated with a 0.40 mm-increase in 6-year-old triceps skinfold.

Urban residence was a positive and significant predictor, and crowding index a negative and significant predictor, in the FMI model. Urban residence was associated with a 1.3 unit-increase in 6-year-old FMI. Increasing the crowding index by 1 was associated with a 0.20 unit-decrease in 6-year-old FMI. Birthweight and cesarean delivery were both positive, non-significant predictors, in the FMI model. A 500 g increase in birthweight was associated with a 0.25 unit-increase in 6-year-old FMI, and cesarean delivery was associated with a 0.25 unit-increase in FMI).

3.4 | Two-way interaction models

Most of the sex and residence interactions we tested were underpowered and not statistically significant. We therefore report on notable non-significant trends as well as statistically significant results. In the models for height, two interactions with sex were significant (birth mode and crowding index, Figures 1 and 2). In the models for triceps skinfold, there was one significant interaction by residence (crowding index, Figure 3). Adjusted ANOVA *f*-values and *p*-values for two-way sex and residence interactions models are provided (Table 3). Full models are shown in the supplemental materials with power statistics (S8, S9) and further summarized with the results of the main effects models (Table 4). Predicted values with 95% confidence intervals are plotted and provided for each non-significant interaction (S10, S11).

3.5 | Sex interactions

Sex interactions with birthweight underpowered and were not statistically significant for any of the anthropometric outcomes (Table 3). However, there is a trend in which girl's anthropometric outcomes all show a stronger positive association with birthweight compared to boys (S10). Sex interactions with birth mode were also underpowered and not statistically significant in the weight, BMI, triceps skinfold, and FMI models; no notable sex-differentiated trends emerged across these outcomes (Table 3, S10).

There was a statistically significant interaction between sex and birth mode (Figure 1, power statistic for the interaction =0.72, $p = 0.02$). Vaginally delivered children's predicted mean height did not differ significantly by sex (boys =108.5 cm (95% CI: 101.60–115.58); girls =108.7 cm (95% CI: 101.7–115.6)). In cesarean delivered children, boys had a significantly higher predicted mean height value compared to girls (boys =110.8 cm (95% CI: 103.8–117.9); girls =107.6 cm (95% CI: 100.5–114.7).

Sex interactions with residence were not significant for any anthropometric outcome (Table 3, S10). Girls had slightly higher FMI and triceps skinfold compared to boys in both rural and urban settings. Boys had slightly higher weights and heights compared to girls

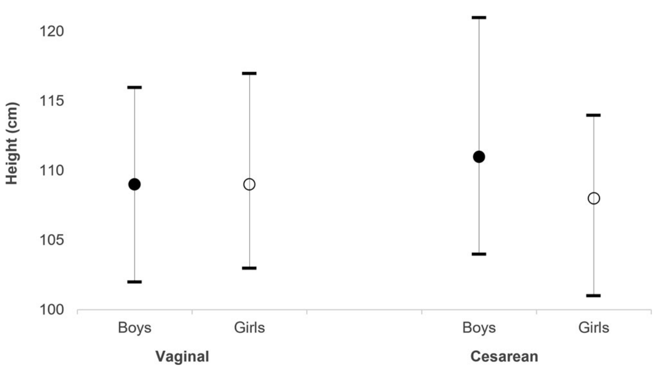

FIGURE 1 Mean predicted child height by sex and birth mode with 95% confidence intervals. The interaction term for sex and birth mode is statistically significant ($p = 0.02$). The power statistic for this interaction is 0.72

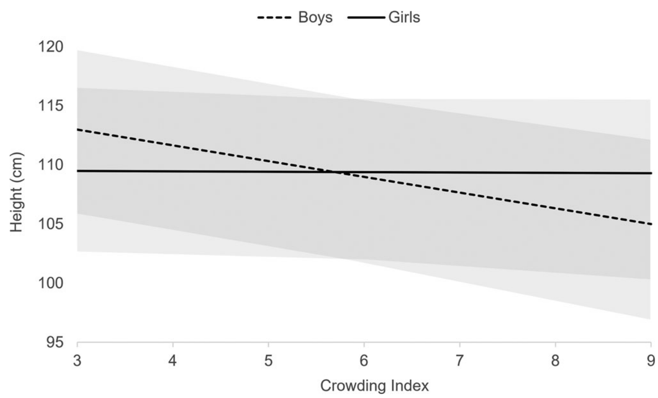

FIGURE 2 Mean predicted child height by sex and crowding index with 95% confidence intervals. The interaction term for sex and crowding index is statistically significant ($p = 0.05$). The power statistic for this interaction is 0.53

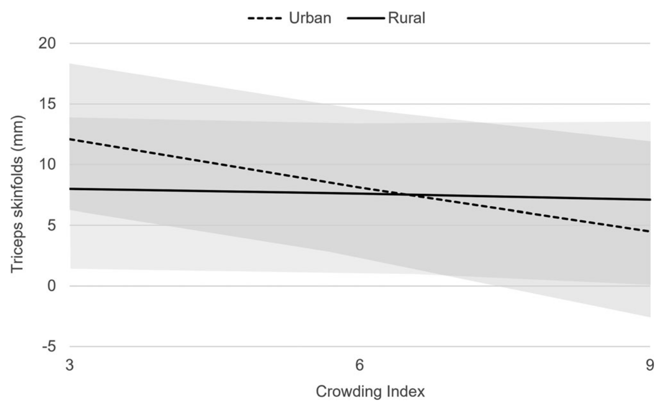

FIGURE 3 Mean predicted child triceps skinfolds by sex and crowding index with 95% confidence intervals. The interaction term for sex and crowding index is statistically significant ($p = 0.04$). The power statistic for this interaction is 0.20

TABLE 3 Adjusted parameter estimate, *SE*, and *p*-values for the interaction term in two-way sex and residence interaction models

Predictor	Outcome	Interaction variable	Parameter estimate	*SE*	*p*-value	Interaction variable	Parameter estimate	*SE*	*p*-value
Birthweight (g)	Weight (kg)	Sex	0.002	0.001	0.164	Residence	0.001	0.001	0.291
Birth mode = Cesarean	Weight (kg)	Sex	0.451	1.213	0.688	Residence	0.175	1.994	0.885
Residence = Urban	Weight (kg)	Sex	−0.406	1.088	0.710	Residence	N/A	N/A	N/A
Crowding Index	Weight (kg)	Sex	0.431	0.280	0.126	Residence	−0.202	0.326	0.538
Birthweight (g)	Height (kg)	Sex	0.002	0.001	0.078	Residence	<0.001	0.001	0.674
Birth mode = Cesarean	Height(kg)	Sex	3.354	1.370	0.016*	Residence	−0.103	1.50	0.945
Residence = Urban	Height (kg)	Sex	−1.769	1.351	0.193	Residence	N/A	N/A	N/A
Crowding index	Height (kg)	Sex	0.687	0.347	0.050*	Residence	0.117	0.408	0.775
Birthweight (g)	BMI	Sex	<0.001	0.001	0.495	Residence	0.001	0.001	0.435
Birth mode = Cesarean	BMI	Sex	−0.660	0.679	0.333	Residence	0.282	0.723	0.699
Residence = Urban	BMI	Sex	0.273	0.661	0.680	Residence	N/A	N/A	N/A
Crowding index	BMI	Sex	0.136	0.171	0.428	Residence	−0.161	0.198	0.417
Birthweight (g)	Triceps skinfold (mm)	Sex	0.001	0.001	0.5033	Residence	<0.001	0.001	0.746
Birth mode = Cesarean	Triceps skinfold (mm)	Sex	−0.750	1.237	0.546	Residence	0.054	1.325	0.967
Residence = Urban	Triceps skinfold (mm)	Sex	0.180	1.202	0.881	Residence	N/A	N/A	N/A
Crowding index	Triceps skinfold (mm)	Sex	0.310	0.286	0.349	Residence	−0.720	0.355	0.045*
Birthweight (g)	Fat mass index	Sex	<0.001	0.001	0.448	Residence	<0.001	0.001	0.755
Birth mode = Cesarean	Fat mass index	Sex	−0.335	0.588	0.570	Residence	0.100	0.629	0.874
Residence = Urban	Fat mass index	Sex	−0.008	0.571	0.989	Residence	N/A	N/A	N/A
Crowding index	Fat mass index	Sex	0.206	0.147	0.163	Residence	−0.286	0.170	0.095

Note: Significance codes: 0 "***" 0.001 "**" 0.01 "*" 0.05.

in the urban but not the rural setting. BMI was nearly identical by sex in both the rural and urban settings.

Sex interactions with crowding index were not significant in the weight, BMI, triceps skinfold, and FMI models (Table 3), though there is a trend in which all boy's anthropometric outcomes show a stronger negative association with crowd index compared to girls (S10). For height, the interaction between child sex and crowding index was statistically significant (Figure 2, power statistic for the interaction =0.53, $p = 0.05$). Boys from uncrowded homes were on average taller than girls: when crowding index = 1, boy's mean height predicted value was 112.3 (95% CI: 105.12–119.49) and girl's mean height predicted value was 109.4 (95% CI: 102.1–116.6). In crowded homes, in contrast, girls were on average taller than boys: when crowding index =8, boy's mean height predicted value was 106.3 (95% CI: 98.93–113.62) and girl's mean height predicted value was 108.2 (95% CI: 100.71–115.62). This pattern resulted from a steep and linear loss in boy's height as crowding index increased; girl's height declined only slightly with crowding index.

3.6 | Residence interactions

Residence interactions with birthweight and birth mode were underpowered and not significant for any of the anthropometric outcomes (Table 3). No discernible residence-differentiated trends emerged across these outcomes (S11). Triceps skinfold models showed no significant interactions between residence and birthweight nor between residence and birth mode (Table 3, S9). However, there is a consistent trend in which urban children's weight, BMI, triceps skinfold and FMI (but not height) show a stronger negative association with crowd index compared to rural children (S11).

For the triceps skinfold model, the stronger negative effect of urban crowding was statistically significant (Figure 3, power statistic for the interaction =0.20, $p = 0.04$). Urban children from uncrowded homes had higher mean triceps skinfold values compared to rural children from uncrowded homes. For example, when the crowding index = 1, the urban predicted mean was 12.2 (95% CI: 5.87–18.55) while the rural predicted mean was 7.8 (95% CI: 1.41–14.26). However, rural children from crowded homes (crowding index =8) had

TABLE 4 Summary of results from main effects and two-way interaction models

Predictor	Outcome	Main effect significant	Main effect direction	Interaction sex	Interaction residence
Birthweight (g)	Weight	Yes	Positive	No	No
Birth mode = Cesarean	Weight	No	Positive	No	No
Residence = Urban	Weight	Yes	Positive	No	N/A
Crowding index	Weight	Yes	Negative	No	No
Birthweight (g)	Height	No	Positive	No	No
Birth mode = Cesarean	Height	No	Positive	Yes	No
Residence = Urban	Height	Yes	Positive	No	N/A
Crowding index	Height	Yes	Negative	Yes	No
Birthweight (g)	BMI	Yes	Positive	No	No
Birth mode = Cesarean	BMI	No	Positive	No	No
Residence = Urban	BMI	Yes	Positive	No	N/A
Crowding index	BMI	Yes	Negative	No	No
Birthweight (g)	Triceps skinfold	No	Positive	No	No
Birth mode = Cesarean	Triceps skinfold	No	Positive	No	No
Residence = Urban	Triceps skinfold	Yes	Positive	No	N/A
Crowding index	Triceps skinfold	No	Negative	No	Yes
Birthweight (g)	Fat mass index	No	Positive	No	No
Birth mode = Cesarean	Fat mass index	No	Positive	No	No
Residence = Urban	Fat mass index	Yes	Positive	No	No
Crowding index	Fat mass index	Yes	Negative	No	No

slightly higher mean triceps skinfold values compared to urban children from crowded homes (urban predicted mean =6.6 (95% CI: −0.21 to 13.42); rural predicted mean =7.3 (95% CI: 0.77–13.77)). This pattern resulted from a steep and linear decrease in urban children's triceps skinfold as crowding index increased; rural children's triceps skinfold decreased very slightly as crowding index increased (Figure 3); the interaction term is significant ($p = 0.05$).

4 | DISCUSSION

4.1 | Overweight and obesity

In this study, urban Yucatec Maya 6-year-olds have higher values for anthropometry and elevated overweight/obesity relative to rural Yucatec Maya children. This finding conforms to a global pattern of anthropometric differentiation of rural and urban children (Dong et al., 2019; Gutiérrez-Jiménez et al., 2019; Oyhenart et al., 2008; Paciorek et al., 2013; Van de Poel et al., 2007). The urban Yucatec Maya children overweight/obesity rate is high (46%) and exceeds the overweight/obesity rate of urban children reported in Mexico's 2012 National Nutrition Survey (37%) (Hernández-Cordero et al., 2017). In contrast, the rural Yucatec Maya children's overweight/obesity rate is quite low (7.6%), even when compared to the overweight/obesity rate of rural children reported in the same survey (26%) (Hernández-Cordero et al., 2017). The urban Yucatec Maya DBM rate was comparable (0%), and the rural rate slightly higher (5.6%), than the Mexican national combined rural/urban DBM rate (1%); the urban stunting rate was comparable (5.6%) and the rural stunting rate much higher (56.1%) than the Mexican national combined rural/urban stunting rate (6.9%). The urban Yucatec Maya children's BMI/FMI values are comparable to a large sample of 6-year-olds from Mexico City, whereas the rural Maya are much shorter and lighter and have lower BMI/FMI values compared to the same urban children from Mexico City (Alpízar et al., 2020).

The rural–urban difference in Yucatec Maya children's overweight/obesity rates are reflective of diet and lifestyle differences that generally characterize rural versus urban environments (Ng & Popkin, 2012; Popkin et al., 2012). For example, studies from Tanzania, Botswana, Colombia, Bolivia and Ecuador, all show that urbanization is associated with decreased dependence on traditional dietary staples and increased consumption of convenient, heavily processed and sugary foods (Chee et al., 2019; Cockx et al., 2018; Lipus et al., 2018; Maruapula et al., 2011; Mora-García et al., 2020). Older research in the Yucatan showed differences in Maya dietary composition in relation to the local economy (tourism vs. farming); coastal communities had a higher consumption of soda and snack foods compared to rural inland communities (Leatherman & Goodman, 2005). In addition to macronutrient differences, urbanized diets are associated with gut microbiome profiles that predispose individuals to obesity (Yatsunenko et al., 2012). While we do not report on dietary composition in the current study, previous work showed that urban Yucatec Maya diets are characterized by high consumption of sugar-sweetened breads and sugar-sweetened soft drinks, and low consumption of fruits and vegetables (Bogin et al., 2020). In contrast, in the rural Maya remain reliant on foods produced by the household (e.g., maize, beans, vegetables, some chicken, and pork); market foods such as pasta, bread and soda are only occasionally purchased and consumed, mainly for special occasions and events (Urlacher & Kramer, 2018; Veile & Kramer, 2018). Finally, in this and our prior studies, breastfeeding (which is obesity-protective) is far more prolonged in the rural setting compared to the urban setting (Sanchez-Escobedo et al., 2020; Veile, Valeggia, & Kramer, 2019). This is likely to play an unexplored role in the etiology of obesity, and disparities in obesity between rural and urban children.

Physical activity levels tend to be lower in urban versus rural settings for several reasons, and inactivity is associated with rising childhood overweight/obesity worldwide (Andrade Neto et al., 2014; Danquah et al., 2020; Muthuri et al., 2014; Navti et al., 2017; Yang et al., 2019). An older study of Guatemalan Maya immigrant children living in the United States, showed that television watching and video games were associated with high obesity rates, although this 20-year-old finding may no longer reflect the biocultural reality of the group (Smith et al., 2002). A recent study similarly showed that obesogenic lifestyle factors (including physical inactivity and immoderate screen time) were prevalent and associated with overweight/obesity in Mexico City schoolchildren (Lopez-Gonzalez et al., 2020). We do not report on physical activity in this study, but previous work using accelerometry showed that urban Maya children were highly active, spending ∼2 h/day in moderate to vigorous physical activities (Wilson et al., 2012). While accelerometry data are not available for the rural Maya, time allocation showed that in 2012, girls spent ∼3 h/day, and boys ∼3.5 h/day, in physically active play (Urlacher & Kramer, 2018). This reflects a major decline in rural children's physical activity from 1992 to 2012 (Kramer, 2005); even so, their physical activity seems to exceed that of urban children.

4.2 | Differences in height

We find significant differences in height between the rural and urban Maya children. The rural children's WHO stunting rate exceeds both the urban children's, and the Mexico national average, for school-aged children (Kroker-Lobos et al., 2014; Vaivada et al., 2020). This aligns with previous work; indigenous Mexican/Guatemalan children are shorter than non-indigenous children and Maya people are particularly short-statured (Batis et al., 2020; Delfin Gurri, 2015; Gatica-Domínguez et al., 2020; Kramer et al., 2016; Varela-Silva et al., 2016; Varela-Silva et al., 2020). Though childhood stunting has been linked with poor health and educational outcomes in many settings (de Onis & Branca, 2016; Chidumwa et al., 2021; Hoddinott et al., 2013; McGovern et al., 2017; Undurraga et al., 2018; WHO, 2018), it correlates with numerous factors (e.g., low household income, low parental education, limited sanitary infrastructure and health care access) that also predict poor outcomes (Vaivada et al., 2020). As such, short childhood stature may become conflated with other factors and then interpreted as a cause (rather than a consequence) of poverty (Kramer et al., 2016). Its associations with obesity are similarly unclear and mediated by socioeconomic factors (Chidumwa et al., 2021). In fact, in the rural Yucatec Maya community studied here, short stature has not been associated with poor child health nor with compromised reproductive success in women (Kramer et al., 2016; Tuller, 2019). As the short-statured rural Maya continue to experience the nutrition transition, decreasing energy expenditure and incorporating more market foods into their diet, however, short stature may render them susceptible to obesity, the double burden, and metabolic disease (Ramirez-Zea et al., 2014). This may explain why (though still low) the individual-level DBM rate is higher in the rural versus urban Yucatec Maya children (5.6% vs. 0%, respectively).

The height difference between rural and urban Yucatec Maya children in this study is likely to have multifactorial causation. Importantly, the short-statured rural children are not pathologically undernourished. While other studies have reported association between child stunting and food insecurity (Campos et al., 2020; Papier et al., 2014; Pirkle et al., 2014), the rural Maya have nutritionally adequate and healthy diets, their BMIs fall within a healthy range, birthweights are normal, and childhood obesity is absent. In contrast, the urban Yucatec Maya children have BMI Z-scores above the WHO median, and nearly half of the urban children are overweight or obese. Non-dietary risk factors for child stunting in Mexico include lower maternal education (Cruz-Cruz et al., 2018), male sex, low birthweight, and maternal short stature (Campos et al., 2020). However, these factors are not statistically associated with child height in the current study. Poor sanitation infrastructure, limited health care access, and intestinal parasitism are other predictors of global stunting (Bogale et al., 2018; Casapía et al., 2006; Gutiérrez-Jiménez et al., 2019; Muslim et al., 2021; Papier et al., 2014; Shang et al., 2010; Vaivada et al., 2020). While we did not include these variables in the current analysis, open defecation and locally derived household construction materials are utilized in the rural community (Veile et al., 2019), whereas these practices and materials are generally not found in the urban settings (Sanchez-Escobedo et al., 2020).

4.3 | Residence and the effects of crowding

Household crowding index was inversely associated with all anthropometric outcomes in the Maya children, consistent with many studies (Bahreini et al., 2013; Bogale et al., 2018; Brewis, 2003; Galgamuw et al., 2017; Jackson et al., 2002; Khuwaja et al., 2005; Mazur & Sanders, 1988; Sereebutra et al., 2006; Victora et al., 1986). This phenomenon has been attributed to large-family resource dilution, particularly in low-income settings with food insecurity (Bronte-Tinkew & DeJong, 2004; Hagen et al., 2001; Jomaa et al., 2019; Lawson & Mace, 2008; Ruiz-Castell et al., 2015). Crowding can also increase environment pathogenic exposures and infectious disease transmission (Ford et al., 2007; Gamboa et al., 2011); repeated immune activation in childhood decreases the energy available for the child to invest in growth and fat deposition (McDade et al., 2008; Urlacher et al., 2018).

The use of different crowding indices and proxies (e.g., family size, sibling number, and birth order) may complicate comparison across studies, as may interaction effects across rural and urban environments (Blake et al., 2007; Fernald et al., 2009; Galgamuwa et al., 2017; Kramer et al., 2016; Lisanu Mazengia & Andargie Biks, 2018). In the current study, significant effects for most outcomes were found for main effects only. Only one residence-based interaction (crowding and triceps skinfold) was significant: the negative association of crowding and triceps skinfold was more pronounced in the urban setting. This pattern was also present (but non-significant) in the weight, BMI and triceps skinfold models even though rural homes were more crowded. We speculate that this rural–urban disparity may reflect differences in housing materials and practices, which can create differences in early-life microbial exposures. For example, in the Brazilian Amazon, modern housing materials decreased some microbial exposures but increased human skin-associated fungi/bacterial exposure (McCall et al., 2020). This may have consequences for child growth, especially in crowded homes. While Yucatán and the Amazon have geologic, climatic, and biotic differences, urban homes with modern housing materials (cement walls, ceilings and floors) may see similarly altered microbial patterns in contrast to rural homes with locally derived construction materials (dirt floors, palm leaf roofs, mud and saplings for walls). While this may explain urban children's lower body fat measures in response to crowding, we note that the magnitude of the effect is small and further studies are required to investigate this phenomenon.

4.4 | Sex differences

We find few sex differences in the anthropometry of Yucatec Maya children, which contrasts with some work showing sex differences in nutritional status (Akombi et al., 2017; Chehab et al., 2021; Cordero & Cesani, 2019; Shah et al., 2020). It is, however, consistent with some studies and observations that Yucatec Maya parents generally do not invest preferentially in their children based on sex (Ahsan et al., 2020; Kramer et al., 2016). FMI values were higher in girls in the rural and urban settings, conforming to a human pattern of body composition dimorphism that appears at ∼6 years of age (Wells, 2007). In the Maya case, this may be associated with enculturated gender differences (e.g., lower energy expenditure in girls vs. boys due to different activity patterns), and/or with biological sex differences (e.g., lower morbidity rates in girls vs. boys, higher leptin levels in girls vs. boys); we lack the data needed to evaluate these mechanisms (Shah et al., 2020; Urlacher & Kramer, 2018; Wells, 2000; Wilson et al., 2012).

We find an interesting sex difference in birth mode, with boys having ≥10% higher cesarean delivery rate in both the rural and urban settings, despite there being no difference in birthweight nor maternal height by child sex. This is consistent with prior work suggesting that birthing boys is more challenging than birthing girls, even independent of infant body size (Eogan et al., 2003; Lorente-Pozo et al., 2018). We also find significantly higher height values in cesarean-delivered boys compared to girls and vaginally delivered boys. While the highest cesarean delivery rates are seen in urban boys (53%), the associations between birth mode, sex and height are unlikely to be conflated with rural–urban differences for two reasons: (a) the cesarean delivery rate in rural girls is low (13.8%) and unlikely to disproportionately affect the interaction; and (b) we account for residence as a main effect in the model.

Other significant sex differences include a stronger negative effect of crowding on boy's anthropometry compared to girls, which was present for all outcomes but statistically significant only in the height model. There is also a non-significant trend in which girl's anthropometric outcomes all show a stronger positive association with birthweight compared to boys. These sex differences are small in magnitude but compelling; they may be linked to the general pattern of greater male sensitivity to environmental conditions (Stinson, 1985; Wells, 2000). More work is needed to understand these differences (Thompson, 2021).

4.5 | Prenatal and perinatal factors

The proxies for prenatal/perinatal conditions (birthweight and birth mode) predicted several 6-year-old Maya anthropometric outcomes. Birthweight was positively associated with child all outcomes (statistically significant for weight and BMI), consistent with prior studies in which high birthweight linked to early-life growth alterations and poor long-term metabolic health outcomes (Kwon & Kim, 2017; Wells, 2010). However, very high birthweight (macrosomia) was absent in the rural and rare in the urban Yucatec Maya. Furthermore, mean infant birthweight did not differ between the rural and urban setting, though urban mothers were taller. This suggests that the mothers were healthy with no major nutritional differences across their pregnancies (Saugstad, 2014).

Birth by cesarean delivery was positively but not statistically associated with all anthropometric outcomes in the main effects models. Cesarean delivery has been epidemiologically associated with rapid infant weight gain and childhood obesity in many studies (Kuhle et al., 2015; Mueller et al., 2017; Mueller et al., 2019), though results vary across studies and underlying mechanisms are debated (Stinson et al., 2018; Thompson et al., 2019). Our previous work showed associations between birth mode and child growth outcomes in the Maya, but the effects were relatively small and interacted with age in the rural setting and sex in the urban setting (Azcorra et al., 2019; Veile & Kramer, 2017). The presence of interaction effects with cesarean delivery in the present study, suggests that more nuanced associations may be detected with a larger sample size.

4.6 | Strengths and limitations

This paper provides insights into the associations of early-life conditions with Maya children's nutritional status in rural and urban settings in Yucatan, Mexico. Although the sample size is small, it is strengthened by our deep ethnographic understanding of the study populations. We also include a wide range of anthropometric outcomes measured in both rural and urban settings, provide important insights into children's nutritional status. Some limitations of this study are its sample size and rural–urban differences in sampling and data collection procedures. Though the sample is large enough to detect anthropometric differences with medium effect sizes, we expect that some interactions with a smaller effect size are not detected using the current sample.

Our study lacks quantitative data on diet, energy expenditure, nor physical fitness; our data on breastfeeding is also limited. We are limited in our ability to compare SES across the rural and urban setting because several proxy variables are non-comparable across populations or are non-varying in the rural setting. Our common SES proxy variable is maternal education, which fails to capture the complex and mixed economic conditions experienced by the rural and urban Maya. For future comparative work, it would be useful to construct multifactorial indices of SES that can be utilized across the rural and urban environments.

5 | CONCLUSIONS

Rural children were short-statured compared to urban children whereas urban children had notably higher rates of overweight and obesity. Household crowding was strongly associated with lower anthropometric indices; the effect was more pronounced for boys and for children in the urban setting. Positive effects of birthweight and birth mode (e.g., cesarean delivery) were also present though less pronounced. Boys were more frequently delivered by cesarean, which was associated with greater height in urban boys. Early life conditions in both the "first" and "second" 1000 days were generally associated with 6-year-old Maya children's anthropometry.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data will be made available by the authors upon reasonable request.

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SUPPORTING INFORMATION

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