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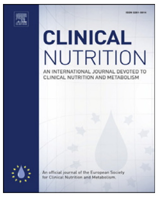

Original article

Plant-based dietary patterns, nutrient intake, growth, and body composition in childhood: Results from a prospective population-based study

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SUMMARY

Background & aims: Transitioning to more plant-based diets promotes environmental sustainability and has health benefits for adults. However, associations with nutrient intake adequacy and growth in children remain unknown. This study aimed to examine associations of plant-based diets with nutrient intake levels among children, and with longitudinal growth and body composition up to adolescence.
Method: We included 3340 children in the Generation R Study, a population-based cohort. Food and nutrient intake were assessed at the age of 8 years, and anthropometrics and body composition (using dual-energy X-ray absorptiometry) were measured at the ages of 10 and 13 years. Plant-based diets were quantified using three plant-based diet indices (PDIs): overall plant-based diet index (PDI), healthful PDI (hPDI), and unhealthful PDI (uPDI). Modified Poisson regression and linear mixed models were used to estimate the associations of PDIs with nutrient intake levels, and with sex- and age-standardized measures of anthropometrics and body composition.
Results: Higher scores on each of the three PDIs were associated with lower intake of vitamin B2, B12, and calcium, while higher hPDI score was associated with higher intake levels of fiber, vitamin C, magnesium, and copper. Higher hPDI score was also associated with higher fat-free mass index (FFMI) z-score (0.05 per 10-hPDI score increment, 95 % CI: 0.01, 0.10), and with lower body fat percentage z-score (−0.05, 95 % CI: −0.09, −0.01), while higher uPDI score was associated with lower height, weight, and FFMI z-score (FFMI: −0.08, 95 % CI: −0.12, −0.03) up to age of 13 years.
Conclusions: In this cohort study, higher adherence to healthful plant-based diets, rather than unhealthful ones, was associated with better nutrient intakes, and subsequent healthy body composition throughout childhood to adolescence. Our findings suggest that consuming healthful plant-based foods may contribute to children's diets' nutrient quality and subsequent body composition. Still, attention should be given to ensuring balanced and adequate nutrient intake for optimal plant-based eating.

1. Introduction

Adequate and balanced nutrition is crucial for optimal growth and development during childhood and adolescence [1], and dietary habits during childhood may track into adulthood [2,3]. Plant-based diets (PBDs), defined by greater amounts of plant-based foods and lower amounts of animal-based foods, have been shown to promote health in adults [4]. Additionally, even gradual shifts to diets higher in healthy plant-based foods and lower in animal-based foods may promote lower greenhouse gas emissions and energy demand, supporting environmental sustainability [5]. However, not much is known about potential health effects or risks of transitioning to more plant-based eating during childhood. Most studies on PBDs during childhood to date are limited to comparing vegetarian (excluding meat and fish, but allowing dairy and/or

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eggs), or vegan (excluding all animal-based foods) versus other diets. High nutritional demands for rapid growth and development in children may render vegetarian and vegan diets vulnerable to inadequate nutritional intake, due to lower content or bioavailability of specific nutrients from plant-based foods [6–8]. Indeed, compared to children following omnivorous diets, vegetarian children have been linked to higher odds of underweight [9], and vegan children have shorter height and lower body fat indices [10]. However, vegetarian or vegan diets are consumed by only a relatively small subset of children, and this dichotomous measure of plant-based eating may not fully capture nutritional or health effects of a more gradual shift toward plant-based diets in the general pediatric population.

To comprehensively understand PBDs reflecting shifts to more plant-based and less animal-based foods without completely excluding animal-based foods, Satija et al. [11] developed three versions of plant-based diet indices: an overall plant-based diet index (PDI), a healthful plant-based diet index (hPDI), and an unhealthful plant-based diet index (uPDI), emphasizing dietary shifts towards more overall, healthful, and unhealthful plant-based foods, respectively. Those PDIs have been extensively studied in relation to health in adults, and meta-analyses of cohort studies have shown that a higher hPDI score is associated with lower risk of obesity [12], type 2 diabetes [13], cardiovascular disease [14,15], cancer [13,16], and mortality [17]. Two small cross-sectional studies ($n = 330–452$) have separately investigated the PDIs on growth and body composition in children, and found beneficial associations with hPDI [18,19]. However, the associations of PDIs with longitudinal growth and body composition in children remain unknown.

This study aims to extensively investigate associations of adherence to different types of plant-based dietary patterns with nutrient intake levels, and with longitudinal growth and body composition up to adolescence in a large population-based pediatric cohort.

2. Methods

2.1. Study design and population

This study was embedded in the Generation R Study, a population-based prospective cohort study in Rotterdam, the Netherlands. A total of 9778 pregnant women with expected delivery dates between April 1, 2002, and January 31, 2006 were included [20]. All participants provided written informed consent and the study obtained approval from the medical ethical committee of Erasmus University Medical Center, Rotterdam [20].

At the children's age of 8 years, parents of 7662 children received a food-frequency questionnaire, the questionnaire was returned for 4787 children. After exclusion of children with extremely energy intake ($n = 54$), defined as a reported energy intake below 650 ($n = 47$) or above 3700 kcal/day ($n = 7$) [21], valid dietary data were available for 4733 children. From this group, we included children for whom we had anthropometric or body composition data at ages 10 and 13 years, resulting in a population for analysis of 3340 children for anthropometrics and 3140 children for body composition (Supplementary Fig. 1).

2.2. Dietary assessment and plant-based diet indices

Dietary intake at age of 8 years was assessed with a validated food frequency questionnaire (FFQ) [22]. The FFQ comprised questions on frequency and amount of consumption of 71 food items and 27 additional food questions about specific types or brands and preparation methods over the past 4 weeks. More details of the FFQ are provided elsewhere [21,22].

We constructed three plant-based diet indices (PDIs): an overall plant-based diet index (PDI), a healthful PDI (hPDI), and an unhealthful PDI (uPDI), based on previously created indices for adults [11,23], and slightly modified to reflect dietary habits among Dutch children (e.g., we excluded coffee and alcoholic beverages). Food items were categorized into 20 food groups, including eight healthful plant-based food groups (whole grains, fruits, vegetables, nuts, legumes, vegetable oil, tea, and low sugar beverages), four unhealthful plant-based food groups (refined grains, potatoes, sugar-containing beverages, and sweets and desserts) and eight animal-based food groups (animal fat, milk and yogurt, cheese, sugary dairy, unprocessed white meat, processed meat and red meat, fish and seafood, and eggs) (Supplementary Table 1). Food items that were not clearly animal or plant-based (e.g. pizza) were excluded from the indices, but were grouped in a miscellaneous food group and adjusted for in statistical models. Children's intakes for each food group were scored from 0 to 4 based on quintiles of the population distribution. For constructing the overall PDI, all plant-based food groups were scored positively, i.e. with 0 representing the lowest and 4 the highest intake levels in this study population. Animal-based food groups were scored reversely, i.e. ranging from 4 for lowest intake levels to 0 for highest intake levels. For constructing the hPDI, positive scores were given to healthful plant-based food groups only, while unhealthful plant-based food groups and animal food groups were both scored reversely. For constructing the uPDI, positive scores were assigned to unhealthful plant-based food groups, while healthful plant-based food groups and animal-based food groups were both scored reversely. Finally, the scores for each food group were summed for each participant to create three indices, in which higher scores reflect diets containing relatively more plant-based (PDI), healthful plant-based (hPDI), or unhealthful plant-based (uPDI) foods and lower intake of animal-based foods. Detailed intakes of the 20 food groups are shown in Supplementary Table 2.

2.3. Nutrient intake

Intakes of macronutrients and micronutrients were computed using the Dutch Food Composition Tables (NEVO 2006). The dietary intake of a wide range of available nutrients related to children's growth and development was evaluated, including energy, carbohydrate, dietary fiber, total fat, saturated fatty acids (SFA), n-3 fish fatty acids (EPA + DHA), protein, plant protein, animal protein, vitamins B1, B2, B3, B6, B12, C, and calcium, phosphorus, magnesium, total iron, haem iron, zinc, selenium and copper. Macronutrients (except for n-3 fish fatty acids and fiber) were analyzed as percentages of energy (E%).

To investigate associations between PDI scores and risk ratios of not meeting recommended nutrient intake levels, we used dietary reference values for 8-year-olds from the European Food Safety Authority (EFSA) [24]. Population Reference Intake (PRI) values were used, reflecting the nutrient intake level is adequate for virtually everyone (97.5 %). Adequate Intake (AI) values were used when PRIs were not available. Additionally, we used the Estimated Average Requirements (EAR) as a more stringent cut-off point, reflecting nutrient intake levels assumed to be adequate for at least half of the individuals. Children's nutrient intake level below the PRI or AI values were defined as not meeting recommended intake levels (Supplementary Table 3). Children's nutrient intake below the EAR values was defined as not meeting EAR-level intake (Supplementary Table 3).

2.4. Anthropometrics and body composition

During follow-up, children were invited to our dedicated research center at Erasmus Medical Center for detailed measurements at ages 10 and 13 years. Height measurements were taken using Harpenden stadiometer (Holtain Limited, Crosswell, Crymych, U.K.) to the nearest 0.1 cm. Weight was measured using an electronic scale (Seca 888; Almere, The Netherlands) to the nearest 0.1 kg. Body Mass Index (BMI) was calculated as weight (kg) divided by the height squared (m^2). Age- and sex-specific standard deviation scores (SDS) for height, weight, and BMI were obtained from Dutch reference growth charts [25].

Total body fat, lean and bone mass were measured using dual-energy X-ray absorptiometry (iDXA scanner, GE Healthcare, Madison, WI, USA). Fat mass index (FMI) was calculated as total fat mass (kg) divided by height squared (m^2), fat-free mass index (FFMI) as total fat-free mass (kg) divided by height squared (m^2), body fat percentage (BF%) as the ratio of fat mass (kg) to weight (kg) multiplied by 100 and expressed as percentage. For all body composition outcomes, age- and sex-specific standard deviation scores [(observed value − mean)/SD] were calculated on available data in the Generation R Study population at 10 and 13 years.

2.5. Covariates

Potential confounders were considered based on previous literature [26–29], and we plotted a simplified Directed Acyclic Graph (DAG) to determine confounders to adjust in the statistical models (Supplementary Fig. 2). Baseline characteristics and lifestyle factors were collected from pregnancy to childhood. Maternal age at birth, child's live birth, and sex were retrieved from medical records and hospital registries. Parental countries of birth were obtained with questionnaires and child's ethnicity was categorized according to the classification of Statistics Netherlands, and further recoded into Dutch and non-Dutch groups. Data on maternal educational levels were collected by questionnaire and categorized into three groups according to the Standard Education Classification in the Netherlands (1): low/intermediate education, which includes low educations (no education, primary school, lower vocational training, or intermediate general school, and up to 3 years of general secondary school) and intermediate educations (more than 3 years of general secondary school, intermediate vocational training, or the first year of higher vocational training) (2); higher professional education (higher vocational training), and (3) high education (university degree) [30]. Household income (<2800; ≥2800 Euros/month), maternal smoking status (never smoked; past smoker; current smoker), children's exercise time (<2 h/week; ≥2 h/week, based on predefined questionnaire options) and screen time (<2 h/day; ≥2 h/day) were collected using questionnaires. Maternal height and weight were measured at our research center.

2.6. Statistical analyses

Multiple linear regression models were used to investigate the associations between PDIs and nutrient intake. We subsequently fitted modified Poisson regression with a robust (sandwich) error variance to investigate the associations between PDIs and the risk ratios of not meeting recommended nutrient intake levels [31]. This approach was chosen when the proportions of not meeting recommended intake levels were common (Supplementary Table 3) [32,33]. We adjusted for energy intake, sex, age at dietary assessment, ethnicity, and the miscellaneous food group.

To study the associations between PDIs and longitudinal anthropometric and body composition outcomes, we used linear mixed models (with random intercept for each child). Model 1 was the basic model, only minimally adjusted for child's sex, energy intake, ethnicity, and age at dietary assessment; Model 2 additionally adjusted for identified potential confounders: maternal age, BMI, educational level, smoking; household income; children's exercise, screen time, and the miscellaneous food group. Given the differences in growth velocity and trajectories between girls and boys during the transition from childhood to puberty [34,35], we additionally tested an interaction term (each PDI × sex), and stratified models by sex. To address missing values on covariates (ranging from 2.4 % to 18.3 %), multiple imputation ($n = 10$ imputations) was employed, and pooled estimates of the imputed datasets were presented.

Several sensitivity analyses were conducted. First, we calculated Pearson's correlations between PDIs and a diet quality score reflecting adherence to current dietary guidelines [21]. Second, the association between plant-based indices and the risk ratios of not meeting EAR-level nutrient intakes was investigated to test if the associations remained in more stringent nutrient cut-offs. Thirdly, we performed cross-sectional analyses for anthropometric and body composition outcomes at age 10 and age 13 separately to test the robustness of our results. Fourthly, given that 231 pairs of children in our cohort were siblings, we randomly excluded one child from each mother to repeat the analysis, testing the robustness of our results. Statistical significance was determined at $P < 0.05$ (two-sided alpha error). The analyses were conducted using SPSS Statistics version 28.0 (IBM Inc., Armonk, NY, USA) and R version 4.2.1 (The R Foundation for Statistical Computing, Vienna, Austria).

3. Results

3.1. Population characteristics

A total of 3340 children (1709 [51.2 %] girls and 1631 [48.8 %] boys, median baseline age 8.1 [IQR 8.0–8.2] years) were followed up for a mean of 5.4 (SD, 0.3) years. Characteristics of the children and their parents are presented in Table 1. The majority of children had a Dutch ethnic background and exercised more than 2 h per week. At both 10 and 13 years, boys were on average taller and had a higher fat-free mass index (FFMI) than girls, and girls had a higher fat mass index (FMI) and body fat percentage (BF%). The majority of mothers had a high household income and were highly educated. Ranges of the overall PDI, hPDI and uPDI score in our study population were 17–60, 17 to 65, and 18 to 68 respectively, within a theoretical score of 0–80. Mean (SD) overall PDI, hPDI and uPDI were 39.6 (6.2), 39.6 (7.2), and 40.0 (7.7) respectively. The differences in the percentage (by weight) of total animal foods, healthy plant foods, and unhealthy plant foods from the lowest quintile (Q1) to the highest quintile (Q5) within each of the plant-based diets is shown in Supplementary Fig. 3, For example, the percentage of healthy plant foods within the hPDI in Q5 is 60 % compared to 35 % in Q1. Also, in Q5 level, the hPDI showed the greatest proportion of healthy plant foods and the smallest proportion of unhealthy plant foods. Information on nutrient intakes of children in the top and bottom quintiles of PDIs is shown in Supplementary Table 4. Characteristics before and after multiple imputation are presented in Supplementary Table 5.

3.2. Association between the plant-based diet indices and intake of nutrients

After adjustment for sex, age, ethnicity, and the miscellaneous food group, higher overall PDI scores were associated with higher energy intake, while higher hPDI and uPDI scores were associated

Table 1
Demographic characteristics of the study population.

Characteristics[a]	Total population (n = 3340)	Girls (n = 1709)	Boys (n = 1631)
Child characteristics			
Age at dietary assessment, y	8.1 (8.0, 8.2)	8.1 (8.0, 8.2)	8.1 (8.0, 8.2)
Girls	1709 (51.2)	NA	NA
Energy intake, kcal/d	1463.2 (1245.6, 1703.9)	1399.1 (1192.1, 1616.4)	1544.8 (1315.5, 1769.1)
Ethnicity			
Dutch	2343 (70.1)	1204 (70.5)	1139 (69.8)
Non-Dutch	997 (29.9)	505 (29.5)	492 (30.2)
Exercise			
<2 h/week	1047 (31.3)	644 (37.7)	404 (24.8)
≥2 h/week	2293 (68.7)	1065 (62.3)	1227 (75.2)
Screen time			
<2 h/d	1657 (49.6)	919 (53.8)	738 (45.2)
≥2 h/d	1682 (50.4)	790 (46.2)	893 (54.8)
Total plant-based diet index	39.6 (6.2)	39.5 (6.2)	39.7 (6.2)
Healthful plant-based diet index	39.6 (7.2)	39.9 (7.1)	39.3 (7.2)
Unhealthful plant-based diet index	40.0 (7.7)	40.7 (7.5)	39.4 (7.7)
Anthropometrics and body composition at 10-y visit			
Weight, kg	33.4 (30.0, 37.6)	33.2 (30.0, 37.8)	33.4 (30.2, 37.6)
Height, cm	141.3 (137.2, 145.7)	141.0 (136.9, 145.8)	141.4 (137.4, 145.7)
BMI, kg/m^2	16.7 (15.5, 18.2)	16.7 (15.5, 18.3)	16.7 (15.6, 18.1)
FMI, kg/m^2	4.1 (3.3, 5.4)	4.5 (3.7, 5.8)	3.7 (3.4, 8.0)
FFMI, kg/m^2	12.5 (11.8, 13.2)	12.1 (11.6, 12.7)	12.8 (12.2, 13.4)
BF%	25.1 (20.9, 30.2)	27.0 (23.5, 32.0)	22.3 (18.9, 27.4)
Overweight/obese	447 (13.4)	245 (14.3)	202 (12.4)
Anthropometrics and body composition at 13-y visit			
Weight, kg	51.4 (45.6, 58.6)	52.0 (46.6, 58.6)	50.8 (44.6, 58.8)
Height, cm	164.5 (159.4, 169.6)	163.9 (159.4, 168.4)	165.3 (159.3, 171.1)
BMI, kg/m^2	18.8 (17.3, 20.9)	19.2 (17.7, 21.2)	18.4 (17.0, 20.4)
FMI, kg/m^2	4.4 (3.4, 5.9)	5.1 (4.1, 6.5)	3.6 (2.9, 5.0)
FFMI, kg/m^2	14.2 (13.3, 15.3)	14.0 (13.1, 14.9)	14.5 (13.4, 15.7)
BF%	24.1 (19.4, 29.4)	26.7 (23.2, 31.0)	20.3 (16.9, 25.7)
Overweight/obese	418 (12.5)	216 (12.6)	202 (12.4)
Maternal characteristics			
Maternal age at birth, y	32.5 (29.7, 35.1)	32.5 (29.5, 35.0)	32.7 (29.9, 35.2)
Maternal BMI, kg/m^2	24.3 (22.1, 27.6)	24.2 (22.1, 27.8)	24.4 (22.2, 27.5)
Maternal smoking			
Never smoked	1811 (54.2)	919 (53.8)	891 (54.6)
Past smoker	1107 (33.2)	560 (32.8)	548 (33.6)
Current smoker	422 (12.6)	230 (13.4)	192 (11.8)
Maternal education level			
Low/intermediate education	1170 (35.0)	595 (34.8)	575 (35.2)
High professional education	1026 (30.7)	520 (30.4)	506 (31.0)
University degree	1144 (34.3)	594 (34.8)	551 (33.8)
Household income			
< 2800 euro per month	946 (28.3)	472 (27.6)	475 (29.1)
≥ 2800 euro per month	2394 (71.7)	1237 (72.4)	1156 (70.9)

Abbreviations: BMI, body mass index; FMI, fat mass index; FFMI, fat-free mass index; BF%, body fat percentage; NA, not applicable.

[a] Values are mean (SD) for continuous variables with a normal distribution, medians (IQR) for continuous variables with a skewed distribution, or valid numbers No. (%) for categorical variables.

with lower energy intake. Higher scores of each of the three PDIs were associated with lower energy intake from fat and protein, but higher energy intake from carbohydrates. In the subsequent models, we adjusted for energy and found that higher scores on each of the three PDIs were associated with lower intakes of total fat, saturated fat, total protein, and animal protein, and with a higher intake of carbohydrate. Higher overall PDI and hPDI scores were also associated with higher plant protein and fiber intake, while higher uPDI scores were associated with lower intake of these nutrients (Supplementary Table 6).

Higher scores on each of the three PDIs were associated with lower vitamin B2, vitamin B12, calcium, and haem iron intake. Vitamin B3, vitamin B6, magnesium, iron and zinc were higher as hPDI increased, whereas the higher uPDI score was associated with lower intake of all the investigated micronutrients (Supplementary Table 6).

Consistent with these findings, higher scores on each of the PDIs were associated with higher risks of not meeting recommended intake levels of vitamin B2, vitamin B12, and calcium, with the smallest relative risks for the hPDI (Figs. 1 and 2). For instance, for calcium, the risk ratio (RR) and 95 % confidence intervals (CI) for not meeting recommended intake levels were 1.37 (1.31, 1.44) per 10-score increment for the overall PDI score, and 1.11 (1.06, 1.16) for the hPDI score. A higher hPDI score was also associated with lower risks of not meeting recommended intake levels of fiber, vitamin B3, vitamin B6, vitamin C, magnesium, and copper (Figs. 1 and 2).

Conversely, Except for iron, the uPDI was associated with higher risks of not meeting recommended intake levels for all of the investigated nutrients. For instance, for fiber, the RR and 95 % CI were 1.52 (1.45, 1.59) for the uPDI score, and 0.49 (0.46, 0.51) for the hPDI score (Figs. 1 and 2).

3.3. *Plant-based diet indices with anthropometrics and body composition*

After adjusting for confounders in model 2, higher hPDI scores at 8 years were associated with higher longitudinal FFMI z-score (0.05 per 10-hPDI score increment, 95 % CI: 0.01, 0.10), and lower BF% z-

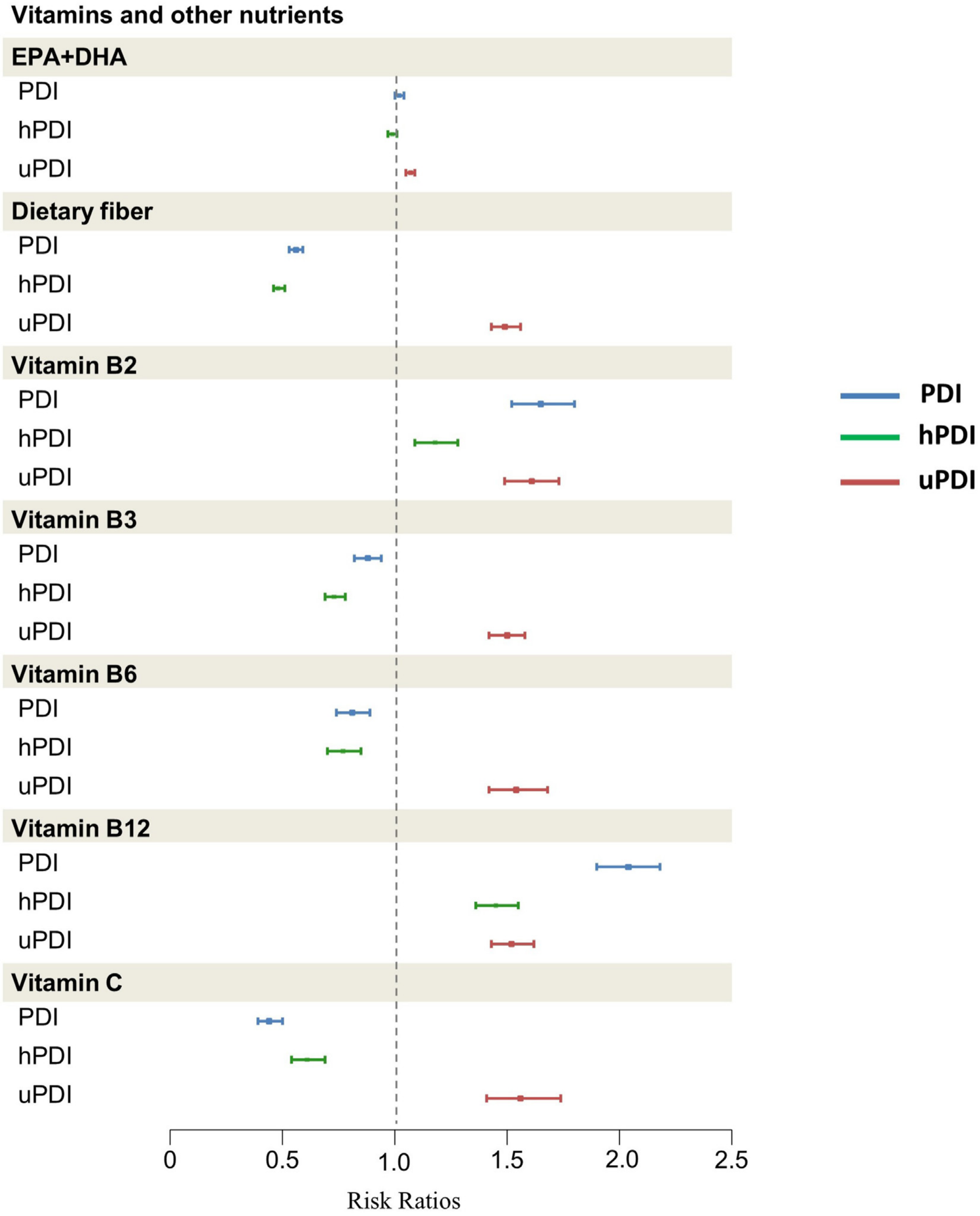

Fig. 1. Forestplot of associations between plant-based diet indices and not meeting recommended intake levels (Vitamins and other nutrients)[a].

[a] The effect estimates represent the risk ratios (RR) with 95 % confidence intervals (CI) for not meeting recommended nutrient intake levels per 10-score increment of each plant-based diet index, obtained from modified Poisson regression models. Models were adjusted for energy intake, sex, age at dietary assessment, ethnicity, and miscellaneous food group.

score (−0.05 SDS, 95 % CI: −0.09, −0.01) up to age 13 years (Table 2). In contrast, higher uPDI scores were associated with lower height z-score (−0.07 SDS, 95 % CI: −0.11, −0.02), weight z-score (−0.06 SDS, 95 % CI: −0.11, −0.02), and lower FFMI z-score (−0.08 SDS, 95 % CI: −0.12, −0.03). We did not observe statistically significant associations for the overall PDI scores (Table 2).

After stratification by sex (*P* for interaction <0.05 for height, weight, FFMI, and BF%), associations of the hPDI and uPDI scores with anthropometrics and FFMI were only found in girls but not in boys, while associations between the hPDI score and BF% were present only in boys (Table 3).

3.4. Sensitivity analyses

A diet quality score reflecting adherence to Dutch dietary guidelines was inversely correlated with the uPDI score (r = −0.70), and positively with the hPDI score (r = 0.33) (Supplementary Table 7). Among nutrients with available Estimated Average Requirements (EAR) values, we observed that higher PDI and hPDI scores were associated with lower risk of not meeting EAR-level intake for vitamin B3, vitamin C, and total iron, but higher risk for not meeting vitamin B2 and calcium EAR-levels. Conversely, higher uPDI scores were associated with higher risk of not meeting

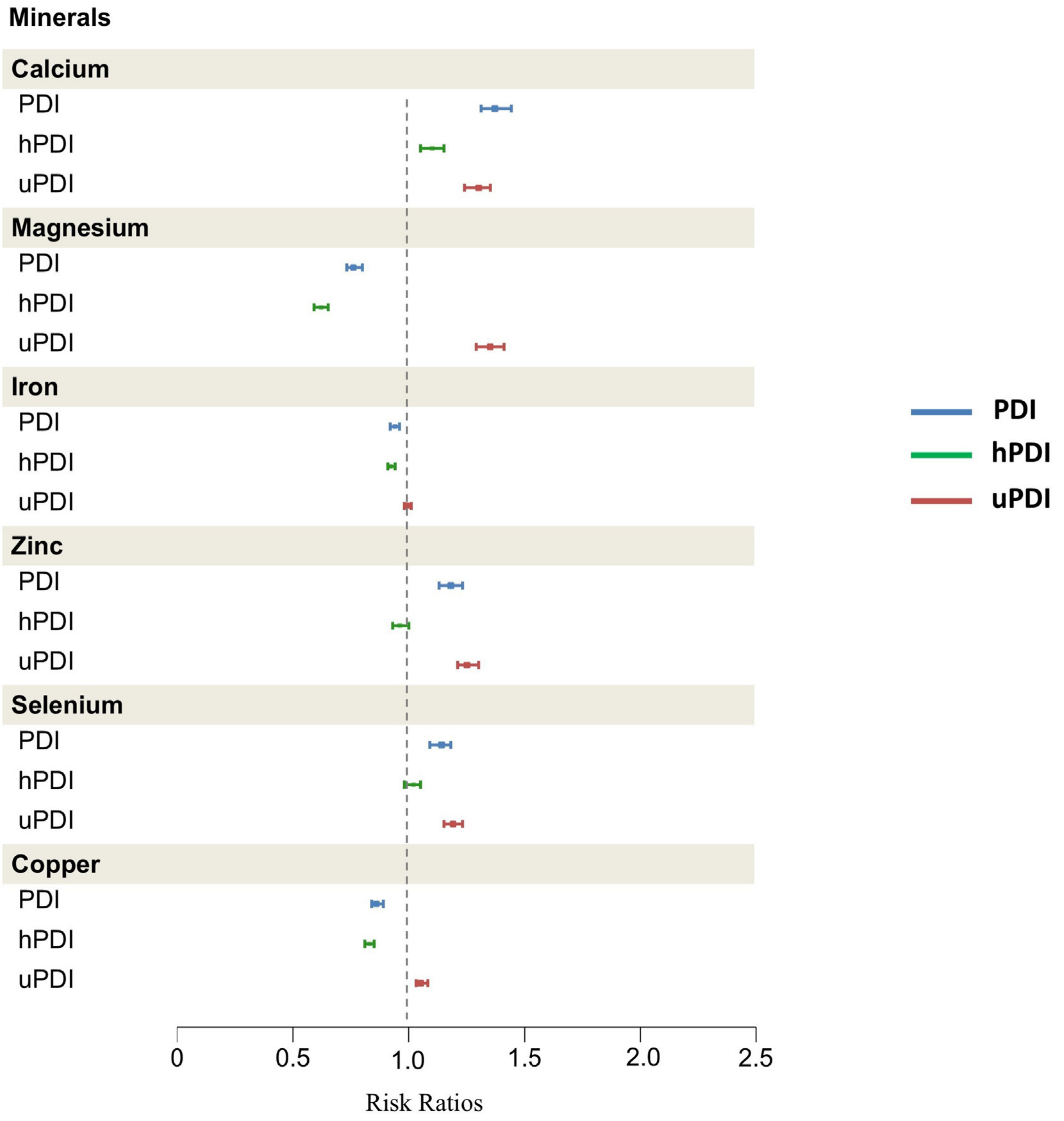

Fig. 2. Forestplot of associations between plant-based diet indices and not meeting recommended intake levels (Minerals)[a].

[a] The effect estimates represent the risk ratios (RR) with 95 % confidence intervals (CI) for not meeting recommended nutrient intake levels per 10-score increment of each plant-based diet index, obtained from modified Poisson regression models. Models were adjusted for energy intake, sex, age at dietary assessment, ethnicity, and miscellaneous food group.

Table 2
Associations of the plant-based diet indices with adolescent anthropometrics and body composition[a].

	Height (SDS) n = 3340	Weight (SDS) n = 3340	Body mass index (SDS) n = 3340	Fat mass index (SDS) n = 3140	Fat-free mass index (SDS) n = 3140	Body fat percentage (SDS) n = 3140
Overall plant-based diet index						
Model 1 (basic)	0.05 (−0.01, 0.10)	−0.02 (−0.07, 0.03)	−0.07 (−0.12, −0.01)	−0.06 (−0.11, −0.01)	0.02 (−0.03, 0.07)	−0.08 (−0.13, −0.03)
Model 2 (confounder)	0.05 (−0.01, 0.10)	0.01 (−0.04, 0.06)	−0.03 (−0.08, 0.02)	−0.02 (−0.07, 0.02)	0.04 (−0.01, 0.09)	−0.04 (−0.09, 0.00)
Healthful plant-based diet index						
Model 1 (basic)	0.07 (0.02, 0.12)	−0.02 (−0.07, 0.03)	−0.07 (−0.12, −0.02)	−0.09 (−0.13, −0.05)	0.03 (−0.01, 0.08)	−0.11 (−0.16, −0.07)
Model 2 (confounder)	0.05 (0.00, 0.10)	0.02 (−0.03, 0.07)	−0.01 (−0.06, 0.04)	−0.03 (−0.07, 0.01)	0.05 (0.01, 0.10)	−0.05 (−0.09, −0.01)
Unhealthful plant-based diet index						
Model 1 (basic)	−0.08 (−0.13, −0.04)	−0.03 (−0.08, 0.01)	0.00 (−0.04, 0.05)	0.06 (0.02, 0.10)	−0.06 (−0.10, −0.02)	0.08 (0.04, 0.12)
Model 2 (confounder)	−0.07 (−0.11, −0.02)	−0.06 (−0.11, −0.02)	−0.05 (−0.09, 0.00)	0.01 (−0.02, 0.05)	−0.08 (−0.12, −0.03)	0.03 (−0.01, 0.07)

[a] In the results of the linear mixed models, the effect estimates represent the difference in growth and body composition outcomes per 10-score increment of each plant-based diet index. Model 1 was adjusted for sex, ethnicity, age at dietary assessment, and energy intake. Model 2 was further adjusted for maternal age, maternal BMI, maternal educational level, maternal smoking status, household income, children's screen time, exercise, and miscellaneous food group. The β coefficients (95 % CI) were presented, and age- and sex-specific standard deviation scores (SDS) were calculated for each outcome.

Table 3
Associations of the plant-based diet indices with adolescent anthropometrics and body composition stratified for sex[a].

	Height (SDS)	Weight (SDS)	Body mass index (SDS)	Fat mass index (SDS)	Fat-free mass index (SDS)	Percentage body fat (SDS)
Girls	**n = 1709**	**n = 1709**	**n = 1709**	**n = 1610**	**n = 1610**	**n = 1610**
Total plant-based diet index						
Model 1 (basic)	0.05 (−0.02, 0.13)	0.01 (−0.06, 0.09)	−0.03 (−0.10, 0.05)	−0.01 (−0.08, 0.05)	0.02 (−0.05, 0.09)	−0.04 (−0.10, 0.03)
Model 2 (confounder)	0.04 (−0.04, 0.12)	0.04 (−0.04, 0.11)	0.01 (−0.06, 0.08)	0.02 (−0.04, 0.08)	0.04 (−0.03, 0.11)	0.00 (−0.06, 0.07)
Healthful plant-based diet index						
Model 1 (basic)	0.12 (0.04, 0.19)	0.04 (−0.03, 0.11)	−0.03 (−0.10, 0.04)	−0.05 (−0.11, 0.01)	0.04 (−0.03, 0.11)	−0.08 (−0.14, −0.01)
Model 2 (confounder)	0.09 (0.02, 0.16)	0.06 (−0.01, 0.14)	0.02 (−0.05, 0.09)	0.003 (−0.06, 0.06)	0.06 (−0.01, 0.12)	−0.02 (−0.08, 0.04)
Unhealthful plant-based diet index						
Model 1 (basic)	−0.15 (−0.22, −0.09)	−0.10 (−0.16, −0.03)	−0.03 (−0.10, 0.03)	0.03 (−0.03, 0.09)	−0.08 (−0.14, −0.02)	0.06 (−0.004, 0.11)
Model 2 (confounder)	−0.13 (−0.20, −0.06)	−0.12 (−0.18, −0.05)	−0.08 (−0.14, −0.01)	−0.003 (−0.06, 0.05)	−0.10 (−0.16, −0.04)	0.02 (−0.04, 0.08)
Boys	**n = 1631**	**n = 1631**	**n = 1631**	**n = 1530**	**n = 1530**	**n = 1530**
Total plant-based diet index						
Model 1 (basic)	0.04 (−0.03, 0.12)	−0.06 (−0.13, 0.02)	−0.10 (−0.19, −0.03)	−0.11 (−0.17, −0.04)	0.03 (−0.04, 0.10)	−0.13 (−0.20, −0.06)
Model 2 (confounder)	0.05 (−0.02, 0.13)	−0.02 (−0.09, 0.06)	−0.06 (−0.14, 0.01)	−0.07 (−0.13, −0.01)	0.04 (−0.03, 0.11)	−0.09 (−0.15, −0.02)
Healthful plant-based diet index						
Model 1 (basic)	0.02 (−0.05, 0.09)	−0.07 (−0.14, −0.00)	−0.11 (−0.18, −0.04)	−0.13 (−0.19, −0.07)	0.03 (−0.03, 0.09)	−0.14 (−0.20, −0.08)
Model 2 (confounder)	0.03 (−0.04, 0.09)	−0.02 (−0.08, 0.05)	−0.04 (−0.10, 0.03)	−0.06 (−0.12, −0.01)	0.05 (−0.01, 0.12)	−0.08 (−0.14, −0.02)
Unhealthful plant-based diet index						
Model 1 (basic)	−0.01 (−0.07, 0.05)	0.03 (−0.04, 0.09)	0.04 (−0.03, 0.10)	0.08 (0.03, 0.14)	−0.04 (−0.10, 0.02)	0.09 (0.04, 0.15)
Model 2 (confounder)	−0.01 (−0.07, 0.05)	−0.01 (−0.07, 0.05)	−0.02 (−0.08, 0.05)	0.04 (−0.02, 0.09)	−0.05 (−0.11, 0.01)	0.04 (−0.01, 0.10)

[a] In the results of the linear mixed models, the effect estimates represent the difference in growth and body composition outcomes per 10-score increment of each plant-based diet index. Model 1 was adjusted for ethnicity, age at dietary assessment, and energy intake. Model 2 was further adjusted for maternal age, maternal BMI, maternal educational level, maternal smoking status, household income, children's screen time, exercise, and miscellaneous food group. The β coefficients (95 % CI) were presented, and age- and sex-specific standard deviation scores (SDS) were calculated for each outcome.

EAR-level intake for all investigated nutrients (Supplementary Fig. 4).

In cross-sectional analysis conducted separately for 10-year-olds and 13-year-olds, we observed similar results of PDI scores with childhood anthropometrics and body composition (Supplementary Table 8 and Supplementary Table 9). After randomly excluding one of the siblings from the same mother in our participants, similar results were also observed (Supplementary Table 10).

4. Discussion

In this longitudinal pediatric population-based cohort study, we found that more plant-based, less animal-based diets were associated with lower intake levels of vitamin B2, vitamin B12, and calcium. However, higher healthful PDI scores were also associated with higher intakes of many other nutrients essential to children's health, and with greater fat-free mass index, and lower body fat percentage up to adolescence. Higher unhealthful PDI scores were associated with lower intakes of all micronutrients investigated, and with lower height, weight, and fat-free mass index. Our findings suggest that following healthful plant-based diets, rather than unhealthful ones, may support children's diets' nutrient quality and subsequent healthy growth and body composition throughout childhood to adolescence, but that attention should be given to ensuring that children meet the recommended nutrient intake levels to promote optimal plant-based eating.

In line with our findings, a cross-sectional study in preschool children in Canada (aged 1.5–5 y, n = 283) showed that higher PDI scores were associated with lower intake of vitamin B12 and calcium [36]. Nutritional inadequacies were primarily found in vegetarian and vegan children, particularly in vegans [8,10,37–39]. A German study found that, compared to omnivorous children, vegetarian and vegan children (aged 6–8 y, n = 401) had lower intake of vitamin B2, B12, and calcium [39], and a Polish study found that both vegan and vegetarian diets during childhood (aged 5–10 y, n = 187) were associated with increased risk of serum vitamin B12 deficiencies [10]. Low intake of dietary calcium was also observed among vegan children [8]. When comparing children with and without supplementation and fortification practices, a Polish study found that vitamin B12 deficiencies in vegetarian and vegan children could be partly rectified by supplementation [10], although caution should be given to adequate supplement use, because a Czech study (aged 0–18 y, n = 200) observed a high prevalence of vitamin B12 over-supplementation among vegetarian and vegan children [40]. In our study population, there were no participants strictly excluding all animal-based foods, and approximately 25 % of the foods consumed by those in the highest quintiles of the plant-based indices were animal-based. Although our study did not differentiate between different types of animal-based foods with varying nutrient composition, we observed that children with higher adherence to each plant-based dietary pattern consume higher amounts of red and processed meat compared to healthier animal-based options (Supplementary Table 2), which may have adverse effects on nutrient intakes and health outcomes. Moreover, even amongst children in the top quintile of hPDI, the Dutch recommended intake levels of fruits, vegetables, and nuts were not met, and legumes were consumed at a relatively low level. Although intake levels of various nutrients were better with greater adherence to the hPDI, intake levels of vitamin B2, vitamin B12 and calcium were at higher risk of not meeting recommended levels. According to EFSA, some plant-based foods can be natural sources of calcium (e.g., legumes) [41], but the vitamin B2 content in plant foods is generally low, with fortified cereals being the primary plant-based source in Europe [42]. Vitamin B12, however, is only present in plant-based foods that contain yeast, or has undergone microbial fermentation that produces vitamin B12, or have been fortified [43]. Importantly, observed nutrient intakes below the recommended nutrient intake do not necessarily indicate a clinical nutrient deficiency. Future research is needed to investigate whether the observed lower intakes of certain nutrients in the transition to healthier plant-based diets among children translate to clinical nutrient deficiencies, and if needed, to what extent changes in intakes of specific plant-based food groups, fortification, or supplementation could help promote optimal plant-based eating among children.

Previous studies on PDI scores with childhood growth and body composition were small-scaled (n = 330–452) and cross-sectional. In line with our findings on anthropometrics, one Iranian study (ages 6–12 y, n = 330) found that higher uPDI, but not hPDI scores were associated with lower height-for-age z-scores in girls [18]. Unlike the standardized FFMI, FMI, and BF% z-scores used in our study, a Chinese study (aged 6–9 y, n = 452) used absolute lean mass, fat mass, and lean mass-to-fat mass percentage as body composition measures. Despite these differences in methodology, this study reported similar findings: higher hPDI, but not uPDI scores, were associated with greater lean mass and lower fat mass percentage [19]. Other studies were among vegetarian and vegan children and showed inconsistent findings [9,10,44,45]. A Canadian and U.S. cohort found an association between vegetarian diets and lower height [9,45]. A Polish study found no significant difference between vegetarian and omnivore children in height, BMI, or body composition except for thigh girth, but they did find that vegan children had lower height, BMI, and fat mass than omnivores [10]. A previous Dutch study also observed that children following a macrobiotic diet who hardly consumed animal-based foods had lower height and sum of four skinfolds for age [44]. These inconsistent findings could be due to limitations such as small sample sizes and lack of confounder adjustments, while still suggesting that vegetarian or vegan diets, as part of plant-based diets, might be associated with lower height, and body fat in some contexts. However, a direct comparison of these studies with our study cannot be made, as they reflected only a dichotomous measure of plant-based eating and did not differentiate the quality of plant-based foods. Our findings highlighted that the quality of plant-based diets may have different impacts on children's growth and body composition.

Our findings from associations between PDIs and nutrient intake levels reinforce the potential differential health effects of healthful and unhealthful plant-based diets. Higher hPDI scores reflect greater consumption of healthy foods such as fruits, vegetables, whole grains, legumes, nuts, and tea. Accordingly, these foods contribute to higher intakes of beneficial nutrients, including plant protein, fiber, multiple micronutrients, and polyphenols. Evidence from studies in adults shows benefits of healthy plant foods on weight management, which may involve reducing inflammation, improving gut microbiome composition, regulating blood sugar, and maintaining energy balance [46]. Plant protein has also been found to be associated with higher fat-free mass index in children [47]. Protein intake enhances body's energy expenditure and satiety, which may improve fat loss [48], and protein from various plant-based food sources may improve muscle protein synthesis and regulate the maintenance or gain in skeletal muscle mass [49]. Also, higher dietary fiber, magnesium, and polyphenol intake may help increase insulin sensitivity [50–52], which in turn is associated with reduced body fat [53]. Higher adherence to healthy plant-based diets is characterized by lower intakes of sugar sweetened beverages, refined grains, and saturated fat, which are food groups or nutrients associated with lower fat-free mass and higher body fat [54–56]. Conversely, higher uPDI scores reflect higher intakes of for example refined grains, sweets, and desserts containing saturated and trans fats, and with a greater glycemic index, is associated with a higher risk to not meet the recommended nutrient intakes levels for fiber and almost all micronutrients. The strong inverse correlation ($r = -0.70$) between the uPDI score and the Dutch dietary guideline adherence score also reinforces the low diet quality of unhealthful plant-based diets. This suboptimal nutrient profile may result in adverse health consequences for children, as we observed lower height, weight, and FFMI, while the healthful PDI was associated with better body composition over time. Every 10-point increase in the hPDI score was associated with an increase of 0.05 in FFMI z scores (corresponding to approximately 0.2 kg increase in fat-free mass) and a decrease of 0.05 in BF% z scores (corresponding to approximately 0.2 kg decrease in body fat). This highlights the public health importance of prioritizing the quality of plant-based foods when adopting a more plant-based diet.

We observed some differences in associations of the PDI scores with growth and body composition between boys and girls. Previous studies showed that both the age of take-off and peak height velocity are earlier in girls than in boys [34]. Given that girls experience rapid growth during this period and have high nutritional demand, they might be more susceptible to harmful effects of unhealthful diets. Concurrently, puberty influences hormonal fluctuations that accompany body composition changes [35]. Indeed, we found that girls in our cohort were in mid-puberty while boys were in early puberty for the measurements at 13 years using a self-reported Pubertal Development Scale questionnaire [57]. Additionally, overall diet quality is relatively low in our cohort [21], even among children with the highest adherence to a healthful plant-based diet. This might explain why we did not observe a slowdown in body fat accumulation among mid-puberty girls following a healthful plant-based diet. Potential mechanisms and sex differences in the context of plant-based diets with growth and body composition need further investigation.

Study strengths are the large pediatric-based sample size and prospective design, which bridged the research gap in longitudinal associations between plant-based diets with anthropometrics and body composition in the general child population, and provided insights into nutrient profiles of higher adherence to plant-based diets without restricting to vegetarian or vegan diets only. We also modified the plant-based diet indices for children. Therefore, our findings are more readily translatable for future intervention studies and public health practice.

Our study also has several limitations. Lack of data on biomarkers and nutrient supplement use limits our understanding of children's nutritional status. However, we used stringent nutrient recommendation values as cut-off points, which still presented a comprehensive picture of nutrient profiles within plant-based diets, and highlighted attention to meeting recommended nutrient intake levels. Additionally, while our FFQ showed reasonable validity for energy intake [22], and dual-energy X-ray absorptiometry (DXA) provided relatively accurate measurement of body composition, dietary measurement errors and DXA measurement biases cannot be completely eliminated. Furthermore, non-response analyses in our cohort suggested a possible selection towards children of families with slightly higher educational level and household income [21], which limit the generalizability of our findings to other populations. For example, associations may differ in families with lower socioeconomic status, as these families might face more barriers in adopting healthier dietary practices for children or accessing health sources. Future research is needed to determine if our findings remain consistent in different socioeconomic settings. Moreover, although healthy diets adhering to dietary guideline were generally affordable for most people in the Netherlands [58], the significant contribution of fruits and vegetables to the cost of a healthy diet suggests that transitioning to a healthy plant-based diet might increase overall food expenses. However, this transition could also potentially reduce costs related to meat, dairy, discretionary foods, and beverages. Future studies are needed to explore the affordability of plant-based eating in children across different socioeconomic statuses. Finally, residual confounding likely exists because of the nature of observational studies.

5. Conclusion

In conclusion, our study suggests that healthful plant-based diets, rather than unhealthful ones, are associated with higher intake of various key nutrients essential to children's health, and higher FFMI and lower BF% up to adolescence. Our findings suggested that consuming healthful plant-based foods may contribute to children's diets' nutrient quality and subsequent healthy growth and body composition. Still, attention should be given to ensuring balanced and adequate nutrient intake for optimal plant-based eating.

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Data sharing: Data Availability

Data described in the article, code book, and analytic code can be obtained upon request.

Conflict of interest

None reported.

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The authors' contributions were as follows Hong Sun, Marinka Steur, Trudy Voortman: Conceptualization, Methodology. Hong Sun: Formal analysis. Hong Sun: Wrote original draft. Marinka Steur, Trudy Voortman: Supervision. Hong Sun, Marinka Steur, Trudy Voortman, Yuchan mou: Writing, Reviewing and Editing.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.clnu.2025.01.010.

References

[1] Norris SA, Frongillo EA, Black MM, Dong Y, Fall C, Lampl M, et al. Nutrition in adolescent growth and development. Lancet 2022;399(10320):172–84.

[2] Mikkila V, Rasanen L, Raitakari OT, Pietinen P, Viikari J. Consistent dietary patterns identified from childhood to adulthood: the cardiovascular risk in Young Finns Study. Br J Nutr 2005;93(6):923–31.

[3] Movassagh EZ, Baxter-Jones ADG, Kontulainen S, Whiting SJ, Vatanparast H. Tracking dietary patterns over 20 Years from childhood through adolescence into young adulthood: the saskatchewan pediatric bone mineral accrual study. Nutrients 2017;9(9):990.

[4] Hemler EC, Hu FB. Plant-based diets for personal, population, and planetary health. Adv Nutr 2019;10:S275–83.

[5] Seconda L, Fouillet H, Huneau JF, Pointereau P, Baudry J, Langevin B, et al. Conservative to disruptive diets for optimizing nutrition, environmental impacts and cost in French adults from the NutriNet-Sante cohort. Nat Food 2021;2(3):174–82.

[6] Nathan I, Hackett AF, Kirby S. The dietary intake of a group of vegetarian children aged 7-11 years compared with matched omnivores. Br J Nutr 1996;75(4):533–44.

[7] Melina V, Craig W, Levin S. Position of the academy of nutrition and dietetics: vegetarian diets. J Acad Nutr Diet 2016;116(12):1970–80.

[8] Sutter DO, Bender N. Nutrient status and growth in vegan children. Nutr Res 2021;91:13–25.

[9] Elliott LJ, Keown-Stoneman CDG, Birken CS, Jenkins DJA, Borkhoff CM, Maguire JL, et al. Vegetarian diet, growth, and nutrition in early childhood: a longitudinal cohort study. Pediatrics 2022;149(6):e2021052598.

[10] Desmond MA, Sobiecki JG, Jaworski M, Płudowski P, Antoniewicz J, Shirley MK, et al. Growth, body composition, and cardiovascular and nutritional risk of 5- to 10-y-old children consuming vegetarian, vegan, or omnivore diets. Am J Clin Nutr 2021;113(6):1565–77.

[11] Satija A, Bhupathiraju SN, Rimm EB, Spiegelman D, Chiuve SE, Borgi L, et al. Plant-based dietary patterns and incidence of Type 2 diabetes in US men and women: results from three prospective cohort studies. PLoS Med 2016;13(6):e1002039.

[12] Nikparast A, Etesami E, Rahmani J, Rafiei N, Ghanavati M. The association between plant-based diet indices and metabolic syndrome: a systematic review and dose-response meta-analysis. Front Nutr 2023;10:1305755.

[13] Wang Y, Liu B, Han H, Hu Y, Zhu L, Rimm EB, et al. Associations between plant-based dietary patterns and risks of type 2 diabetes, cardiovascular disease, cancer, and mortality - a systematic review and meta-analysis. Nutr J 2023;22(1):46.

[14] Gan ZH, Cheong HC, Tu YK, Kuo PH. Association between plant-based dietary patterns and risk of cardiovascular disease: a systematic review and meta-analysis of prospective cohort studies. Nutrients 2021;13(11).

[15] Quek J, Lim G, Lim WH, Ng CH, So WZ, Toh J, et al. The association of plant-based diet with cardiovascular disease and mortality: a meta-analysis and systematic review of prospect cohort studies. Front Cardiovasc Med 2021;8:756810.

[16] Zhao Y, Zhan J, Wang Y, Wang D. The relationship between plant-based diet and risk of digestive system cancers: a meta-analysis based on 3,059,009 subjects. Front Public Health 2022;10:892153.

[17] Jafari S, Hezaveh E, Jalilpiran Y, Jayedi A, Wong A, Safaiyan A, et al. Plant-based diets and risk of disease mortality: a systematic review and meta-analysis of cohort studies. Crit Rev Food Sci Nutr 2021;62(28):7760–72.

[18] Jannati N, Mahmoodi MR, Azadbakht L. Adherence to plant-based dietary patterns and anthropometric indices among primary school girls in Kerman: a cross-sectional study. PLoS One 2024;19(2):e0298454.

[19] Chen G, Su M, Chu X, Wei Y, Chen S, Zhou Y, et al. Plant-based diets and body composition in Chinese omnivorous children aged 6–9 years old: a cross-sectional study. Front Nutr 2022;9:918944.

[20] Kooijman MN, Kruithof CJ, Van Duijn CM, Duijts L, Franco OH, Van Ijzendoorn MH, et al. The Generation R Study: design and cohort update 2017. Eur J Epidemiol 2016;31(12):1243–64.

[21] Van Der Velde LA, Nguyen AN, Schoufour JD, Geelen A, Jaddoe VWV, Franco OH, et al. Diet quality in childhood: the generation R study. Eur J Nutr 2019;58(3):1259–69.

[22] Dutman AE, Stafleu A, Kruizinga A, Brants HA, Westerterp KR, Kistemaker C, et al. Validation of an FFQ and options for data processing using the doubly labelled water method in children. Publ Health Nutr 2011;14(3):410–7.

[23] Chen Z, Zuurmond MG, Van Der Schaft N, Nano J, Wijnhoven HAH, Ikram MA, et al. Plant versus animal based diets and insulin resistance, prediabetes and type 2 diabetes: the Rotterdam Study. Eur J Epidemiol 2018;33(9):883–93.

[24] European Food Safety A. Dietary reference values for nutrients summary report. EFSA Supporting Publications 2017;14(12):e15121E.

[25] Fredriks AM. Body index measurements in 1996-7 compared with 1980. Arch Dis Child 2000;82(2):107–12.

[26] Jebeile H, Kelly AS, O'Malley G, Baur LA. Obesity in children and adolescents: epidemiology, causes, assessment, and management. Lancet Diabetes Endocrinol 2022;10(5):351–65.

[27] Bae JH, Lee H. The effect of diet, exercise, and lifestyle intervention on childhood obesity: a network meta-analysis. Clin Nutr 2021;40(5):3062–72.

[28] White PA, Awad YA, Gauvin L, Spencer NJ, McGrath JJ, Clifford SA, et al. Household income and maternal education in early childhood and risk of overweight and obesity in late childhood: findings from seven birth cohort studies in six high-income countries. Int J Obes 2022;46(9):1703–11.

[29] Willett WC, Howe GR, Kushi LH. Adjustment for total energy intake in epidemiologic studies. Am J Clin Nutr 1997;65(4 Suppl):1220S–8S. discussion 9S-31S.

[30] Silva L, Coolman M, Steegers E, Jaddoe V, Moll H, Hofman A, et al. Maternal educational level and risk of gestational hypertension: the Generation R Study. J Hum Hypertens 2008;22(7):483–92.

[31] Zou G. A modified Poisson regression approach to prospective studies with binary data. Am J Epidemiol 2004;159(7):702–6.

[32] Greenland S. Interpretation and choice of effect measures in epidemiologic analyses. Am J Epidemiol 1987;125(5):761–8.

[33] Chen W, Qian L, Shi J, Franklin M. Comparing performance between log-binomial and robust Poisson regression models for estimating risk ratios under model misspecification. BMC Med Res Methodol 2018;18(1):63.

[34] Abbassi V. Growth and normal puberty. Pediatrics 1998;102(Supplement_3):507–11.

[35] Siervogel RM, Demerath EW, Schubert C, Remsberg KE, Chumlea WC, Sun S, et al. Puberty and body composition. Horm Res Paediatr 2003;60(Suppl. 1):36–45.

[36] Acosta PFC, Landon OA, Ribau ZJ, Haines J, Ma DWL, Duncan AM, et al. Plant-based dietary indices in relation to nutrient and food group intakes in preschool-aged children. Nutrients 2023;15(21).

[37] Neufingerl N, Eilander A. Nutrient intake and status in children and adolescents consuming plant-based diets compared to meat-eaters: a systematic review. Nutrients 2023;15(20).

[38] Jensen CF. Vitamin B12 levels in children and adolescents on plant-based diets: a systematic review and meta-analysis. Nutr Rev 2023;81(8):951–66.

[39] Alexy U, Fischer M, Weder S, Längler A, Michalsen A, Sputtek A, et al. Nutrient intake and status of German children and adolescents consuming vegetarian, vegan or omnivore diets: results of the VeChi youth study. Nutrients 2021;13(5):1707.

[40] Svetnicka M, Sigal A, Selinger E, Henikova M, El-Lababidi E, Gojda J. Cross-sectional study of the prevalence of cobalamin deficiency and vitamin B12 supplementation habits among vegetarian and vegan children in the Czech republic. Nutrients 2022;14(3).

[41] EFSA NDA Panel (EFSA Panel on Dietetic Products NaA). Scientific opinion on dietary reference values for calcium. EFSA J 2015;13(5).

[42] EFSA Panel on Dietetic Products, Nutrition, Allergies (NDA), Turck D, Bresson JL, Burlingame B, Dean T, Fairweather-Tait S, et al. Dietary reference values for riboflavin. EFSA J 2017;15(8):e04919.

[43] EFSA NDA Panel (EFSA Panel on Dietetic Products NaA). Scientific opinion on dietary reference values for cobalamin (vitamin B12). EFSA J 2015;13(7).

[44] Van Dusseldorp M, Arts IC, Bergsma JS, De Jong N, Dagnelie PC, Van Staveren WA. Catch-up growth in children fed a macrobiotic diet in early childhood. J Nutr 1996;126(12):2977–83.

[45] O'Connell JM, Dibley MJ, Sierra J, Wallace B, Marks JS, Yip R. Growth of vegetarian children: the farm study. Pediatrics 1989;84(3):475–81.

[46] Jarvis SE, Nguyen M, Malik VS. Association between adherence to plant-based dietary patterns and obesity risk: a systematic review of prospective cohort studies. Appl Physiol Nutr Metabol 2022;47(12):1115–33.

[47] Jen V, Karagounis LG, Jaddoe VWV, Franco OH, Voortman T. Dietary protein intake in school-age children and detailed measures of body composition: the Generation R Study. Int J Obes 2018;42(10):1715–23.

[48] Gilbert JA, Bendsen NT, Tremblay A, Astrup A. Effect of proteins from different sources on body composition. Nutr Metabol Cardiovasc Dis 2011;21(Suppl 2): B16–31.

[49] van Vliet S, Burd NA, van Loon LJ. The skeletal muscle anabolic response to plant- versus animal-based protein consumption. J Nutr 2015;145(9):1981–91.

[50] Morais JBS, Severo JS, de Alencar GRR, de Oliveira ARS, Cruz KJC, Marreiro DDN, et al. Effect of magnesium supplementation on insulin resistance in humans: a systematic review. Nutrition 2017;38:54–60.

[51] Weickert MO, Pfeiffer AFH. Impact of dietary fiber consumption on insulin resistance and the prevention of type 2 diabetes. J Nutr 2018;148(1):7–12.

[52] Hanhineva K, Torronen R, Bondia-Pons I, Pekkinen J, Kolehmainen M, Mykkanen H, et al. Impact of dietary polyphenols on carbohydrate metabolism. Int J Mol Sci 2010;11(4):1365–402.

[53] Kullmann S, Valenta V, Wagner R, Tschritter O, Machann J, Haring HU, et al. Brain insulin sensitivity is linked to adiposity and body fat distribution. Nat Commun 2020;11(1):1841.

[54] Rousham E, Goudet S, Markey O, Griffiths P, Boxer B, Carroll C, et al. Unhealthy food and beverage consumption in children and risk of overweight and obesity: a systematic review and meta-analysis. Adv Nutr 2022;13:1669–96.

[55] Kahleova H, Hlozkova A, Fleeman R, Fletcher K, Holubkov R, Barnard ND. Fat quantity and quality, as part of a low-fat, vegan diet, are associated with changes in body composition, insulin resistance, and insulin secretion. A 16-week randomized controlled trial. Nutrients 2019;11(3).

[56] de Ruyter JC, Olthof MR, Seidell JC, Katan MB. A trial of sugar-free or sugar-sweetened beverages and body weight in children. N Engl J Med 2012;367(15):1397–406.

[57] Carskadon MA. A self-administered rating scale for pubertal development. J Adolesc Health 1993;14(3):190–5.

[58] Hoenink JC, Waterlander W, Vandevijvere S, Beulens JWJ, Mackenbach JD. The cost of healthy versus current diets in The Netherlands for households with a low, middle and high education. SSM Popul Health 2022;20:101296.