Potential Nutritional and Economic Effects of Replacing Juice With Fruit in the Diets of Children in the United States

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Objective: To estimate the nutritional and economic effects of substituting whole fruit for juice in the diets of children in the United States.

Design: Secondary analyses using the 2001-2004 National Health and Nutrition Examination Survey and a national food prices database. Energy intakes, nutrient intakes, and diet costs were estimated before and after fruit juices were completely replaced with fruit in 3 models that emphasized fruits that were fresh, inexpensive, and widely consumed and in a fourth model that partially replaced juice with fruit, capping juice at recommended levels.

Setting: A nationwide, representative sample of children in the United States.

Participants: A total of 7023 children aged 3 to 18 years.

Main Exposures: Systematic complete or partial replacement of juice with fruit.

Main Outcome Measures: Difference in energy intakes, nutrient intakes, and diet costs between observed and modeled diets.

Results: For children who consumed juice, replacement of all juice servings with fresh, whole fruit led to a projected reduction in dietary energy of 233 kJ/d (−2.6% difference [95% CI, −5.1% to −0.1%]), an increase in fiber of 4.3 g/d (31.1% difference [95% CI, 26.4%-35.9%]), and an increase in diet cost of $0.54/d (13.3% difference [95% CI, 8.8%-17.8%]).

Conclusions: Substitution of juice with fresh fruit has the potential to reduce energy intake and improve the adequacy of fiber intake in children's diets. This would likely increase costs for schools, childcare providers, and families. These cost effects could be minimized by selecting processed fruits, but fewer nutritional gains would be achieved.


One hundred percent fruit juice (FJ) makes up a substantial part of the total fruit intakes of children and is a major contributor to their total nutrient intake.1 However, FJs have energy densities similar to sugar-sweetened beverages and might contribute to excess energy intake,2 obesity,3 and weight gain.4 The evidence linking FJ with obesity is mixed, a point that was acknowledged by the Dietary Guidelines Advisory Committee.5 Nevertheless, the 2010 Dietary Guidelines recommended that no more than half of total fruit servings be in the form of FJ, based on the suggestion that whole fruits confer greater health benefits.

This recommendation placed the Dietary Guidelines in line with previous recommendations from the American Academy of Pediatrics to limit FJs and encourage fruit.6 Those recommendations drove the suggested changes to the Special Supplemental Nutrition Program for Women, Infants, and Children, which reduced the availability of FJ and introduced a fruit and vegetable benefit.7 More recently, the Institute of Medicine recommendations for improving school meals8 and the Child and Adult Care Food Program9 both prioritized whole fruit over FJ.

Little quantitative information exists about the potential nutritional effects of substituting fruit for FJ in the diets of children under current eating patterns. Substituting whole fruit for FJ might reduce the energy content of the diet while increasing the intake of fiber.10,11 Substitution might also drive up food costs, given that FJs are often more affordable than fresh fruits.12 Thus, the complete substitution of whole fruit for juice has the potential to substantially change and improve the nutrient intakes of children while at the same time increasing costs for...
school, childcare providers, and families. Accordingly, nutrition recommendations and policies need to take into account potential costs and benefits. Our study used data from the National Health and Nutrition Examination Survey (NHANES) to examine the potential nutritional benefits and economic costs of substituting fruit for FJ in the diets of US children.

**METHODS**

**SUBJECTS**

Our analyses were based on children and adolescents (3-18 years of age) who completed a valid 24-hour recall during either of 2 cycles of the NHANES: from 2001 to 2002 and from 2003 to 2004. We analyzed these 2 cycles of NHANES because they allowed us to link quantities of foods and beverages consumed to MyPyramid equivalent servings. These releases also allowed us to link each food and beverage consumed with nationally representative food prices, through a database described below. Adolescent girls who were pregnant, based on self-report or a positive pregnancy test result, were excluded (n = 70). The use of this existing, publicly available data set did not qualify as "human subjects research" and was exempt from human subjects review by the University of Washington institutional review board.

**DIETARY ASSESSMENT IN NHANES**

All examined survey participants are eligible to participate in the dietary interview, the protocol and methods of which are fully documented elsewhere. Dietary intakes were based on a single 24-hour dietary recall. The NHANES staff monitored interviewers and developed criteria to determine the acceptability of each recall.

For children 12 years or older, the primary source of dietary recall information was the child, but these children could be assisted by an adult who had knowledge of their diet. For children 6 to 11 years of age, the primary respondent was the child, but a proxy was present and able to assist. For children younger than 6 years, proxy was not present and able to assist. For children 12 years or older, the primary source of dietary recall information was the child, but these children could be assisted by an adult who had knowledge of their diet. For children 6 to 11 years of age, the primary respondent was the child, but a proxy was present and able to assist.

**FJ CLASSIFICATION**

We identified FJs from the individual foods file, defining them as beverages with a 1-digit US Department of Agriculture prefix code of 6 (US Department of Agriculture fruit category), which contained the word "juice" in their short description and that contained no added sugars from the MyPyramid Equivalents database. Fruit nectars and vinegars, sugar-sweetened fruit drinks, and FJ are included in the US Department of Agriculture fruit food grouping but were not defined as FJs in the present analysis. Fruit juice servings less than 60 g (approximately 2 fl oz [60 mL]) were excluded from the analysis because such small servings may be used in recipes and are not likely to represent opportunities for substitution. This exclusion eliminated 32 instances of juice consumption by children and adolescents aged 3 to 18 years.

**DIET COST**

The methods for deriving the monetary cost of diets in the NHANES rely on merging the dietary recalls with nationally representative food prices released by the Center for Nutrition Policy and Promotion. The analytic procedures have been described previously. We computed the diet cost from each individual's dietary recall by multiplying the price per gram with the portion of each food consumed by the respondent and then summing these values for each participant. Diet cost estimations were based on all foods and beverages reported, excluding tap water, bottled water, and alcoholic beverages.

**SUBSTITUTION MODELS**

The key feature of our study was the systematic replacement of FJ with fruit under 4 different scenarios. Fresh and prepared fruits (including canned, frozen, and dried options) were eligible for substitution in place of FJ. Prepared foods containing added sugars were not eligible for inclusion. In some cases, this exclusion removed frequently consumed canned and frozen fruits (eg, canned peaches in syrup). The quantity of fruit used in substitution models was dependent on the quantity of FJ reported in the recall. All 4 substitution models replaced FJs with equal portion sizes of fruit using MyPyramid equivalents of fruit servings. It should be noted that the weight of MyPyramid servings varied depending on the food or beverage. For example, a single MyPyramid fruit serving of fresh, raw apple is 106 g, whereas the same serving of raw orange is 184 g.

The first 3 models replaced all servings of FJ with fruit, differing only on the type of fruit that was substituted. The first model replaced each FJ with the fresh, intact form of the same or similar fruit (eg, apple for apple juice). For mixed FJs with specified ingredients, the first ingredient was used. For mixed FJs with nonspecified ingredients or juices without a relevant fresh equivalent, such as cranberry juice, apples were used because apples are both an important ingredient in blended FJ and the most frequently consumed whole fruit. The second model recognized economic constraints and identified the lowest cost equivalent of the FJ consumed. The lowest cost option was identified in the food prices database as the lowest cost per gram. Examples include applesauce (no sugar added) for apple juice or canned oranges for orange juice. In some cases (eg, grapes), the replacements for the first 2 models were the same. A third model recognized social norms, by substituting each FJ serving with the most frequently consumed raw fruits: apple, orange, or banana. Each FJ serving was randomly assigned one of these replacements at a 1/3 probability.

A fourth model only replaced servings of FJ that were in excess of amounts recommended by the American Academy of Pediatrics. This value was 4 fl oz for young children (aged 3-6 years) and 8 fl oz for older children (aged ≥7 years). Energy and nutrients were included from the FJ up to the amount allowed. Random allocations of apple, orange, and banana were applied to the excess amount of FJ consumed. The random allocations were used because many children consumed different types of juice. The features of the 4 models are summarized in Table 1.

**OUTCOME MEASURE AND STATISTICAL ANALYSIS**

The population effects of substitution were examined for all children and separately for juice consumers (children consuming ≥60 g on their recall day). Survey-weighted means were estimated for diet composition and cost for the observed data and the 4 substitution models. Age-specific models were also evaluated using 3 age groups (3-5, 6-11, and 12-18 years). Diet composition effects of substitution were quantified for energy (kilojoules), dietary weight (grams), and 4 nutrients. Three of the nutrients (dietary fiber, potassium, and calcium) are short-fall nutrients in the diets of children. Vitamin D is also a short-fall nutrient but was not available in the nutrient database linked.
to these releases of NHANES. Although not a shortfall nutrient among children, vitamin C effects were also examined because FJs are an important source for this nutrient.  

We focused our statistical analyses on determining whether the substitution models resulted in a substantive change in nutrient intake. This approach was used because the nature of our models imposed a change in nutrient intake and diet cost. For nutrients, a 10% daily value threshold was used to represent a change of public health significance (2.5 g for fiber, 350 mg for potassium, 100 mg for calcium, and 6 mg for vitamin C). A 10% change in cost was the threshold value for diet cost. For energy, there is little consensus on what warrants a substantive change; therefore, model effects were reported, and no hypothesis testing was performed. A survey-weighted Wald test was used for all statistical testing following the estimation of survey-weighted means. This approach fully accounted for the complex nature of NHANES data. All analyses used Stata version 11.0 (StataCorp).

SAMPLE CHARACTERISTICS

Valid dietary recalls were available for 7023 of the 7756 respondents aged 3 to 18 years over both survey cycles. The characteristics of the weighted sample for all 7023 respondents are shown in Table 2.

CONSUMPTION OF 100% FJ

For the single 24-hour recall, at least 1 serving (>60 g) was reported by 33.4% of the total child sample across both survey years; 17.8% of children consumed more than the recommended amounts of FJ (4 fl oz [120 mL] for those 3–6 years of age and 8 fl oz [240 mL] for those ≥7 years of age). For all children 3 to 18 years of age, FJs accounted for 46% of MyPyramid servings of total fruit in the diet. The share varied by age, with FJ contributing 49%, 44%, and 46% of the total fruit servings for children 3 to 5, 6 to 11, and 12 to 18 years, respectively. The

<table>
<thead>
<tr>
<th>Model</th>
<th>Approach</th>
<th>Substitute&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Full substitution, fresh equivalent</td>
<td>106 g of raw apple</td>
</tr>
<tr>
<td>2</td>
<td>Full substitution, lowest cost</td>
<td>244 g of unsweetened applesauce</td>
</tr>
<tr>
<td>3</td>
<td>Full substitution, most common&lt;sup&gt;c&lt;/sup&gt;</td>
<td>136 g of raw banana, 106 g of raw apple, 184 g or raw orange</td>
</tr>
<tr>
<td>4</td>
<td>Partial substitution, most common&lt;sup&gt;c&lt;/sup&gt;</td>
<td>124 g of apple juice and 53 g of raw apple</td>
</tr>
</tbody>
</table>

<sup>a</sup>Portions for juice servings were replaced at a 1:1 ratio with fruit based on MyPyramid equivalents.

<sup>b</sup>An example of what fruits would replace 248 g of apple juice (MyPyramid serving) consumed by a 5-year-old child.

<sup>c</sup>Bananas, apples, and oranges substituted with equal probability for each occurrence of juice.

<sup>d</sup>Fruit replaces only fruit juice amounts greater than 4 fl oz (120 mL) for children aged 3 to 6 years and greater than 8 fl oz (240 mL) for children and adolescents aged 7 years or older, following recommendations from the American Academy of Pediatrics.

mix of 100% FJs consumed was dominated by a few varieties, with orange, apple, unspecified FJ blends, and grape accounting for 52.6%, 27.5%, 10.0%, and 5.7% of all juices consumed, respectively (95.8% total). Mixed vegetable juice, carrot juice, and tomato juice made up only 1.1% of all juices combined.

SUBSTITUTION EFFECTS ON ENERGY AND NUTRIENT INTAKES

For the overall sample of children, all substitution models lowered dietary energy and dietary mass. Fiber was increased in all 4 models, but vitamin C, potassium, and calcium were reduced to varying extents. The results of the 4 models and the observed dietary characteristics for the overall sample are shown in Table 3.

Model 1, in which FJ was substituted with the fresh fruit equivalent, showed the largest reduction of energy. For children who had reported consuming FJ, model 1 showed a mean reduction in energy intake of 2.6% compared with observed diets. Model 2, the cost-sensitive substitution, showed the weakest energy effects, with a reduction of 0.9% compared with observed diets. Fiber effects showed a similar hierarchy across models, with the largest increase in model 1 (31.1%) and a more moderate increase in model 2 (25.9%). Model 4 had the smallest increase in fiber among juice consumers (13%). Across the 4 models, vitamin C was reduced by small amounts in model 1 (~7.1%) and model 4 (~8.3%) and by the greatest amount in model 3 (~23.3%). However, the trend was reversed for potas-
The age-specific effects on diet cost differed across the
strata of children who consumed FJ (3-5, 6-11, and 12-18
years). Results for model 1 across the 3 age groups did
not differ markedly. The largest effect on dietary en-
calium, which was reduced the least in model 4 (−1.5%) and
model 3 (−3.3%) and was reduced the most in model 1
(−7.1% difference from observed diets), owing to the in-
clusion of bananas in models 3 and 4. Model 2 affected
calcium intake the most (−4.0%), and model 4 affected it
the least (−0.9%), relative to observed diets.
We further examined the effects of model 1 on 3 age
strata of children who consumed FJ (3-5, 6-11, and 12-18
years). Results for model 1 across the 3 age groups did not
differ markedly. The largest effect on dietary energy,
in terms of percentage change, was observed in chil-
dery intakes of children who reported consuming FJ.23
This projected energy reduction is roughly half of the es-
timated 460 kJ (110 kcal) excess in energy intake driv-
ing no compensatory increases in energy intake from other
sources.19 This assumption might be realistic given that
fresh, whole fruits are low in energy density and high in
fiber and are associated with greater satiety than FJ.11,20

SUBSTITUTION EFFECTS ON DIET COST
All of the substitution models resulted in an increase in
estimated diet cost. Of the 4 models, model 1 showed the
largest monetary effects, with a 13.3% increase in diet cost
per day relative to observed diets. Model 2 was specifi-
cally designed to minimize the monetary impact of switch-
ing from FJ to fruit, resulting in a 1.5% increase. Model
3 showed intermediate effects, with a 6.9% increase in
diet cost. Model 4 showed an increase in cost of 3.7%.
The age-specific effects on diet cost differed across the
3 age strata. Implementing model 1 for children 12 to 18
years of age brought the largest increase in diet cost
(17.1%). The effects of model 1 on diet cost were small-
est for children 3 to 5 years of age (10.0%).

The diet simulations presented indicate that replacing all
servings of FJs with fruit has the potential to reduce en-
ergy intake and increase intakes of dietary fiber. These
findings are consistent with previous analyses commis-
sioned by the Dietary Guidelines Advisory Committee,
which showed that replacing FJs with fruit reduced the
content of energy and some nutrients in model food pat-
tterns.12 Based on the present findings, replacing FJ with
a variety of fresh, whole fruit (model 1) would have the
greatest impact on energy intake, resulting in a reduc-
tion in energy intake of 233 kJ (56 kcal) per day. Such a
reduction, if sustained, could translate to a reduction in
body weight of more than 2.3 kg (5 lb) per year, assum-
ing no compensatory increases in energy intake from other
sources.19 This assumption might be realistic given that
fresh, whole fruits are low in energy density and high in
fiber and are associated with greater satiety than FJ.11,20

Weight and weight gain in children and adolescents were
not systematically associated with FJ consump-
tion, according to a recent, comprehensive review.22 Ir-
respective of body weight associations, the intake of FJs
has been associated with higher overall dietary energy
intake,2 and based on data from 1999-2004 NHANES, FJs
contributed between 7% and 9% to the total dietary en-
calory intakes of children who reported consuming FJ.23
Replacing FJs with fruit could potentially reduce overall
dietary energy intake.

Table 3. Observed and Projected Differences for Energy, Nutrients, and Diet Costs Among Children in the United Statesa

<table>
<thead>
<tr>
<th>Measure</th>
<th>Observed</th>
<th>Model 1 (Fresh Equivalent)</th>
<th>Model 2 (Lowest Cost)</th>
<th>Model 3 (Most Common)</th>
<th>Model 4 (Capped)</th>
<th>Benchmark for Effectsb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy intake, kJ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All children</td>
<td>8830 (8689-8970)</td>
<td>−77 (−85 to −70)</td>
<td>−26 (−29 to −23)</td>
<td>−52 (−57 to −46)</td>
<td>−22 (−27 to −17)</td>
<td>Not available</td>
</tr>
<tr>
<td>Juice consumers only</td>
<td>8986 (8761-9211)</td>
<td>−233 (−252 to −214)</td>
<td>−80 (−87 to −72)</td>
<td>−155 (−169 to −141)</td>
<td>−67 (−81 to −53)</td>
<td></td>
</tr>
<tr>
<td>Dietary fiber, g</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All children</td>
<td>12.8 (12.5-13.2)</td>
<td>1.4 (1.3-1.6)</td>
<td>1.2 (1.1-1.3)</td>
<td>1.5 (1.3-1.6)</td>
<td>0.6 (0.5-0.7)</td>
<td>&gt;2.5 g or</td>
</tr>
<tr>
<td>Juice consumers only</td>
<td>13.7 (13.2 to 14.2)</td>
<td>4.3 (4.0 to 4.6)c</td>
<td>3.5 (3.3 to 3.7)c</td>
<td>4.4 (4.1 to 4.7)c</td>
<td>1.8 (1.6 to 2.1)</td>
<td>≤&lt;−2.5 g</td>
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<tr>
<td>Potassium, mg</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>All children</td>
<td>2305 (2230-2380)</td>
<td>−65 (−71 to −59)</td>
<td>−49 (−54 to −44)</td>
<td>−30 (−37 to −24)</td>
<td>−14 (−19 to −9)</td>
<td>&gt;350 mg or</td>
</tr>
<tr>
<td>Juice consumers only</td>
<td>2724 (2632-2814)</td>
<td>−195 (−209 to −180)</td>
<td>−147 (−158 to −136)</td>
<td>−91 (−108 to −73)</td>
<td>−41 (−55 to −27)</td>
<td>≤&lt;−350 mg</td>
</tr>
<tr>
<td>Calcium, mg</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>All children</td>
<td>1005 (966-1044)</td>
<td>−4 (−7 to −1)</td>
<td>−14 (−17 to −11)</td>
<td>−10 (−13 to −7)</td>
<td>−3 (−5 to −2)</td>
<td>&gt;100 mg or</td>
</tr>
<tr>
<td>Juice consumers only</td>
<td>1071 (1017-1125)</td>
<td>−13 (−22 to −3)</td>
<td>−43 (−53 to −33)</td>
<td>−31 (−40 to −21)</td>
<td>−10 (−15 to −5)</td>
<td>≤&lt;100 mg</td>
</tr>
<tr>
<td>Vitamin C, mg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>All children</td>
<td>86 (81-91)</td>
<td>−3 (−5 to −2)</td>
<td>−7 (−8 to −6)d</td>
<td>−11 (−13 to −9)c</td>
<td>−4 (−5 to −3)</td>
<td>&gt;6 mg or</td>
</tr>
<tr>
<td>Juice consumers only</td>
<td>144 (136-152)</td>
<td>−10 (−13 to −7)d</td>
<td>−22 (−25 to −19)f</td>
<td>−34 (−38 to −28)c</td>
<td>−12 (−16 to −9)p</td>
<td>≤&lt;6 mg</td>
</tr>
<tr>
<td>Diet cost, $</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All children</td>
<td>3.87 (3.78-3.97)</td>
<td>0.18 (0.15-0.22)</td>
<td>0.02 (0.01-0.03)</td>
<td>0.09 (0.08-0.11)</td>
<td>0.05 (0.04-0.07)</td>
<td>&gt;$0.387f</td>
</tr>
<tr>
<td>Juice consumers only</td>
<td>4.38 (3.95-4.22)</td>
<td>0.54 (0.46-0.63)</td>
<td>0.08 (0.04-0.09)</td>
<td>0.28 (0.24-0.32)</td>
<td>0.15 (0.11-0.20)</td>
<td></td>
</tr>
</tbody>
</table>

a There was a total of 7023 children, of whom only 2385 were juice consumers.
b Benchmarks for nutrients are based on 10% daily values.
c P <.05, comparing the difference between the models to the benchmark value in the rightmost column of the table.
d P <.05, comparing the difference between the models to the benchmark value in the rightmost column of the table.
e P <.01, comparing the difference between the models to the benchmark value in the rightmost column of the table.
f Ten percent of the average diet cost for children.
However, this replacement can also reduce intakes of potassium and vitamin C. Vitamin C was not identified as a shortfall nutrient for children by the Dietary Guidelines Advisory Committee, and our analyses indicated that the mean and median levels of consumption for FJ consumers exceeded the dietary reference intake (25-75 mg). Children did fall short of recommended intakes for potassium, and replacing FJ with fruit led to a greater shortfall for this nutrient. The intake of potassium decreased because the most frequently consumed FJs (eg, orange juice and apple juice) contained significantly more potassium per serving than fruits used to replace these juices.

Replacing FJ with fruit in our models also led to higher diet costs. Cost is one of several factors that may explain the preponderance of FJ in the diets of children. In 2004-2005, FJs and juice drinks made up more than half of the MyPyramid fruit servings for children. Fresh, whole fruit and fresh produce, in general, are among the most costly sources of dietary energy, and FJs provide a lower cost per serving and more nutrients per dollar than many fresh fruits.

Among the 3 full replacement models (models 1-3), food costs were best controlled in model 2, which relied on the lowest-cost fruit equivalent of each FJ serving reported. The fruits in this model were typically canned or otherwise processed, indicating that these options provide an avenue for institutions and families to switch from FJ to fruit while respecting cost constraints. However, it should be noted that model 2 resulted in the smallest decrease in energy, an increase in fiber, and the largest decrease in calcium.

A minimal cost effect was also observed in model 4, which conformed to recommendations for limits on FJ from the American Academy of Pediatrics. Although this scenario generally resulted in the smallest reduction in nutrient intakes relative to observed diets, it also produced the smallest reduction in energy.

Our study had a number of limitations. First, the effects of FJ substitution on dietary intakes are entirely projected, based on systematic complete or partial replacement of 100% FJs with fruit, with quantities scaled using MyPyramid portion sizes. As such, our findings represent an estimation of the maximal efficacy of implementing recommendations to replace FJ with fruit. Implementation of nutrition recommendations is often most feasible within institutions such as schools and child care settings. Based on the 2003-2004 NHANES, approximately 9% of fruit servings from FJ were from school cafeteria or child care settings, indicating that replacing juice with fruit only in these settings is not likely to have a substantial impact at the population level. A second limitation is that our models did not explore other potential substitution scenarios that might have also improved nutrition. For example, replacing juice drinks and other sugar-sweetened beverages with fruit would further reduce total energy intake while reducing consumption of added sugars. Third, the monetary cost of substituting fruit for FJ was based on a single, nationally representative database of food prices that could not account for regional variations in food prices and, hence, differences in the cost of making the substitutions described herein. Finally, other factors that might favor FJs over fruit were not taken into account in these models.

Other factors that might drive a preference for FJs over fruit include ease of storage, preparation, and portioning for institutions such as schools and child care centers and the cost of wasting overripe fruit. Fruit juices may be more convenient for parents and caregivers who have little time to prepare food and who look for easy and quick options.

Complete replacement of FJ with a variety of whole, fresh fruits has the potential to reduce the dietary energy intake and increase the intake of dietary fiber among children. These benefits might come at the cost of lower intakes of some vitamins and minerals and higher food costs. Studies using national surveillance data may be useful in assessing the potential benefits and costs of dietary recommendations and nutrition policies.

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