# Carbon and nitrogen stable isotopes in fast food: Signatures of corn and confinement

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Communicated by Steven M. Stanley, University of Hawaii, Honolulu, HI, October 2, 2008 (received for review July 3, 2008)

**Americans spend >100 billion dollars on restaurant fast food each year; fast food meals comprise a disproportionate amount of both meat and calories within the U.S. diet. We used carbon and nitrogen stable isotopes to infer the source of feed to meat animals, the source of fat within fries, and the extent of fertilization and confinement inherent to production. We sampled food from McDonald's, Burger King, and Wendy's chains, purchasing >480 servings of hamburgers, chicken sandwiches and fries within geographically distributed U.S. cities: Los Angeles, San Francisco, Denver, Detroit, Boston, and Baltimore. From the entire sample set of beef and chicken, only 12 servings of beef had $\delta^{13}C < -21‰$; for these animals only was a food source other than corn possible. We observed remarkably invariant values of $\delta^{15}N$ in both beef and chicken, reflecting uniform confinement and exposure to heavily fertilized feed for all animals. The $\delta^{13}C$ value of fries differed significantly among restaurants indicating that the chains used different protocols for deep-frying: Wendy's clearly used only corn oil, whereas McDonald's and Burger King favored other vegetable oils; this differed from ingredient reports. Our results highlighted the overwhelming importance of corn agriculture within virtually every aspect of fast food manufacture.**

diet | stable isotope

By purchasing and eating 1 serving of the substrates of this study (i.e., 1 hamburger, 1 chicken sandwich, and 1 small order of fries), the consumer has gained 50% of that day's recommended calories, 80% of carbohydrates, 75% of protein (90% if the consumer is a woman), and the full day's limit of dietary fat at a cost of $3* [based on the National Academy of Sciences 2005 Dietary Reference Intakes Series (www.nap.edu) and the McDonald's Dollar Menu (www.mcdonalds.com/usa/eat/features/dollar.html)]. As meat consumption has skyrocketed in the United States, the consumption of fast food has increased disproportionately*. The production of fast food meat is a unique problem in cost-optimization: to accelerate tissue production in animals, calorie consumption is maximized, and calorie expenditure is minimized. We turned to carbon and nitrogen stable isotopes to tell us the origin of the animals' diet, based on classical models (1, 2) and observations of the conspicuous $^{13}C$ signature of corn [*Zea mays* (3)]. Multiple studies have used $\delta^{13}C$ value to infer the origin of meat based on assumptions of corn-based diet in North American (4–6) and conventional retail [vs. "organic" (7, 8)] farmed animals. We sought to answer the following question: What can the $\delta^{13}C$ and $\delta^{15}N$ of fast food beef, chicken, and fries tell us about the process of food production and the ingredients within the products?

## Results

Fastfood was purchased from America's top 3 chains: McDonald's, Burger King, and Wendy's; each restaurant was sampled at 3 locations within 6 major U.S. cities: Los Angeles, San Francisco, Denver, Detroit, Boston, and Baltimore [supporting information (SI) Table S1]. At each location, 9 items were purchased: 3 hamburgers, 3 chicken sandwiches, and 3 orders of fries. Fig. 1 depicts the results of all stable isotope analyses according to the location of food purchase within the U.S.; within restaurant, servings of all foods were isotopically homogeneous (summarized in Table 1). Carbon stable isotope values in beef showed the largest total variability (11.8‰), compared with ranges in $\delta^{13}C$ value in both chicken (2.7‰) and fries (4.9‰). Burger King beef exhibited the largest variability (10.7‰), whereas the variability within McDonald's beef (7.1‰) and Wendy's beef (6.3‰) was considerably lower. Although the maximum $\delta^{13}C$ value found for beef was similar (within 1‰) for all chains, the minimum value for Burger King beef (−25.5‰) was ≈4‰ lighter than the minimum values for the other chains. Statistical analyses showed that carbon isotope signature of beef was significantly different between chains (Table 2): After adjusting for geographic region (Model 3), McDonald's and Wendy's beef were of significantly higher $\delta^{13}C$ value, by 3.5 and 5.2‰, respectively. After similar adjustment for chain, West coast beef was found to be significantly depleted relative to East coast beef by 1.5‰. As for carbon isotopes in chicken, maximum and minimum values compared across all chains did not differ by >1‰. McDonald's chicken was slightly, but significantly, depleted compared with Burger King chicken (by 0.3‰), after adjustment for adjustment for geographic region. Otherwise, no significant difference was seen in the $\delta^{13}C$ value of chicken from different chains, or different geographical regions.

For nitrogen isotopes in meat products, variability was constrained, relative to carbon isotopes. The entire range in $\delta^{15}N$ value of all beef sampled was <2.2‰; for $\delta^{15}N$ value of chicken, the range was even smaller (<1.4‰). After adjustment for geographic region, both Wendy's and McDonald's beef were found to be significantly depleted in $^{15}N$ compared with Burger King beef, but by values comparable to the small amount of variability in the substrates (0.4 and 0.5‰, respectively). Similarly, after adjustment for chain, Midwest and West Coast beef was found to be significantly depleted in $^{15}N$ compared with East Coast beef (0.9 and 0.4‰, respectively). For chicken, no significant difference in $\delta^{15}N$ value was associated with geographical region; slight, but significant, differences were found in Wendy's and McDonald's chicken relative to chicken from Burger King (−0.2 and −0.3‰, respectively), after adjustment for geographic region.

Author contributions: A.H.J. and R.A.K. performed research; and A.H.J. wrote the paper.

The authors declare no conflict of interest.

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*Total meat consumption has increased 63% between 1950 and 2005 in the United States according to the USDA 2008 United States per capita food availability report (www.ers.usda.gov/data/FoodConsumption/FoodAvailQueriable.aspx); total consumption by food type can be found within the 2007 USDA food consumption and nutrient intake tables (www.ers.usda.gov/data/FoodConsumption/FoodAvailSpreadsheets.htm).

†Bahar *et al.* (ref. 8, p 1300) provides an example of this: "This survey was originally designed to relate patterns in isotopic compositions of beef to geographical and husbandry background information; however, because of a lack of disclosure of farm-level information by the suppliers, the interpretation is mainly restricted to the description of overall seasonality of Irish organic and conventional beef."

This article contains supporting information online at www.pnas.org/cgi/content/full/0809870105/DCSupplemental.

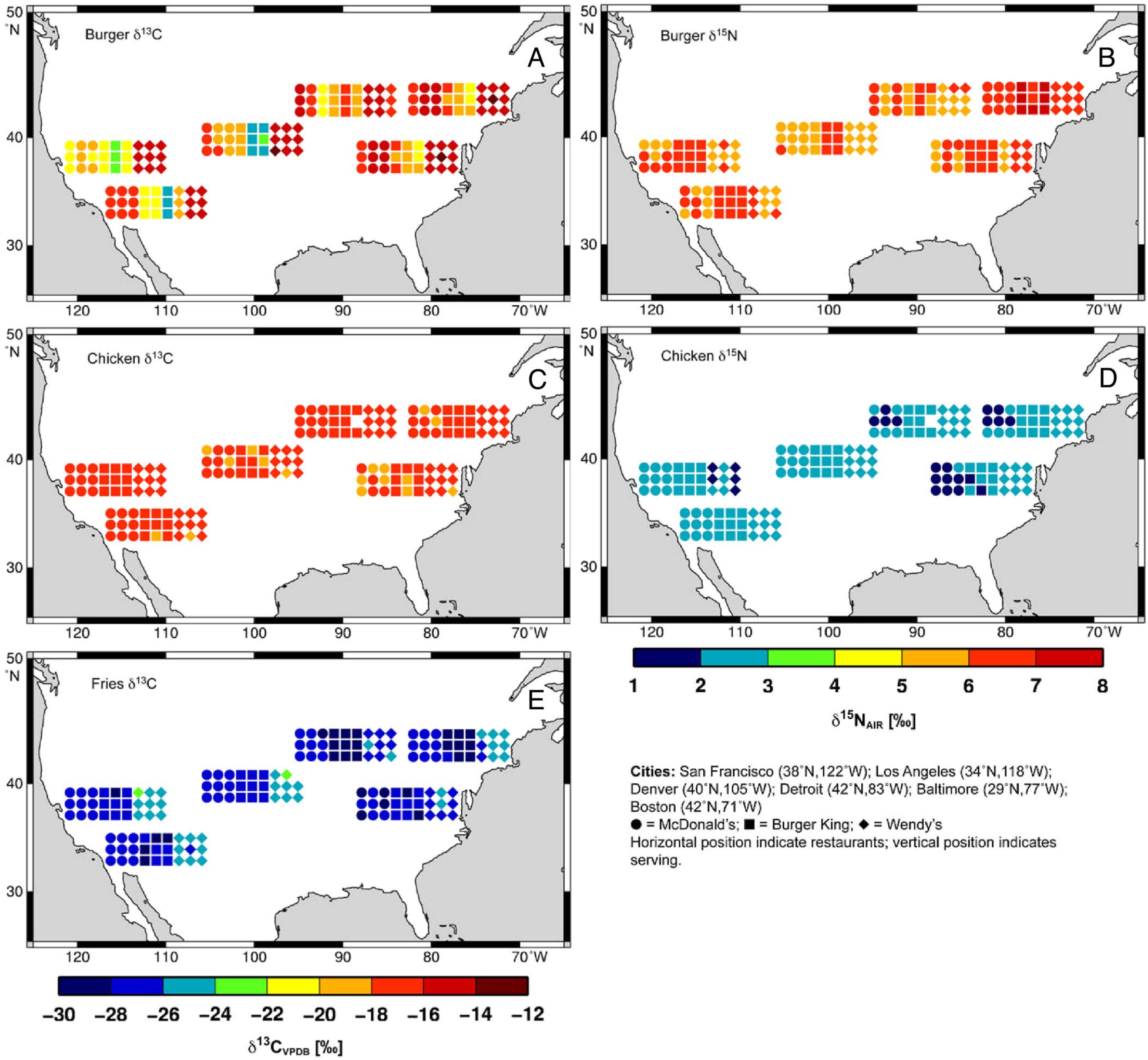


**Fig. 1.** Carbon and nitrogen stable isotope values of all foods sampled, positioned according to geographic region (*A–E*). Chains are designated by symbol, stable isotope value is designated by color. The 3 restaurants sampled differ by horizontal position, whereas the 3 servings differ by vertical position, creating a grid of 9 values for each chain within each city. Three missing points (*C–E*) reflect 2 lost substrates from within the entire study (1 serving of chicken and 1 serving of fries).

French fries are composed of starch fried in lipid, and contain negligible protein, therefore only carbon isotope analysis could be performed on fries. All fries sampled ranged in $^{13}C$ composition across 4.9‰, within significant and relatively large differences between chains. Both Wendy's and McDonald's fries were found to be enriched in $^{13}C$ compared with Burger King fries, even after adjustment for geographical region (by 2.4 and 1.9‰, respectively). Lesser differences can be significantly attributed to geographical region: After adjustment for chain, Midwest and West Coast fries were found to be enriched in $^{13}C$ compared with East Coast fries (both by 0.4‰).

## Discussion

Fastfood corporations do not raise livestock, but instead buy it from other companies. Birth, growth, and slaughter are distinct events occurring at different facilities, often under different companies. Each fast food chain employs distributor companies: These suppliers organize and broker the production and transport of meat to the site of food fabrication and sale. In this way, distributors act as a barrier to consumer information[†]; suppliers relevant to this study provide little information beyond their use of "local farms" that feed "mixed grains." The distributor for McDonald's is Martin–Brower, L.L.C.; Burger King and Wendy's employ the same distributor, Maines Paper and Food Service, Inc. These differences probably drive the significant differences in $^{13}C$ content of beef among chains, and between West Coast and other restaurants (Table 2). In contrast, all chicken is distributed to each chain by the same company, Tyson Foods, Inc.; the extreme homogeneity seen in chicken $^{13}C$ content across all aspects of the study (Tables 1 and 2; Fig. 1),

**Table 1. Summary of $\delta^{13}C$ and $\delta^{15}N$ values of fastfood sampled**

| | Mean, ‰ | Range, ‰ | Minimum, ‰ | Maximum, ‰ |
|---|---|---|---|---|
| All samples | | | | |
| Beef (*n* = 162) | | | | |
| $\delta^{13}C$ | −18.0 | 11.8 | −25.5 | −13.7 |
| $\delta^{15}N$ | 6.1 | 2.1 | 5.3 | 7.4 |
| Chicken (*n* = 161) | | | | |
| $\delta^{13}C$ | −17.5 | 2.7 | −19.3 | −16.6 |
| $\delta^{15}N$ | 2.3 | 1.3 | 1.5 | 2.8 |
| Fries (*n* = 161) | | | | |
| $\delta^{13}C$ | −26.9 | 4.9 | −28.8 | −23.9 |
| $\delta^{15}N$ | | | | |
| McDonald's | | | | |
| Beef (*n* = 54) | | | | |
| $\delta^{13}C$ | −17.7 | 7.1 | −21.7 | −14.6 |
| $\delta^{15}N$ | 6.0 | 1.2 | 5.3 | 6.5 |
| Chicken (*n* = 54) | | | | |
| $\delta^{13}C$ | −17.7 | 2.2 | −19.1 | −16.9 |
| $\delta^{15}N$ | 2.2 | 1.3 | 1.5 | 2.8 |
| Fries (*n* = 54) | | | | |
| $\delta^{13}C$ | −27.2 | 2.5 | −28.5 | −26.1 |
| $\delta^{15}N$ | | | | |
| Burger King | | | | |
| Beef (*n* = 55) | | | | |
| $\delta^{13}C$ | −20.8 | 10.7 | −25.5 | −14.9 |
| $\delta^{15}N$ | 6.4 | 1.8 | 5.6 | 7.4 |
| Chicken (*n* = 53) | | | | |
| $\delta^{13}C$ | −17.4 | 2.7 | −19.3 | −16.6 |
| $\delta^{15}N$ | 2.5 | 0.9 | 1.9 | 2.8 |
| Fries (*n* = 54) | | | | |
| $\delta^{13}C$ | −28.0 | 1.8 | −28.8 | −27.0 |
| $\delta^{15}N$ | | | | |
| Wendy's | | | | |
| Beef (*n* = 53) | | | | |
| $\delta^{13}C$ | −15.5 | 6.3 | −20.0 | −13.7 |
| $\delta^{15}N$ | 6.0 | 1.0 | 5.6 | 6.6 |
| Chicken (*n* = 54) | | | | |
| $\delta^{13}C$ | −17.3 | 1.9 | −18.7 | −16.8 |
| $\delta^{15}N$ | 2.3 | 0.7 | 1.9 | 2.6 |
| Fries (*n* = 53) | | | | |
| $\delta^{13}C$ | −25.5 | 3.8 | −27.7 | −23.9 |
| $\delta^{15}N$ | | | | |

For a complete list of isotope measurements, see Table S2.

speaks to the virtually identical process of chicken production for the majority of American fast food.

Most of the tissue of meat animals is constructed during the final weeks before slaughter: This is also the period when stable isotope value is set within muscle and lipid tissue. For example, $\delta^{13}C$ in muscle and lipid tissue in cows fed on corn silage for the final 6 months of life were 7.0 and 8.1‰ heavier (respectively) than those fed on grass silage for the same period (9). In addition, $\delta^{13}C$ in animal tissues has been positively correlated with percentage of corn in diet (7, 10–13). For beef cattle, a final diet of corn silage yielded $\delta^{13}C = -18.1$ and $-21.1$‰ for lipid and muscle, respectively (9). In contrast, a final diet of grass silage yielded average $\delta^{13}C = -29.8$ and $-24.9$‰ for lipid and muscle, respectively, and intermediate diets yielded intermediate values (9, 10). For chicken, corn-meal diet yielded breast meat with $\delta^{13}C = -16.6$‰, whereas "cereal"-meal diet yielded breast meat with $\delta^{13}C = -26.8$‰ (5). Based on a comparison with these values, 100% of the chicken and 93% of the beef sampled in this study had $\delta^{13}C$ value consistent with an exclusively corn-based diet. From the entire study, only 12 servings of beef had $\delta^{13}C < -21$‰; for these animals only was an additional food source besides corn possible. We note that all 12 servings were purchased at Burger King restaurant at West Coast locations.

Besides the pioneering studies of Schmidt *et al.* (4) and Bahar *et al.* (8), empirical $\delta^{15}N$ datasets have not been reported for meat. Beef from Europe, Brazil, and the United States ranged in $\delta^{15}N$ value from 4.8 to 9.8‰ (4); beef raised in Ireland ranged in $\delta^{15}N$ value from 6.2 to 7.2‰ (8); both studies suggest that high $\delta^{15}N$ values reflect "system-wide" enrichment of $^{15}N$ because of addition of mineral fertilizers. Schwertl *et al.* (7) found the $\delta^{15}N$ value of cattle hair positively correlated with stocking rate [kilograms of live-weight per hectare], and also showed that stocking rate is well-correlated with N-input surplus ($r^2 = 0.78$). Fertilization required for corn production renders corn seed and silage enriched in $^{15}N$ by 2 to 3‰ (on average), compared with both natural vegetation (14) and other feeds (Table 3). Beef produced in confinement was enriched by up to 0.8‰ in $^{15}N$ compared with animals raised outdoors (8). The high $\delta^{15}N$ values of fast food beef determined by this study (average $\delta^{15}N$ = 6.1‰; Table 1), resulted from the confinement and fertilized feed necessary for rapid tissue production. Bahar *et al.* (8) also

**Table 2. Statistical associations within δ13C and δ15N value of foods sampled**

| | Model 1 | | Model 2 | | Model 3 | |
|---|---|---|---|---|---|---|
| | Δ, ‰ | *P* | Δ, ‰ | *P* | Δ, ‰ | *P* |
| **$\delta^{13}C$** | | | | | | |
| Beef | | | | | | |
| Chain | | | | | | |
| Burger King (reference) | | | | | | |
| Wendy's | 6.0 | <0.001* | | | 5.2 | <0.001* |
| McDonald's | 3.4 | <0.001* | | | 3.5 | <0.001* |
| Region | | | | | | |
| East Coast (reference) | | | | | | |
| Midwest | | | 2.3 | <0.001* | 0.1 | 0.657 |
| West Coast | | | −0.9 | <0.001* | −1.5 | <0.001* |
| Chicken | | | | | | |
| Chain | | | | | | |
| Burger King (reference) | | | | | | |
| Wendy's | 0.5 | 0.604 | | | 0.5 | 0.604 |
| McDonald's | −0.3 | <0.001* | | | −0.3 | <0.001* |
| Region | | | | | | |
| East Coast (reference) | | | | | | |
| Midwest | | | 0.2 | 0.171 | 0.2 | 0.178 |
| West Coast | | | 0.2 | 0.133 | 0.2 | 0.120 |
| Fries | | | | | | |
| Chain | | | | | | |
| Burger King (reference) | | | | | | |
| Wendy's | 1.5 | <0.001* | | | 2.4 | <0.001* |
| McDonald's | 1.0 | <0.001* | | | 1.9 | <0.001* |
| Region | | | | | | |
| East Coast (reference) | | | | | | |
| Midwest | | | 0.7 | <0.001* | 0.4 | <0.001* |
| West Coast | | | 0.8 | <0.001* | 0.4 | <0.001* |
| **$\delta^{15}N$** | | | | | | |
| Beef | | | | | | |
| Chain | | | | | | |
| Burger King (reference) | | | | | | |
| Wendy's | −0.3 | <0.001* | | | −0.4 | <0.001* |
| McDonald's | −0.3 | <0.001* | | | −0.5 | <0.001* |
| Region | | | | | | |
| East Coast (reference) | | | | | | |
| Midwest | | | 0.3 | <0.001* | −0.9 | <0.001* |
| West Coast | | | −0.2 | <0.001* | −0.4 | <0.001* |
| Chicken | | | | | | |
| Chain | | | | | | |
| Burger King (reference) | | | | | | |
| Wendy's | −0.2 | 0.009* | | | −0.2 | 0.009* |
| McDonald's | −0.3 | <0.001* | | | −0.3 | <0.001* |
| Region | | | | | | |
| East Coast (reference) | | | | | | |
| Midwest | | | 0.1 | 0.484 | 0.1 | 0.426 |
| West Coast | | | 0.1 | 0.281 | 0.1 | 0.309 |

*, $P < 0.01$.

commented on the "remarkably invariant" values of $\delta^{15}N$ in confined animal meat, which we have observed for both beef and chicken (Tables 1 and 2). We speculate that chicken exhibited lower $\delta^{15}N$ values than beef (average $\delta^{15}N = 2.3‰$; Table 1) because chicken are not ruminants, and therefore digest feed in only 1 step. However, the relatively high and invariant (Tables 1 and 2) values of $\delta^{15}N$ in chicken meat also reflect the monotony and confinement of tissue production.

The result that the $\delta^{13}C$ value of fries differed significantly among restaurants (Table 2) led us to test the hypotheses that different chains employ different protocols for deep-frying. French fries are manufactured by immersing preformed emulsified potato (*Solanum tuberosum*) meal in ≈190 °C fat for ≈3 min. The resulting product is mostly composed of potato, fat (17.6, 15.5 and 22.9 mass percentage for Burger King, McDonalds, and Wendy's, respectively), and minor additives [some with major consequences (15)], with negligible amounts of protein and sugar. Elsewhere we have documented the $\delta^{13}C$ value of commercially available potatoes [$\delta_{potato} = -25.8‰$ (16)]; based on this value we can estimate the carbon isotope composition of the fat added to potatoes ($\delta_{fat}$) based on the fraction of mass as fat ($f_{fat}$) reported by each chain:

$$\delta_{fat} = (\delta_{fries} - (\delta_{potato}*1 - f_{fat}))/f_{fat}.$$

**Table 3. Carbon and nitrogen stable isotope composition of animal feeds**

| Feed | $\delta^{13}C$, ‰ | $\delta^{15}N$, ‰ | Source or ref. |
|---|---|---|---|
| | Whole plant | | |
| Alfalfa (*Medicago sativa*) | −28.3 to −27.4 | −1.5 to 0.3 | 7, 12 |
| Grass (unspecified) | −29.3 to −27.9 | −0.3 to 4.3 | 7, 22 |
| Wheat (*Triticum aestivum*) | −26.7 to −22.9 | 2.1 to 2.5 | 7, 12, 16 |
| Potato (*Solanum tuberosum*) | −25.8 | −1.7 to 2.6 | 16, 23 |
| Total range of above | −29.3 to −22.9 | −0.3 to 4.3 | |
| | Seed | | |
| Triticale (*Triticale secale*) | −27.7 | 4.2 | 7 |
| Field pea (*Pisum sativum*) | −27.5 | 1.8 | 7 |
| Broad beans (*Vicia faba*) | −27.6 | 1.3 | 7 |
| Barley (*Hordeum vulgare*) | −27.8 to −22.2 | 0.8 to 6.3 | 7, 12, 16 |
| Sunflower (*Helianthus Annuus*) | −26.2 | 4.3 | 12, 16 |
| Soy (*Glycine max*) | −27.4 to −25.4 | 1.1 | 12, 16 |
| Oats (*Avena sativa*) | −25.1 to −24.1 | 2.2 | 12, 16 |
| Acorns (*Quercus* spp.) | −24.8 to −21.0 | n.d. | 12 |
| Rapeseed ("canola") (*Brassica napus*) | −35.6 to −32.3 | n.d. | (Brassicaceae) 24 |
| Total range of above | −35.6 to −21.0 | 0.8 to 6.3 | |
| Corn (*Zea mays*) | −13.1 to −10.7 | 3.4 to 5.7 | 12, 16, 23, 25 |
| | Silage and meal | | |
| Alfalfa-based | −29.0 | 2.4 | 7 |
| Ryegrass-based (*Lolium* sp.) | −27.9 | 3.9 | 7 |
| Grass (unspecified) | −29.6 to-27.7 | −0.2 to 4.0 | 7, 9 |
| Soybean-based | −26.0 to −25.1 | 0.1 to 1.5 | 7, 22 |
| Rapeseed-based | −26.6 | 2.7 to 2.9 | 7, 22 |
| Sugarbeet-based (*Beta vulgaris*) | −28.3 to −28.0 | 3.6 to 5.2 | 7, 22 |
| Total range of above | −29.6 to −25.1 | −0.2 to 5.2 | |
| Corn-based | −14.0 to −11.0 | 4.5 to 7.2 | 7, 9, 13 |

n.d., not determined.

This calculation assumes that potato and fat are the major mass and isotopic contributors to fries, an assumption confirmed by the negligible amount of nitrogen we found in fries (< 1% by mass) upon combustion, and by the ingredient reports available. The results of this calculation are show in Fig. 2; $\delta^{13}C$ ranges for corn oil (−16.4 to −13.7‰) and other vegetable oils (−32.4 to −25.4‰), with cottonseed, rapeseed, soybean, sunflower, sesame, peanut, olive and palm oil are also specified (17). The statistically significant difference in the $\delta^{13}C$ value of fries between chains implied a corn-oil based protocol for Wendy's, whereas McDonald's and Burger King favored other vegetable oils. Although Burger King reports soybean oil as the only oil used in their fries, both Wendy's and McDonald's report that their fries "may contain one of more" of canola, soy, cottonseed or corn oil.

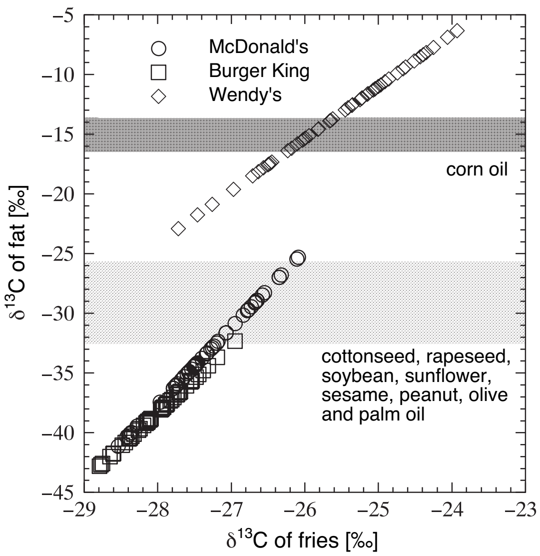


**Fig. 2.** Calculated value of $\delta^{13}C$ in fat plotted against measured value of $\delta^{13}C$ in fries; carbon stable isotope ranges reported for corn oil and other vegetable oils shaded for comparison (17). We note that variable %-fat within servings may account for the wide spread in $\delta^{13}C$ of fat calculated for each restaurant.

## Conclusions

Fast food corporations, although they constitute more than half the restaurants in the U.S. and sell more than 1 hundred billion dollars of food each year (18), oppose regulation of ingredient reporting‡. Ingredients matter for many reasons: U.S. corn agriculture has been criticized as environmentally unsustainable (19) and conspicuously subsidized (20). Of 160 food products we purchased at Wendy's throughout the United States, not 1 item could be traced back to a noncorn source. Our work also identified corn feed as the overwhelming source of food for tissue growth, hence for beef and chicken meat, at fast food restaurants. We note that this study did not include an examination of beverages served, which are dominantly sweetened with high fructose corn syrup (21). In 2002, the European Union adopted Regulation 178 (11) requiring suppliers to trace the origin of materials used for production. At this time in the United States, such tracing is voluntary and seldom-invoked. [A description of the U.S. Department of Agriculture National Animal Identification System is at http://animalid.aphis.usda.

‡"Providing calories, or any other nutrition information, should be an education issue, not a political one" (www.wendys.com/food/pdf/us/menuboard.pdf).

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gov/nais/.] Our work highlights the absence of adequate consumer information necessary to facilitate an ongoing evaluation of the American diet.

## Materials and Methods

For each serving of meat, charred material or remnants of bun were removed by scraping away ≈2 mm of the outer surfaces of the patty/fillet at the subsampling locations before collection. Each patty/fillet was then subsampled in 4 places, then combined to produce an averaged sample. For each serving of fries, 3 individual fries were combined to create an averaged sample. All samples were freeze-dried and homogenized by hand, using a mortar and pestle. Samples were analyzed for carbon and nitrogen composition, using a Eurovector Elemental Analyzer configured with a Micromass Stable Isotope Ratio Mass Spectrometer; values are reported in standard $\delta$-notation relative to VPDB and AIR (Table S2). Measurement of $CO_2$ and $N_2$ upon combustion revealed homogeneous carbon and nitrogen content of the substrates: burger patties = 60 ± 2%C and 9 ± 1%N; chicken fillets = 46 ± 2%C and 13 ± 1%N; fries = 49 ± 2%C and <1%N ($\mu \pm \sigma$; the low N-content of fries precluded $\delta^{15}$N analysis). A summary of isotopic results is presented in Table 1.

Because samples are considered clustered within restaurants and cities, we adopted a 3-level statistical model to evaluate associations within $\delta^{13}$C and $\delta^{15}$N value of foods sampled. Each model is a simple/multivariate linear regression: The analysis was performed separately for $\delta^{13}$C and $\delta^{15}$N in beef, chicken, and fries. Model 1 evaluated the association of isotope composition with fast-food chain; model 2 evaluated the association of isotope composition with geographical region; model 3 evaluated the association of isotope composition with fast-food chain and geographical region together. Estimates ($\Delta$) of coefficients for covariates were calculated from the following linear models (Table 2):

**Model 1.** $\Delta = I_{ref} + (\beta_1 \times \delta_{Wendy's}) + (\beta_2 \times \delta_{McDonald's}) + RI_{restaurant} + RI_{city}$.

**Model 2.** $\Delta = I_{ref} + (\beta_1 \times \delta_{Midwest}) + (\beta_2 \times \delta_{West\ Coast}) + RI_{restaurant} + RI_{city}$.

**Model 3.** $\Delta = I_{ref} + (\beta_1 \times \delta_{Wendy's}) + (\beta_2 \times \delta_{McDonald's}) + (\beta_3 * \delta_{Midwest}) + (\beta_4 \times \delta_{West\ Coast}) + RI_{restaurant} + RI_{city}$.

Models 1, 2, and 3 were referenced against Burger King, East Coast, and both Burger King and East Coast values, respectively. Intercepts represented $\langle\delta\rangle$ for the reference group ($I$), or random values based on normal distribution ($RI$); slopes ($\beta$) were calculated separately for each model; $\delta$ represented the $\delta^{13}$C or $\delta^{15}$N of the food substrate.

**ACKNOWLEDGMENTS.** We thank the participants who donated their time, travel, and expertise; J. M. Cotton, K. J. Foebler, and W. M. Hagopian for purchasing fast food samples and for laboratory help; the Department of Earth and Planetary Sciences at The Johns Hopkins University, where the isotopic analyses took place; and E. Yeung and H. C. Hsu of the Johns Hopkins School of Public Health for statistical analyses and interpretation.

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