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Survey of American food trends and the growing obesity epidemic

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Abstract

The rapid rise in the incidence of obesity has emerged as one of the most pressing global public health issues in recent years. The underlying etiological causes of obesity, whether behavioral, environmental, genetic, or a combination of several of them, have not been completely elucidated. The obesity epidemic has been attributed to the ready availability, abundance, and overconsumption of high-energy content food. We determined here by Pearson's correlation the relationship between food type consumption and rising obesity using the loss-adjusted food availability data from the United States Department of Agriculture (USDA) Economic Research Services (ERS) as well as the obesity prevalence data from the Behavioral Risk Factor Surveillance System (BRFSS) and the National Health and Nutrition Examination Survey (NHANES) at the Centers for Disease Control and Prevention (CDC). Our analysis showed that total calorie intake and consumption of high fructose corn syrup (HFCS) did not correlate with rising obesity trends. Intake of other major food types, including chicken, dairy fats, salad and cooking oils, and cheese also did not correlate with obesity trends. However, our results surprisingly revealed that consumption of corn products correlated with rising obesity and was independent of gender and race/ethnicity among population dynamics in the U.S. Therefore, we were able to demonstrate a novel link between the consumption of corn products and rising obesity trends that has not been previously attributed to the obesity epidemic. This correlation coincides with the introduction of bioengineered corns into the human food chain, thus raising a new hypothesis that should be tested in molecular and animal models of obesity.

Key Words: Obesity, food trend, corn product, genetically modified, bioengineered

Introduction

It is estimated that, worldwide, approximately 937 million adults are overweight and 396 million are obese [1]. This rising trend continues unabated both globally and in the United States, which claims the largest population of overweight and obese adults [2,3]. Various etiologic factors associated with obesity have been reported, including a number of genes identified from genome-wide scans and functional genomic studies as well as some viruses and bacteria [4-7]. The current prevailing hypothesis centers on the premise that the problem of obesity is one of energy imbalance, wherein total energy intake far exceeds energy output [8]. In addition, the global epidemic of obesity has been attributed to heuristic observations of an increase in the consumption of high-energy/high-fat content foods coupled with a sedentary lifestyle that expends little energy.

The notion that particular nutrients or food sources might influence obesity is controversial [9]. For example, the increased consumption of some food types, including beverages and foods that contain high-fructose corn syrup (HFCS), is speculated to be associated with obesity [10,11]. Moreover, in a previous study, mice given HFCS-sweetened water gained more weight and showed increase adiposity [12]. While the results of this animal study seem to provide experimental evidence that supports the hypothesis that consumption of HFCS causes obesity, the results from epidemiological and clinical studies in human are inconclusive [13,14], leaving the question of HFCS association with obesity unanswered. Therefore, whether or not the intake of certain food types predisposes an individual to increased risk for obesity needs to be examined.

Quantifying the amount of food an individual consumes daily is difficult, and determining the intake of specific food types is intractable, thus posing significant challenges to the investigation of food intake and the development of obesity. It is known that the Loss-Adjusted Food Availability Data from the Economic Research Services (ERS) of the United States Department of Agriculture (USDA) constitute time series data on the national food supply of several hundred food-types targeted to the food marketing system. These data are represented as per capita food availability and are useful for studying food consumption trends, as they are an indirect measurement of actual food intake [15].

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To determine whether or not excess energy intake or the consumption specific food types contribute to the development of obesity, we surveyed Loss-Adjusted Food Availability and obesity prevalence data to investigate the correlation between total energy intake and consumption of certain food types with rising trends in obesity. We confirmed a novel association of rising obesity trends with increased corn product consumption that may be linked to the growing and ubiquitous presence of genetically modified (GM) or engineered (GE) corn in the human diet.

Subjects and Methods

Datasets

We obtained the Loss-Adjusted Food Availability Data (1970-2008) from the Food Availability (Per Capita) Data System at the United States Department of Agriculture (USDA) Economic Research Services (ERS). The per capita food availability data was adjusted for food spoilage, waste, and other losses, as well as converted to average daily per capita calories. The data are downloadable at the USDA ERS data bank [16].

The obesity prevalence and trends data spanning from 1995 and 2008, comprised of health survey data on health risk behaviors such as obesity, were obtained from the Behavioral Risk Factor Surveillance System (BRFSS) at the Centers for Disease Control and Prevention (CDC) [17]. Trends data with body mass index (BMI) $\geq$ 30, classified as obese, were used in this study. The National Health and Nutrition Examination Survey (NHANES) obesity data between 1960 and 2008 were downloaded from the E-Stats data bank at CDC [18].

Data for genetically modified corn varieties adopted in the U.S. were obtained from USDA ERS National Agricultural Statistics Service [19].

Statistical analysis

We analyzed the relationship between the trends in obesity prevalence and the average daily per capita calories consumed for various food types using Pearson's correlation. To validate the positive correlations, we investigated the dependence of the obesity trends on different food types by fitting a multiple linear regression using both full and reduced model functions.

Since the BRFSS obesity prevalence and trends data were only available between 1995 and 2008, we tested the correlation between each food type from 1995 through 2008 by Pearson's correlation and multiple linear regression. The food types analyzed were red meat, poultry, dairy products, grains, fats and oils, sweeteners, and average total calories consumed daily per capita. In addition, specific food types such as fish, eggs, nuts, and some dairy products exhibiting either negative or no change in the trends of consumption between 1995 and 2008 were not subjected to Pearson's analysis.

Results

To determine the correlation between obesity and food type intake, we first assessed the suitability of the BRFSS dataset for our analysis. Use of the NHANES obesity prevalence data was hampered by the availability of only five data points, NHANES (1999-2000), (2001-2002), (2003-2004), (2005-2006), and (2007-2008), in contrast to the 14 data points in the BRFSS dataset between 1995 and 2008, which is statistically more favorable for our study. However, the BRFSS dataset, which is based on self-reported weights and heights, is generally considered inferior to the NHANES obesity prevalence data [20,21]. Despite the qualitative and quantitative differences between the NHANES and BRFSS data, our results show that the obesity trends between 1995 and 2008 derived from the two datasets were remarkably similar by regression analysis (Fig. 1). Therefore, we used the BRFSS data for our correlation study with the food trends data since it is statistically more robust than the NHANES dataset.

We analyzed the USDA ERS Loss-Adjusted Food Availability Data, which include seven major aggregated food groups including 1, meat, eggs, and nuts; 2, dairy; 3, fruit; 4, vegetables; 5, flour and cereal products; 6, added fats and oils, and dairy fats; and 7, caloric sweeteners. These groups are further comprised of more than 100 individual or specific food types (commodities). Analysis of these food types revealed that a large number of them including fresh vegetables, fresh fruit, beverage milk, fish and shellfish, fruit juice, nuts, and others, showed either negative trends or no change in trends of consumption and did not coincide with rising trends in obesity (Fig. 2).

Since energy imbalance resulting from excess calorie intake is thought to contribute to obesity, we first analyzed the trends in calorie intake between 1995 and 2008. The food availability data indicated that the average daily per capita total calorie intake has plateaued since year 2000, whereas obesity exhibited a rising trend (Fig. 3A), and Pearson's analysis showed a correlation coefficient of 0.79 (Table 1). In contrast, strong positive correlations with

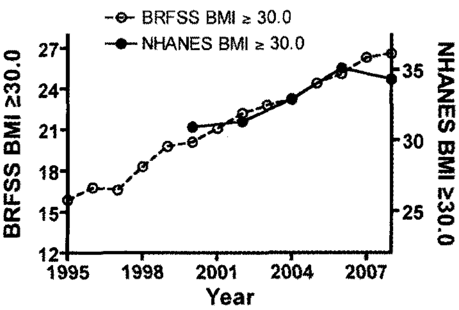

Fig. 1. Comparison of rising obesity trends of NHANES and BRFSS datasets. Alignment of the NHANES and BRFSS obesity trend datasets was performed to find the optimal correspondence. The left ordinate indicates the obesity prevalence by median %; and the right ordinate shows the average daily per capita calories consumed for each food type. The rising obesity trends are similar between the NHANES and BRFSS datasets. Open circles (O) are BRFSS; and closed circles (●) are NHANES obesity trends data with BMI $\geq$ 30 from their respective datasets.

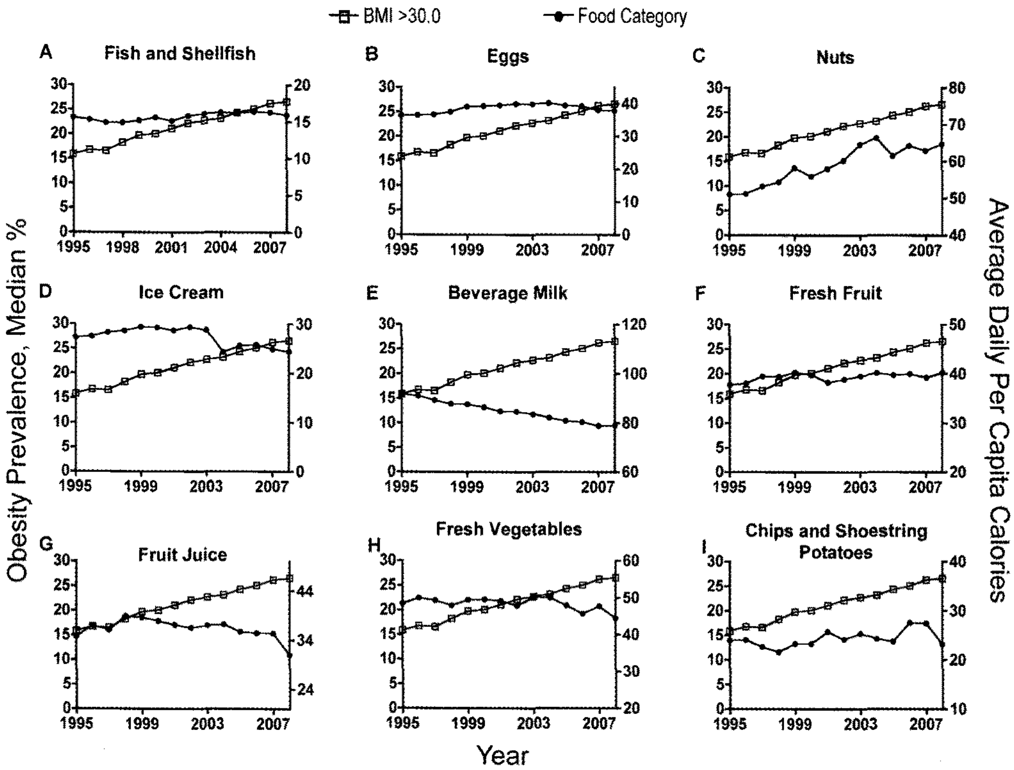

Fig. 2. Food types showing no correlation with rising obesity trends. The left ordinate indicates the obesity prevalence by median %; and the right ordinate shows the average daily per capita calories consumed for each indicated food type. Rising obesity did not overlap with the trends in consumption of the indicated food types. Open squares (□), obesity trends data with BMI > 30; and closed circles (●), food type.

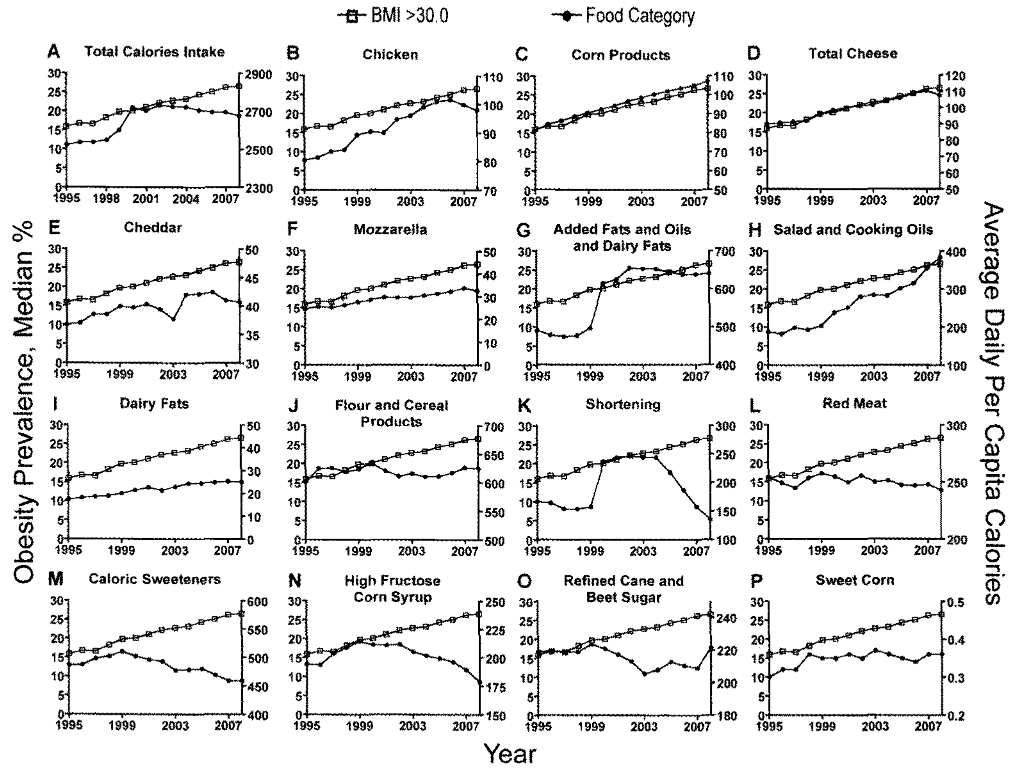

Fig. 3. Regression analysis of the relationship between food type consumption and obesity trends by Pearson's correlation. Regression analysis by Pearson' s correlation was performed to determine the relationship between obesity trends and the average daily per capita calories consumed for various food types. The left ordinate indicates the obesity prevalence by median %; and the right ordinate shows the average daily per capita calories consumed for each food type. Open squares (□), obesity trends data with BMI > 30; and closed circles (●), food type.

Table 1. Correlation between trends in food type consumption and obesity

Food type	Correlation coefficient
Total calories intake	0.79
Red meat	-0.40
Chicken	0.96
Flour and cereal products	0.03
Corn products	0.99
Added fats and oils and dairy fats	0.86
Added fats and oils	0.85
Dairy fats	0.97
Salad and cooking oils	0.97
Shortening	0.18
Caloric sweeteners	-0.74
High fructose corn syrup (HFCS)	-0.38
Total cheese	0.99

Table 2. Multiple linear regression analysis of food types and obesity trends

Variable	Full model	
	β_i (SE)	*P*
Chicken	-0.045 (0.077)	0.578
Corn products	0.349 (0.107)	0.011
Dairy fats	-0.257 (0.226)	0.289
Salad and cooking oils	-0.000 (0.009)	0.987
Total cheese	0.257 (0.120)	0.065
	Reduced model	
Corn products	0.302 (0.061)	0.000
Total cheese	0.162 (0.071)	0.044

obesity were unexpectedly found for chicken and corn products (Fig. 3B and C), with Pearson's correlation coefficients of 0.96 and 0.99, respectively (Table 1).

We also observed a positive correlation between total cheese intake and obesity (Fig. 3D). However, further analysis revealed that, with the exception of cheddar and mozzarella cheese, most other cheeses, such as provolone, parmesan, Swiss cheese, blue cheese, and others, showed little or no changes in consumption trends between 1995 and 2008, and Pearson's analysis of either cheddar (Fig. 3E) or mozzarella (Fig. 3F) did not show correlation with rising obesity.

Even though correlation with obesity was not found for "Added Fats and Oils, and Dairy Fats" (Fig. 3G), with a correlation coefficient of 0.86 (Table 1), analysis of Salad and Cooking Oils (Fig. 3H) and Dairy Fats (Fig. 3I) revealed correlation with obesity, each with a correlation coefficient of 0.97 (Table 1). These correlations subsequently did not cross-validate upon further analysis by multiple linear regression (see below).

Additionally, either poor or negative correlations were found for foods such as flour and cereal products, shortening, red meat, caloric sweeteners, and HFCS, with correlation coefficients of -0.03, -0.18, -0.40, -0.74, and -0.38, respectively (Fig. 3J-N, and Table 1). The consumption of refined cane and beet sugar (Fig. 3O) as well as sweet corn as a fresh vegetable (Fig. 3P) also did not correlate with obesity. The consumption of corn as a fresh vegetable constituted only a small percentage (averaging 0.01%) of the total calorie intake between 1995 and 2008.

To further test these positive correlations with obesity trends, we performed a fitting by multiple linear regression analysis with food types that showed correlation coefficients >0.95, which included chicken, corn products, dairy fats, salad and cooking oils, and total cheese, in a full model function. This analysis showed that only corn products had p-values smaller than 0.05 (Table 2), suggesting that consumption of corn products had a significant effect on rising obesity trends. In the reduced model, we analyzed corn products and total cheese, which have p-values closest to 0.05 from the full model analysis, and our results confirmed a correlation between corn products, but not total cheese, and obesity trends (Table 2).

The observed correlation between consumption of corn products and rising obesity is surprising. It is noteworthy that HFCS is classified separately as a caloric sweetener and not aggregated with other corn products. Moreover, HFCS showed a negative correlation with rising obesity (Table 1). We were not able to fully analyze whether or not corn product consumption correlated with obesity trends between 1970 and 1994 because the National Health and Nutrition Examination Survey (NHANES) datasets are only available in four cross-sectional,

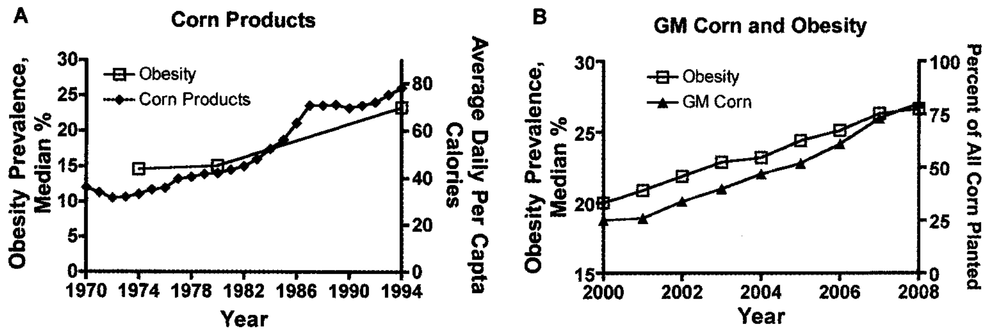

Fig. 4. Trends in corn consumption and rising obesity. (A) Relationship of corn product consumption and obesity prevalence between 1970 and 1994. Obesity prevalence from NHANES I (1971-1975), II (1976-1980), and III (1988-1994) were plotted against corn product consumption, revealing the lack of overlap in the trends of these data. Open squares (□), obesity trends data with BMI 〉 30; and closed circles (◆), corn products. (B) Relationship between rising obesity and rate of GM corn adoption in U.S. between 2000 and 2008. Rate of adoption of GM corn by farmers represented as the acreage of farms planted with GM corn as a percent of total acreage of corn planted in the U.S. was plotted against rising obesity trends. Open squares (□), obesity trends data with BMI >30; and closed circles (□), GM corn.

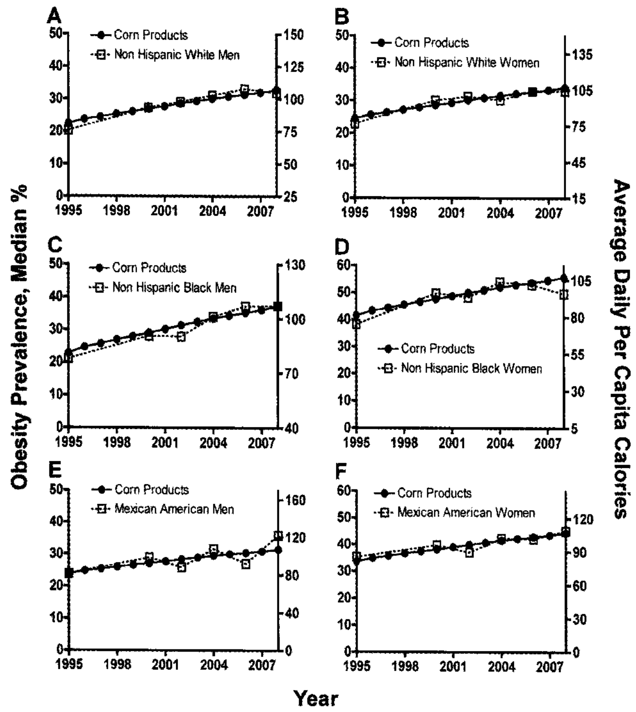

Fig. 5. **Correlation of corn products intake with NHANES obesity prevalence data stratified by race/ethnicity and gender.** Obesity prevalence data stratified by race/ethnicity and gender from NHANES III (1988-1994), NHANES (1999-2000), (2001-2002), (2003-2004), (2005-2006), and (2007-2008) were plotted against corn product consumption between 1995 and 2008. Open squares (□), obesity trends data with BMI $\geq$ 30; and closed circles (●), average daily per capita corn products intake in calories. Alignment was performed for the relationship of rising obesity with corn product consumption between 1995 and 2008 for non-Hispanic white men (A) and women (B); non-Hispanic black men (C) and women (D); and Mexican-American men (E) and women (F).

nationally representative surveys prior to 1995, including NHANES I (1971-1975), II (1976-1980), and III (1988-1994) [22], thus yielding only three data points for Pearson's correlation analysis of corn-rich products. Nevertheless, we showed that the trends in obesity prevalence and corn product consumption between 1970 and 1994 did not align (Fig. 4A).

We were also aware that genetically modified (GM) corn has been planted in the U.S. since 1996 [23]. To further investigate the relationship between bioengineered corn and rising obesity, we obtained data on the adoption of GM corn from the USDA, which covered the period between 2000 and 2008, for comparison with rising obesity. These data did not take into account the use of GM corn for other purposes besides as a food or animal feed. Despite this limitation, our result shows that the trends of obesity and adoption of GM corn were similar (Fig. 4B).

We further asked whether or not the consumption of corn products might be associated with the demographic distribution of the population. Using the NHANES stratified obesity prevalence data between NHANES III (1988-1994), NHANES (1999-2000), (2001-2002), (2003-2004), (2005-2006), and (2007-2008), we examined the relationship between corn product consumption and race/ethnicity of men and women between 1995 and 2008. Our results show that the trends of obesity and corn product consumption rose in parallel irrespective of gender among non-Hispanic white men and women (Fig. 5A and B), non-Hispanic black men and women (Fig. 5C and D), and Mexican-American men and women (Fig. 5E and F), thus suggesting that the association of rising obesity trends with increased corn product consumption is independent of race/ethnicity and gender.

Discussion

Our analysis of obesity and food type consumption trends data in this report yielded three major findings. First, it has been long accepted that overconsumption of food coupled with a sedentary lifestyle results in a positive energy imbalance, which is a formula for obesity development. Our analysis in this report, however, indicates that even though total calorie intake in the U.S. has plateaued in recent years, the incidence of obesity continues to rise, thus suggesting that rising obesity trends do not correlate with total energy intake. Alternatively, it is conceivable that the total caloric intake has plateaued while the levels of physical activity have also not increased, thus explaining the intransigent obesity trends.

Second, HFCS as a cause of obesity has been intensely debated. It was shown recently that rats given HFCS along with a regular chow diet gained more weight than control rats, even when they consumed the same amount of calories [24]. Further, consumption of an HFCS-containing diet increased visceral fats and blood triglycerides over time. However, our results show a negative correlation of HFCS with rising obesity, as HFCS consumption has been on the decline since 2000. However, this negative correlation does not refute the underlying biological role of HFCS in obesity. Instead, it suggests that HFCS consumption on the whole may not contribute to rising obesity trends. Though we initially also observed positive correlations between increased consumption of chicken, salad and cooking oils, dairy fats, and total cheese with obesity, subsequent multiple linear regression analysis and cross-validation of these results revealed a lack of significance in these correlations.

The above observations suggest that additional factors may be involved in rising obesity trends. Therefore, our third finding of a correlation between increased corn product intake and rising obesity between 1995 and 2008 is intriguing, as these foods are not generally considered unhealthy. What are the underlying etiologic links between these foods and obesity?

In the ERS dataset, corn products are considered an aggregate comprised of flour and meal, hominy and grits, cornstarch, and other corn products, which are widely used in the manufacture of a large variety of food products consumed by humans. Recently, it was reported that approximately 85% of the corn grown in the U.S. is transgenic [25]. The increased ubiquity of GM or genetically engineered corn products in human food sources is noted, but their potential impact on human health has not been investigated despite recent reports of hepatorenal toxicity in rats fed GM maize [26,27]. Moreover, the rising trends in obesity coincide, in part, with the introduction of GM corn in foods and animal feeds in the U.S. [28,29]. These observations prompted us to hypothesize that consumption of GM corn products may contribute to rising obesity trends. The implications of our results and the new hypothesis raised here are provocative but testable, as the effects of GM corn products can be assessed in molecular and animal models of obesity. No data are currently available on how much genetically engineered food is on the market due to a lack of proper labeling and traceability.

We further speculate that the bacterial antigen derived from the Bacillus thuringiensis (Bt) entomocidal crystalline protein protoxin [30], which is genetically engineered into corn to confer resistance to insect pests, may be the underlying culprit that causes anomalous adipose tissue dysregulation and obesity development.

While our trends study has yielded novel insights into the potential impact that some food types may have on the development of obesity, there are some possible confounding factors that should be discussed. It is noteworthy that the Loss-Adjusted Data do not reflect actual consumption or the quantities of food ingested. Moreover, it was difficult to collect data on the actual amount of food or the specific food types consumed, as most previous clinical studies have relied on questionnaires and voluntary reporting or recollection of food consumed by study subjects, which are well known to be prone to psychosocial behavioral errors. In the absence of true food consumption data, therefore, trends in food use obtained from the USDA ERS Food Availability Data served as an alternative indirect measure of whether Americans are consuming more or less of various foods over time. Similarly, the weight and height information collected from phone interviews for the BRFSS obesity trends data is also highly susceptible to erroneous self-reporting. In contrast, physical measurements for weight and height were obtained from participants in the NHANES studies. Despite such shortcomings, the BRFSS obesity trends were remarkably similar to the NHANES dataset. In addition, the data for the rate of GM corn adoption in the U.S. did not take into consideration the different uses of these transgenic corns other than as foods and feeds. Although it is clear that transgenic corn has penetrated into human foods and animal feeds, and the consumption of GM crops has been deemed safe [31], precise data regarding the amounts and types of foods containing transgenic corn products are unavailable, and the correlation with increased emergence of common human diseases including diabetes and obesity has not been investigated.

Taken together, our results reveal a novel association of corn product consumption with rising trends of obesity, which may be linked to the increased ubiquity of transgenic corn in the diet. These trends data findings warrant further investigation and confirmation through laboratory testing.

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