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Hyper-Palatable Foods: Development of a Quantitative Definition and Application to the US Food System Database

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Objective: Extensive research has focused on hyper-palatable foods (HPF); however, HPF are defined using descriptive terms (e.g., fast foods, sweets), which are not standardized and lack specificity. The study purpose was to develop a quantitative definition of HPF and apply the definition to the Food and Nutrient Database for Dietary Studies (FNDDS) to determine HPF prevalence in the US food system.

Methods: A numeric definition of HPF was developed by extracting common HPF descriptive definitions from the literature and using nutrition software to quantify ingredients of fat, simple sugars, carbohydrates, and sodium. The definition was applied to the FNDDS.

Results: HPF from the literature aligned with three clusters: (1) fat and sodium (>25% kcal from fat, $\geq 0.30\%$ sodium by weight), (2) fat and simple sugars (>20% kcal from fat, >20% kcal from sugar), and (3) carbohydrates and sodium (>40% kcal from carbohydrates, $\geq 0.20\%$ sodium by weight). In the FNDDS, 62% (4,795/7,757) of foods met HPF criteria. The HPF criteria identified a variety of foods, including some labeled reduced or low fat and vegetables cooked in creams, sauces, or fats.

Conclusions: A data-derived HPF definition revealed that a substantial percentage of foods in the US food system may be hyper-palatable, including foods not previously conceptualized as hyper-palatable.

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Introduction

As scientific evidence has revealed that individuals eat for hedonic or reward-driven reasons (1,2), attention has turned to the source of the reward: palatable foods (3). Extensive research has been conducted examining the effects of palatable foods on various psychological and physiological mechanisms that drive food intake and energy balance regulation (4-6). Since 2010, more than 20 reviews have been conducted on topics focused on the impact of palatable foods on appetite regulation, energy balance, and obesity, e.g., (4-6). Our literature search on PubMed using keyword “palatable food(s)” demonstrated that the number of annual publications on the topic increased by 550% from 2000 to 2018 ($n=17$ published in 2000; $n=111$ published in 2018), suggesting that this is a crucial area of focus for obesity and nutrition fields.

Despite the immense scientific focus on palatable foods, there is one substantial limitation in this area of the research. In the literature, palatable foods have been defined using descriptive terms (e.g., fast foods, sweets), and there is no standardized definition. Most of the published research has referred to palatable foods as being energy dense and containing ingredients that enhance palatability, such as fat, sugar, and

sodium (3,7). However, operational definitions have varied substantially and focused on food categories like fast foods or fried foods (8,9) or sweets and desserts (10), while others have identified a variety of specific foods (11,12) or provided no operational definition (13).

Descriptive definitions of palatable foods are simultaneously too broad because of their categorical nature and too restrictive because of their lack of specificity. For example, a palatable food description of fast food suggests that any food sold at a fast food restaurant is a palatable food. However, some fast food restaurants sell salads and grilled items, which may or may not be as palatable as a cheeseburger. At the same time, a definition of fast food does not consider other foods that may have similar ingredients of fat, sugar, and sodium (and likely similar effects on palatability) but that would not be considered using this descriptive definition (e.g., trail mix with chocolate).

Descriptive definitions of palatable foods lack specificity as to the key mechanisms (ingredients) driving palatability. It has been widely publicized in documentaries and popular media books that the food industry has well-established food formulas based on combinations of fat, sugar, sodium, and carbohydrates that are designed to maximize palatability and consumption (14,15). However, these specific

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quantitative definitions are virtually unknown to the scientific community. Scientific efforts to identify the key ingredients in palatable foods linked to overconsumption and obesity have been sparse, although initial evidence points to the combination of palatability-inducing ingredients as being important in heightening palatability and increasing consumption. For example, several small experimental studies in humans have demonstrated that a combination of fat and sodium (FSOD) may synergistically enhance food palatability and increase consumption by up to 30% (16,17). Others have reported that combinations of fat and simple sugars (FS) may heighten preference and palatability (18-21) and that consumption of high fat and high sugar may lead to future weight gain (22). Findings from the behavioral literature are supported by the findings of a recent neuroimaging study in humans that reported supra-additive effects of combining fat and carbohydrates; foods with fat-carbohydrate combinations were more efficient in activating brain reward neural circuitry than foods with either fat or carbohydrates alone (23). Thus, preliminary research suggests that foods may be designed in ways that create hyper-palatability, a condition in which the synergy between key ingredients in a food creates an artificially enhanced palatability experience that is greater than any key ingredient would produce alone.

Theoretical support for the role of combined ingredients in creating hyper-palatability and enhancing food reward is derived from the mechanism of sensory-specific satiety (SSS). SSS refers to the process by which the pleasantness of a food being consumed declines during an eating occasion, which is a mechanism that regulates feeding cessation (24). While SSS is a general physiological mechanism, foods were shown to differ in their degree of eliciting SSS (25). Foods that contain multiple palatability-inducing ingredients (such as carbohydrates and salt) and fewer nutrients (such as fiber) may activate a weaker SSS response and delay eating cessation, as was found when participants consumed white bread compared with whole wheat bread (26). SSS may be further circumvented by the effects of combined palatability ingredients on brain reward neural circuitry, which can result in a highly rewarding eating experience that may facilitate overconsumption despite satiety (3,27). Thus, given the available theoretical and scientific evidence, foods designed to be hyper-palatable, herein referred to as hyper-palatable foods (HPF), may contain combinations of palatability-inducing ingredients (fat, sugar, carbohydrates, and/or sodium) at moderate to high levels that may circumvent physiological satiety mechanisms and activate brain reward neural circuitry. In contrast, foods such as raw fruits and unsalted nuts that contain one primary palatability-inducing ingredient and/or that contain satiety-inducing nutrients (e.g., fiber) would not be expected to circumvent SSS. However, the specific ingredients that distinguish between HPF and non-HPF have not been investigated or defined systematically.

The lack of a standard definition of HPF is a serious limitation, and research on HPF lags behind other related research with established dietary indices, such as energy density (28) and ultraprocessed foods (29). A specific, quantitative definition of HPF would provide a more flexible framework with which to identify any food that could be modified to enhance palatability. For example, some foods marketed as breakfast items, such as sweetened cereals and muffins, may not be considered HPF using a standard description but may be hyper-palatable, and a quantitative definition would lead to the identification of such foods. Furthermore, a quantitative definition would allow for better characterization of the prevalence of HPF

within the US food system. Because of the lack of a standardized HPF definition, it is unclear how prevalent HPF may be in the US food system, despite the widespread research suggesting that HPF, defined descriptively, and their outlets are widespread (30). Thus, the purpose of the present study was to use a data-driven approach to derive a quantitative definition of HPF and apply the definition to the US Department of Agriculture (USDA) Food and Nutrient Database for Dietary Studies (FNDDS), a database that is representative of the US food system. In addition, we sought to examine evidence for discriminant and convergent validity when applying the HPF criteria to the FNDDS.

Methods

Identification of descriptive HPF definitions

A systematic review of the literature was conducted to identify articles that provided descriptive definitions of a full range of HPF that could be included in the study. Studies were (1) established survey measures of food reward or appetite-related constructs that used a standard descriptive definition of HPF, (2) studies that used experimental surveys or lab tasks to identify descriptive definitions of HPF/constructs implicated in food reward, or (3) review articles that provided an operational definition of HPF and identified a range of specific HPF items. Studies were required to be conducted in humans and focus on palatability of Western foods and/or diets. In line with the study purpose, exclusion criteria consisted of studies in animals, studies determining optimum palatability of a single food item (and not a range of HPF), and studies that did not provide an operational, descriptive definition of HPF (full exclusion criteria are detailed in online Supporting Information). PubMed and Web of Science databases were searched using terms with variations on food palatability (details in Supporting Information). These searches were supplemented with a hand search of relevant journal articles. Studies with sample characteristics from any nonmedical/special population were included to obtain data on food palatability from the broadest range of individuals. Studies were reviewed for inclusion by two separate reviewers using parallel processes. A flowchart of the search is presented in Supporting Information Figure S1. Out of 2,963 studies screened, 14 articles met inclusion criteria and were included in the study (11,12,29,31-41). Supporting Information Table S1 presents details of the review process, studies selected for inclusion, and HPF descriptions extracted.

HPF definitions were entered into nutrition software to translate HPF descriptions into quantitative nutrition data. HPF items were entered into the Automated Self-Administered 24-Hour Diet Recall (ASA24) program, which facilitates dietary research using validated procedures (42). ASA24 was originally designed to collect participant self-reported dietary intake; however, researchers have also used this platform to facilitate researcher data entry and preparation for analysis (43). Data entry was conducted using standardized procedures (detailed in online Supporting Information).

A total of 171 HPF descriptors were obtained from the literature. Eleven were liquids and were excluded from analyses; liquids differ from solid foods in levels of optimal palatability (18). Each article contributed 4 to 21 HPF descriptor items used in analyses (mean=11.4 items; SD=5.0 items). Of the 160 total descriptor items, some were identified by more than one publication and were duplicates. A total of 75 nonduplicate items were available for analysis.

TABLE 1 HPF clusters and their contents

Cluster	% kcal from fat	% kcal from carbohydrates	% kcal from simple sugars	% sodium by weight	Food description	n items in cluster
FSOD	>25%	–	–	≥0.30%	Meats (e.g., bacon, hot dog) and meal-based items with fat and carbohydrates (e.g., pizza)	46 ^a
FS	>20%	–	>20%	–	Desserts (e.g., cake, ice cream, brownie)	23 ^b
CSOD	–	>40%	–	≥0.20%	Breads, snacks (crackers, pretzels), and carbohydrate-based savory items (popcorn, biscuits)	16 ^c

^an=9 items overlapped with FS cluster.

^bn=1 item overlapped with CSOD cluster.

^cn=5 items overlapped with FSOD cluster.

HPF, hyper-palatable foods; CSOD, carbohydrates and sodium; FS, fat and simple sugars; FSOD, fat and sodium.

Identification of HPF quantitative definition

R statistical software (R Foundation for Statistical Computing, Vienna, Austria) was used for data processing and analysis. Based on prior literature, fat, simple sugars, carbohydrates, and sodium were the focuses of the analyses (16,19,23,35,44). Specifically, fat, simple sugars, and sodium have been directly implicated in enhancing food palatability (16,19,23). Carbohydrates have been strongly implicated in the experience of food reward via activation of the insulin system, which enhances dopamine responding in brain reward regions, which has been strongly correlated with food palatability ratings in humans (23,44,45). Percent calories (kilocalories) from fat (PFAT), simple sugars (PSUGR), and carbohydrates (PCARB) per serving was calculated using standard values of 9 kcal/g for fat and 4 kcal/g for carbohydrates and simple sugars (46). Percent kilocalories from carbohydrates was calculated from a total carbohydrates variable, which included fiber. Fiber slows the process of absorption of carbohydrates and sugar into the system, enhances satiety, and can alter palatability and food texture (47). Therefore, we subtracted fiber before calculating percent kilocalories from carbohydrates. To avoid overlap between the carbohydrates and simple sugars variables, we also subtracted sugar before calculating percent kilocalories from carbohydrates. The total sugars variable, which consisted of both naturally occurring and added sugars, was used to calculate percent kilocalories from simple sugars. For sodium, percent sodium by food weight (PSODI) (in grams) per portion was calculated.

The multistep, parallel process that was conducted independently by two authors to identify HPF criteria consisted of the following: (1) examination of descriptive statistics of variables of interest (PFAT,

PSUGR, PCARB, and PSODI), (2) data visualization procedures using ggplot2 package in R (48) to identify foods with similar levels of the key ingredients, (3) refinement of graphing by segmenting foods with similar levels of ingredients, (4) identification of minimum values of key ingredients within each cluster of foods, and (5) evaluation of the degree to which HPF criteria covered all 75 HPF items. There was very strong agreement between the HPF criteria identified by both authors; two clusters were identified with the same criteria, and for a third cluster, both authors were within three points for one criterion, which was reconciled by revisiting the data and graphic procedures. Three types of HPF that clustered together with similar ingredients were identified: (1) FSOD, (2) FS, and (3) carbohydrates and sodium (CSOD). The final three clusters covered the vast majority of items (93%; 70/75). Five foods high in sugar and carbohydrates (jam, gummy bears, licorice, hard candy, and fruit snacks) had similar contents but did not fit within any cluster and were not sufficient in number to form their own cluster. The HPF criteria are presented in Table 1, and descriptive statistics for each cluster are presented in Table 2.

Application of HPF quantitative definition to USDA database

The USDA's FNDDS is a publicly available data set that is representative of the US food system. The most recently available data set (version 8; 2015-2016) was used in the study and contained 8,690 food and beverage items (49). Beverages and infant formulas (n=933) were excluded from analyses because the HPF definition does not address liquids. The final data set contained 7,757 food items for analysis. PFAT, PSUGR, PCARB, and PSODI were calculated for all food items, and HPF cluster criteria were applied. In addition,

TABLE 2 Descriptive statistics for HPF clusters derived from literature

Cluster	% kcal from fat	% kcal from carbohydrates	% kcal from simple sugars	% sodium by weight
FSOD	47.35 (15.78)	22.21 (16.36)	10.72 (13.76)	0.62 (0.38)
	20.41-99.07	0.00-58.09	0.00-55.02	0.31-2.08
FS	40.91 (10.72)	14.30 (11.31)	36.94 (10.55)	0.24 (0.17)
	20.41-64.81	0.00-43.03	20.68-62.66	0.02-0.58
CSOD	22.73 (11.66)	57.19 (10.94)	5.60 (6.97)	0.55 (0.28)
	8.13-49.36	41.28-77.33	0.13-28.98	0.20-1.15

Data shown as mean (SD) and range. Statistics presented are for HPF cluster criteria derived from systematic review of available literature. CSOD, carbohydrates and sodium; FS, fat and simple sugars; FSOD, fat and sodium; HPF, hyper-palatable foods.

TABLE 3 Descriptive statistics for HPF criteria applied to the Food and Nutrient Database for Dietary Studies (FNDDS)

Cluster	% kcal from fat	% kcal from carbohydrates	% kcal from simple sugars	% sodium by weight
FSOD	48.50 (14.58)	13.28 (14.12)	6.96 (9.10)	0.51 (0.27)
	25.01-100.00	0.00-100.00	0.00-66.61	0.30-4.97
FS	39.93 (11.34)	1.42 (4.36)	33.64 (11.63)	0.25 (0.17)
	20.00-77.08	0.00-25.09	20.07-78.05	0.001-1.60
CSOD	18.38 (11.53)	53.97 (11.97)	5.34 (4.58)	0.44 (0.26)
	0.00-50.15	40.05-100.00	0.00-21.89	0.20-2.73

Data shown as mean (SD) and range. HPF criteria derived from literature applied to FNDDS. Descriptive statistics for HPF clusters as identified in FNDDS are presented in the table. Information in this table can be compared with descriptive statistics from original HPF clusters derived from literature as presented in Table 2. CSOD, carbohydrates and sodium; FS, fat and simple sugars; FSOD, fat and sodium; HPF, hyper-palatable foods.

the FNDDS contained food items (e.g., chicken leg) prepared with multiple variations on similar ingredients (e.g., cooked with butter, margarine, or olive oil). Thus, we also calculated the percentage of foods that met HPF criteria when aggregating by item (e.g., chicken leg) using the FNDDS food and ingredient code specifiers to provide estimates across specific foods. A total of 478 items were available when aggregating across food items. Finally, we examined characteristics of the foods that met HPF criteria, including (1) FNDDS food group, (2) items labeled as low or reduced calorie, sugar, fat, or carbohydrates, and (3) items with varying energy density (28).

To examine preliminary evidence for discriminant validity of the HPF criteria, we determined whether items labeled as raw or fresh were classified as HPF in any cluster. To evaluate evidence of convergent validity of the HPF criteria with items descriptively labeled as HPF, we calculated the percentage of items that met HPF criteria that were labeled as (a) fast foods and/ or fried foods and (b) sweets and/or desserts.

Results

The HPF criteria identified 62% (4,795/7,757) of foods in the FNDDS that met criteria for at least one cluster. Most HPF items (70%; 3,351/4,795) met criteria for the FSOD cluster. Twenty-five percent of items (1,176/4,795) met criteria for the FS cluster, and 16% (747/4,795) met criteria for the CSOD cluster. The clusters were largely distinct from each other, and <10% of all HPF items met criteria for more than one cluster. Similar to the HPF items derived from the literature, the FSOD cluster consisted of primarily meats and meat-based dishes and other items high in protein and fat such as egg- and milk-based foods (e.g., omelets, cheese dips) (53%; 1,878/3,551). Additionally, 22% of items in the FSOD cluster (797/3,551) consisted of sweet and/or carbohydrate-based foods, such as pancakes, cookies, and buttered popcorn. Foods in the FS cluster were primarily dessert and grain-based sweet items, including cakes, pies, and sweet cereals (55%; 651/1,176). Thirty-nine percent of items (453/1,176) were sweet vegetables cooked in fats and related ingredients, such as sugar-glazed carrots cooked in butter. Among items in the CSOD cluster, the vast majority (71%; 529/747) consisted of dense meal-based items such as pizza and pastas, breads, cereals, and salty snack items such as pretzels and crackers. Items labeled as reduced or no fat, sugar, salt, or calories represented 5% of HPF items (216/4,795).

Table 3 presents the descriptive statistics of HPF cluster criteria as applied to the FNDDS data. Descriptive statistics from the cluster

criteria applied to the FNDDS were broadly consistent with the original HPF clusters derived from the literature (Tables 2 and 3). However, some ranges were greater in the FNDDS data set, particularly at upper thresholds, such as PSODI for FSOD and CSOD clusters (Tables 2 and 3). Figure 1 presents graphical depictions of items in the HPF clusters from FNDDS and the original items obtained from the literature.

Analyses across 478 food items that were aggregated by FNDDS food and ingredient codes revealed that the majority (81%; 386/478) of items were prepared or cooked in at least one way that caused the item to meet HPF criteria. However, among 43% of the aggregated food items (204/478), $\geq 70\%$ of the ways in which each item could be prepared or cooked did not meet HPF criteria. Thus, the findings suggest that method of preparation, as opposed to food item, determined whether a food met HPF criteria.

Food characteristics

Table 4 provides descriptive information of HPF items based on USDA-defined food groups. Thirty percent of HPF items (1,451/4,809) were grain products (e.g., pastas, cereals), and 32% were processed/cooked meats and meat-based dishes (1,559/4,809). Only 7% of HPF items were fruit-based products. Notably, >70% of meats, grains, and egg-based products available in the full FNDDS met criteria as HPF.

The energy density scores of HPF items were diverse and ranged from <1.0 kcal/g (e.g., vegetables cooked in fat and added sodium; sweetened breakfast yogurt) to 8.4 kcal/g (fatback from pork cooked with added sodium). Almost half of HPF items (49%; 2,337/4,809) had low energy density (<2 kcal/g) (50).

Of the 443 items labeled as reduced or no fat, sugar, salt, or calorie, 49% (216/443) met criteria for HPF (Supporting Information Table S2). The percentage of items differed across the ingredients targeted for reduction. Most notably, 80% of items labeled as reduced fat or calorie (102/127) met criteria for HPF. Of all 216 HPF items, almost half of items met criteria for the FSOD cluster (48%; 103/216), 22% met criteria for the FS cluster (47/216), 19% met criteria for the CSOD cluster (41/216), and 12% met criteria for multiple clusters (25/216).

Evidence of discriminant and convergent validity

Initial evidence supports the HPF criteria as appropriately distinguishing HPF from foods that are naturally occurring and minimally processed. The HPF criteria did not capture any fresh or raw fruits, meats, or fish. In addition, the HPF criteria appropriately did not

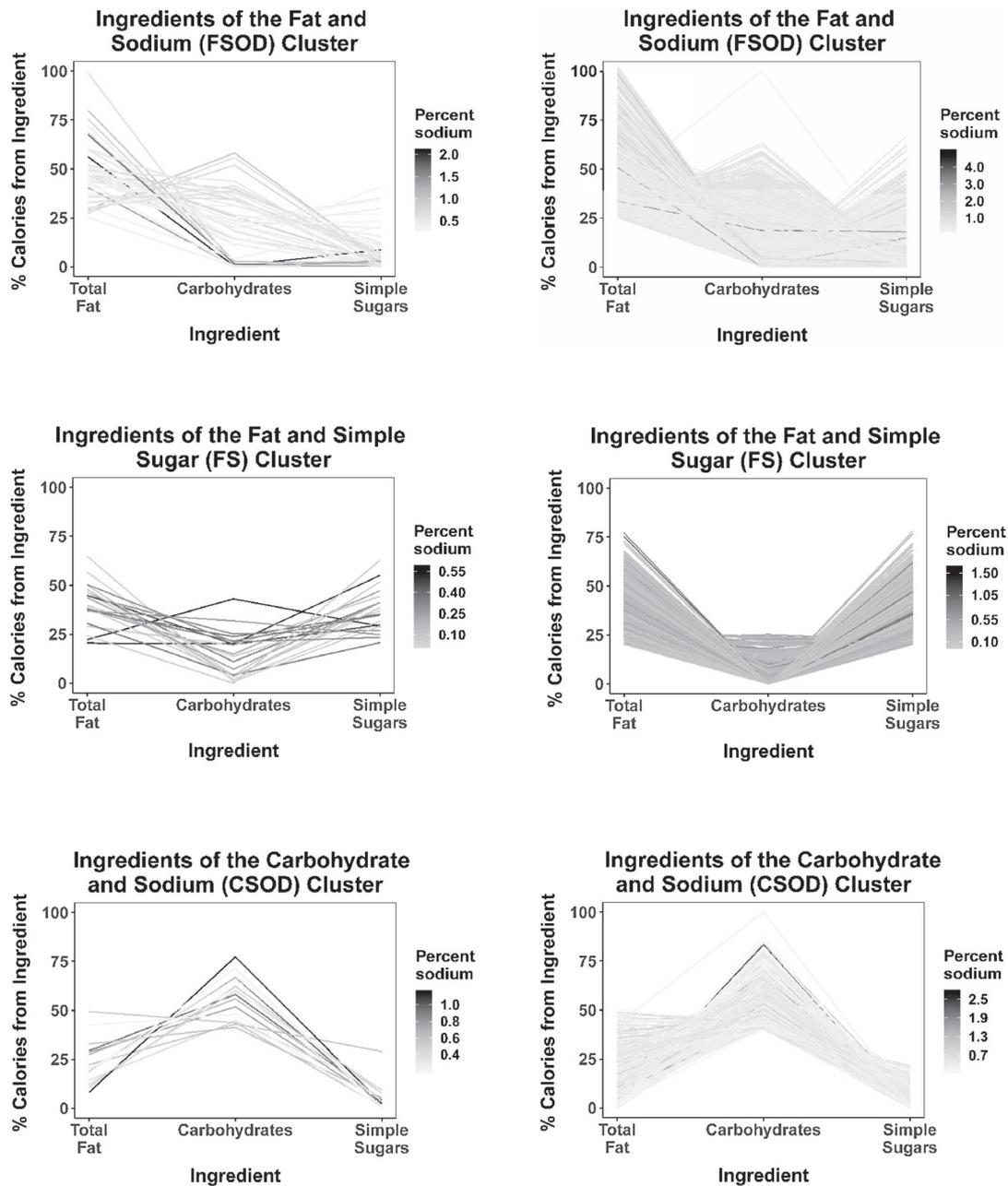


Figure 1 Key ingredients of hyper-palatable foods as derived from the literature and identified in the Food and Nutrient Database for Dietary Studies.

capture 97% of the 69 raw vegetables. Two items, chives and arugula, were captured via the FS cluster. Both vegetables had very low ratios of total kilocalories per serving (25-30 kcal) to kilocalories per ingredient, which resulted in PFAT and PSUGR ranges of 21.9% to 32.8%. Foods with one palatability ingredient that would not be

expected to circumvent SSS were not identified as HPF, including heavy cream (with no ingredients added) and unsalted nuts. Finally, the HPF criteria distinguished carbohydrate-dense items with higher fiber, such as oatmeal and most beans, from HPF that were high in carbohydrates and lower in fiber.

TABLE 4 Items by FNDDS food category identified as hyper-palatable

FNDDS food category	FNDDS (N=7757)	HPF items identified in FNDDS (n=4809)	% of FNDDS items identified as HPF
Milk/milk products	428	296	69%
Meats	2,065	1,559	75%
Eggs	224	191	85%
Beans, nuts	337	142	42%
Grains	2,038	1,451	71%
Fruits	314	23	7%
Vegetables	1,956	917	47%
Fats/oils/dressings	111	72	65%
Sugars and sweets	284	144	51%

FNDDS, Food and Nutrient Database for Dietary Studies; HPF, hyper-palatable foods.

TABLE 5 Evidence for convergent validity with fast foods and sweets

Food category/descriptor	FNDDS	HPF items identified in FNDDS	% of FNDDS items identified as HPF
Fast foods/fried foods	477	409	86%
Fast foods	151	139	92%
Fried foods	326	270	83%
Sweets and desserts	191	163	85%
Carbohydrate-dense sweets	84	74	88%
Chocolate bars and candy-related items	107	89	83%

FNDDS, Food and Nutrient Database for Dietary Studies; HPF, hyper-palatable foods.

Evidence for convergent validity was examined for fast foods or fried foods and sweets or desserts (8,9,11). Evidence for convergent validity with fast foods or fried foods was high; 86% of items in the FNDDS labeled as fast foods or fried foods were captured by the HPF criteria (Table 5). Of the items not captured, most had subthreshold sodium for the FSOD cluster (e.g., $n=11$ fried vegetables: $PSODI \leq 0.20\%$; $n=6$ hamburgers: $PSODI=0.278\%-0.299\%$). Evidence of convergent validity for sweets and desserts was similarly strong; the majority (88%) of carbohydrate-dense sweets and desserts (e.g., cakes, waffles with toppings) were captured by HPF criteria, as were most chocolate and related sweets (83%) (Table 5).

Discussion

The obesity and nutrition science fields have relied on descriptive definitions of HPF, which lack specificity as to the key mechanisms (ingredients) driving palatability. While it has been widely publicized that the food industry has well-established cut points for fat, sugar, sodium, and carbohydrates designed to maximize palatability and consumption (14,15), these quantitative definitions are virtually unknown to the scientific community. The current study used a data-driven approach to develop a numeric definition of HPF by extracting common HPF descriptive definitions from the literature and quantifying key ingredients of fat, simple sugars, carbohydrates, and sodium. Findings revealed that HPF fall into three distinct clusters based on similar levels

of ingredients: (1) FSOD (>25% kcal from fat and $\geq 0.30\%$ sodium by weight), (2) FS (>20% kcal from fat and >20% kcal from sugar), and (3) CSOD (>40% kcal from carbohydrates and $\geq 0.20\%$ sodium by weight). The findings are consistent with the theoretical and scientific literature indicating that two or more palatability-inducing ingredients at moderate to high levels may be sufficient to induce hyper-palatability (23,27). Our findings expand on the existing literature by highlighting the role of sodium in enhancing palatability, an ingredient that was key in two of our three clusters, as prior research has primarily focused on combinations of fat and sugar (21,22) or fat and carbohydrates (23). In addition, our findings lend further support to the existing literature that has identified fat and sugar as important ingredients that synergistically enhance food palatability (21,22,35).

Application of the data-derived HPF definition to the US food system database revealed that a substantial percentage of food items met criteria for HPF. Importantly, we evaluated prevalence of HPF in two ways, by identifying items within the entire data set (>7,800 items) and by aggregating across food types (e.g., chicken leg prepared with variations of butter, oil, etc.). Prevalence of HPF was similar across the two methods (~60%). However, findings also provided nuance in suggesting that the method of food preparation/processing, not the food item categorically, is key to determining hyper-palatability. In addition, our findings indicate that combinations of ingredients that yield hyper-palatability may be differentially prevalent in the US food system. For example, the majority of HPF items identified in the FNDDS met criteria for

the FSOD cluster, which represented >70% of meat and grain products available in the FNDDS. Thus, combinations of sodium and fat may be extremely common in the US food system. Considered alongside the additional foods captured in the FS and CSOD clusters, which spanned the full range of FNDDS food categories, the high prevalence of HPF in the US food system may present a frequent, if not constant, challenge to maintaining energy balance.

The HPF criteria demonstrated their flexibility in identifying a variety of food items as hyper-palatable. For example, while the majority of FSOD items were meats, the FSOD criteria also identified most carbohydrate-dense sweets such as cakes and breakfast foods (e.g., French toast). Similarly, the CSOD cluster identified many snack-based items such as pretzels and crackers that may not be considered HPF with a standard descriptive definition. In addition, the HPF criteria identified foods labeled as reduced or no fat, sugar, salt, or calories. Notably, 49% of these reduced-ingredient items met criteria for hyper-palatability, suggesting that foods marketed as tools for weight management, particularly those labeled as reduced fat or calorie, may have characteristics of enhanced palatability. Overall, a strength of the HPF definition appears to be its flexibility in identifying items not traditionally considered to be HPF using a standard description (but that have similar ingredients as foods typically considered to be hyper-palatable).

Evidence from the study also supports the discriminant and convergent validity of the HPF criteria. Overall, the HPF criteria accurately distinguished HPF from naturally occurring foods such as raw fruits and other items not expected to be hyper-palatable. Regarding convergent validity, HPF criteria identified the vast majority (83%-92%) of fast foods or fried foods and desserts or sweets, providing support for the convergent validity of HPF criteria in identifying savory and sweet foods via FSOD, FS, and CSOD clusters. Our criteria are broadly consistent with the small pool of existing literature on HPF characteristics. Mean values of key ingredients within each HPF cluster were similar to criteria used in other studies; however, the lower bounds of our cluster criteria were generally substantially lower than the criteria used in prior studies. For example, researchers have generally used >30% kcal from fat and simple sugars as criteria to examine palatability (22,35), and while the mean percent kilocalories from fat and sugar were within that range in the FS cluster, the lower bounds for FS criteria were substantially different (>20% fat and sugar). However, it is important to consider that the ingredients examined herein have a synergistic impact on palatability and would likely not produce the same effects alone. Furthermore, some foods commonly referenced in descriptive HPF definitions, such as cakes and sweet bread-based items (11,33,34,36), are at the low end of the FS criteria (e.g., soft pretzels coated in cinnamon sugar; cornbread muffins), suggesting that the criteria presented herein may be an appropriate lower bound for the FS cluster. Overall, the data-informed HPF criteria appear to have initial evidence supporting their validity, although further work is needed.

The HPF definition and cluster criteria presented in this study are a starting point to facilitate further research. The criteria should be adapted, refined, and tested for their predictive utility with a variety of constructs related to obesity, including overeating (passive and loss-of-control/binge), weight gain, obesity risk, and obesity-related diseases such as type 2 diabetes. In this regard, while the study used a data-driven approach to identify HPF criteria, the cut points presented are inherently dependent on the nutrient estimates provided by the ASA24 program and should not be assumed to be fixed or final. We provided descriptive statistics of HPF clusters, including their full ranges, to facilitate researchers in using and testing adaptations of the criteria.

HPF criteria will likely need refinement to reach an optimal definition that is well supported by a variety of evidence in the literature, and researchers in the obesity and nutrition science fields are needed to support and contribute to this process.

The study had several limitations. First, the HPF definition was developed for solid foods and should not be generalized to liquids, which have different levels of optimal palatability (18). Future work should evaluate hyper-palatability criteria for liquid beverages (e.g., sugar-sweetened beverages), as they can contribute substantial kilocalories to a standard diet (51). Second, HPF criteria were identified using data visualization procedures; we were unable to use advanced statistical analyses with the numeric nutrition data because of limited (nonduplicate) HPF items obtained from the literature ($n=75$). However, we developed the definition using the most parsimonious criteria that encompassed almost all HPF items (93%). In addition, our data-driven approach relied on prior literature, which examined a range of foods associated with palatability to create an index for hyper-palatability. Most studies referenced the importance of combinations of ingredients in determining palatability in their descriptive definitions; however future work is needed to examine to what degree the HPF criteria are truly sensitive to foods that have synergistic enhancement in palatability. Finally, we evaluated convergent validity of the quantitative HPF criteria with commonly used descriptive definitions of HPF (e.g., fast foods). While there are limitations to comparing the quantitative criteria to existing descriptive definitions, these definitions have established predictive validity for weight gain and obesity outcomes (8), and thus they were a reasonable test for this initial purpose.

Strengths of the study included use of a data-driven approach to develop the HPF definition and the application of the definition to the FNDDS that is representative of the US food system. The study also evaluated evidence for discriminative and construct validity of the criteria, as well as established that HPF criteria are distinct from existing dietary-related indices such as energy density. Another strength of the study is the demonstrated flexibility of the HPF definition in identifying a variety of foods that may be hyper-palatable. Because of this, the HPF criteria have the potential to elucidate palatability-based mechanisms that may underlie associations in the broader literature between a variety of dietary indices and obesity-related outcomes, including energy-dense and ultraprocessed foods. For example, a recent study established a causal relationship between ultraprocessed food consumption and weight gain; however, the authors noted that their study did not identify the mechanism within ultraprocessed foods driving their outcomes (52). The HPF definition may shed light onto such an underlying mechanism and should be investigated in the future.

Conclusion

The study is the first to provide a quantitative definition of HPF to be used as a starting point for future research. Given the immense contributions of HPF to obesity risk and related health conditions (53), it is imperative that the research community develop and validate a specific, quantitative definition of HPF that will advance the field's understanding of potential mechanisms that may drive overeating and obesity. The HPF definition may also be an asset to inform future food policy work. A major barrier to policy legislation on HPF is that there is no precise definition to inform regulation, and it is not feasible to limit or restrict entire categories of foods (e.g., desserts). Given the ways in which HPF are integrated into our existing food system, strong and

specific scientific evidence will be needed to dislodge and eventually regulate some of the most problematic foods that are associated with extensive disease and disability in the US. The HPF definition and quantitative criteria presented in this study represent a crucial first step in this process. **O**

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