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High Quality Carbohydrates: A Concept in Search of a Definition

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Abstract:	The terms “high- and low-quality carbohydrate” are often ascribed to individual foods as a means of describing the healthfulness of the food in question, without any empirical definition of what constitutes high- or low-quality. This article summarizes the views of experts on the concept of carbohydrate quality, and the numerous factors that should be considered when assessing the quality of a carbohydrate-containing food or meal.
Response to Reviewers:	Reviewer #2: Under State of the Science Line 4 at top of page - There should be a reference the statement after "Asian compared to Western populations". --Reference added Under Historical Definitions for Characterizing Carbohydrates Lines 26 and 27 are too strong. A large part of fiber is fermented and resulting FFA absorbed. They do provide calories. --Removed the term “overly simplistic”. Made sentence sound less strident. Lines 28 - 32 - You should indicate that soluble fiber may be fermented (depending on type). --Added this point. Under Importance of the glycemic index in assessing carbohydrate quality The four papers by laboratory of Lichtenstein et al on glycemic index indicate that GI can move from general "low" to "moderate" or "moderate" to "high" within the same individual between replicates. Additionally, other items in the foods modify the response somewhat as does effect of prior meal. It is correct that GI shouldn't stand alone. I would suggest that GI be a very minor contribution to the quality issue. I am wondering if you would like to modify your discussion in lines 33-43 to reflect this.

--The points about prior meal affecting GI, as well as the individual variability among subjects was made in the original submission. A sentence was added at the end of the paragraph to more fully make the point that GI is one marker of carbohydrate quality, but on its own is a limited marker

Reviewer #3: The paper presents a summary of a panel of experts convened to discuss the definition of carbohydrate quality, how to measure it, and where we have research gaps.

My assessment pertains to revision 2. I see that several reviewers' comments have been previously submitted and addressed.

In the current version, I would suggest the following:
Page 1, line 11. I am not sure that experts have questioned the overall need for carbohydrates -- our brains would not function without sugars. Perhaps you mean they have questioned the overall role of carbohydrates in the diet? Also, is the rise in obesity associated with overall carbohydrate intake, or only from certain types of carbohydrates (e.g., sugars) or certain food categories (e.g., sugar-sweetened beverages, for example)? Please be precise.
--Section was tweaked to make these points.

Page 1, line 25. I think providing would be a better word than approximating.
--Changed “approximating” to “providing”.
Line 26. Neither ref 9 or 10 mentioned disappearance data, so this word should be removed. These references do not seem to be correct for this sentence, as ref 9 is about obesity rates in different segments of the population and ref 10 is a clinical trial showing that fat oxidation is increased when consuming fewer carbs. Please insert the correct references.
--Reference corrected.

Page 2, line 46. Reference 10 seems to be the wrong reference here, too.
--Reference corrected.
Page 2, line 50. Your point seems to be about avoiding excess calories with fewer nutrients, but you list grain-based snacks. One could argue that chips may provide excess calories with few nutrients, but not whole wheat crackers. Consider to revise.
--Reference to grain-based snacks removed.

Page 4, line 32. I think you mean that sugar-sweetened beverages or snack cakes offer fewer nutrients and lower fiber.
--I left this sentence as-is. Recommendation was to change verbiage to “fewer nutrients and lower fiber.” But fiber is a nutrient. So I felt that saying “fewer nutrients” implied the inclusion of fiber in the statement. I can easily add “lower fiber” to the end of the sentence. Please let me know if you’d like me to add it.

Page 5, line 4. Please change the title. Glycemic index has little importance, so the title is misleading. Something like 'Glycemic Index and Other Factors for Assessing Carbohydrate Quality' would be better.
--Section titled changed as recommended.
Page 5, line 33. Since your second sentence focuses on glycemic load (not GI), I suggest that you replace GI in that first sentence with glycemic response.
--GI replaced by glycemic response as suggested.

Call out: This sounds much too positive for GI and does not agree with your text. I suggest to say something like 'Glycemic Index is a popular determinant of carbohydrate quality, but it is a poor marker of heath outcomes. There are numerous other criteria that may be of importance in determining carbohydrate quality.'
--Call out changed as recommended.

Page 6, lines 20-22: This conclusion could be broadened to include Others call for reducing simple sugars. This type of reductionist thinking should be avoided.
--Changed as suggested.

An acknowledgement of the panel participants is warranted. I am curious why they are

	not included as co-authors. --The initial intent was to include all panelists as co-authors. However, 3 of 4 panelists did not provide any input to the manuscript after multiple requests, and one provided minimal input. Having had no direct input on development of the manuscript, it didn't seem right to include these individuals as authors. All of the panelists were acknowledged. In the initial draft of the manuscript they were more prominently called out, and their backgrounds cited. In the final draft, it was requested that they be listed in the footnotes. Table 2: possible research questions for the historical role of carbohydrate-containing foods could also include rice. --Changed as suggested.

Mitch Kanter, PhD serves as a technical consultant to FoodMinds, and as the Chief Science Officer for the Alliance for Potato Research and Education.

TITLE:

High Quality Carbohydrates: A Concept in Search of a Definition

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Abstract:

The terms “high- and low-quality carbohydrate” are often ascribed to individual foods as a means of describing the healthfulness of the food in question, without any empirical definition of what constitutes high- or low-quality. This article summarizes the views of experts on the concept of carbohydrate quality, and the numerous factors that should be considered when assessing the quality of a carbohydrate-containing food or meal.

High Quality Carbohydrates: A Concept in Search of a Definition

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The implications of macronutrient intake on health and disease are controversial. In the late 1950s Dr. Ancel Keys and others seemingly declared dietary fat "the enemy of the people" (1), and fat consumption as a percentage of calories declined somewhat during the ensuing decades. More recently, fat's role in promoting obesity and chronic disease has been re-evaluated and advice to decrease total and saturated fat intake has been vigorously debated (2,3). At the same time, some experts have questioned the overall volume of carbohydrate necessary in the diet based largely on observational data indicating a concomitant rise in carbohydrate intake (particularly low nutrient dense carbohydrate sources) and overweight/obesity, as well as an increased prevalence in metabolic syndrome and Type II diabetes (3). Nevertheless, suggestions that the primary macronutrient concern should be the amount of carbohydrate one consumes are equivocal (4). Those who support this perspective often do not consider data indicating calories from nearly all food groups with the exception of fruits and vegetables have increased in the recent past. Average energy intake in the United States is 700 calories per day higher than in 1950 (5), while energy expenditure has decreased (6).

These issues are prompting nutrition experts to re-think the most desirable mix and volume of macronutrients for human health. While most experts agree that a diet comprised of 70% or more calories as carbohydrate is too high (this was the upper limit of recommendations often made in the 1980s and '90s), an "optimal" ratio of carb/fat/protein for health remains elusive. Carbohydrate intakes of 300 g/d, or about 40-60% of calories, are associated with the lowest BMIs in adults (7), and lower mortality has been associated with carbohydrate intakes providing 50-55% of calories (8). At the same time, disappearance data from the U.S. Department of Agriculture suggest an overall increase in caloric intake, and not the macronutrient mix, may have precipitated the rising obesity epidemic in the United States (9,10).

Although much has been written in recent years about the benefits of low carbohydrate, high protein and fat diets, most health experts continue to promote a more balanced approach with carbohydrates the predominant source of macronutrients. There seems to be no clear answer to this diet/health/disease conundrum, particularly as it relates to carbohydrate intake (11).

When assessing carbohydrate needs, various factors must be considered (12). Carbohydrates are not homogeneous entities, and carbohydrate-containing foods differ greatly in nutritional quality. The amount and type of sugar, starch, and fiber in a carbohydrate-containing food can greatly affect its physiological impact (13,14). Lifestyle differences among people, as well as their state of health can also affect the way that carbohydrates are assimilated and metabolized (15).

With respect to carbohydrate quality, some nutritionists suggest that the glycemic index, a highly labile measurement that can fluctuate based on various nutritional, lifestyle, and physiological factors, is a key metric of quality. Others have argued that nutrient density, or the chemical structure of carbohydrate foods are more indicative of quality. This issue remains hotly debated. Does whole grain connote high-quality? Quantity of fiber? Degree of processing? What role should the glycemic response play in determining carbohydrate quality? Are there other metrics that need to be considered?

Call out: In determining carbohydrate quality, the context in which a food is consumed, its chemical composition, and its physiological impact are all important

To address these and related questions, The Alliance for Potato Research and Education (APRE) convened a panel of carbohydrate researchers, educators, clinicians, and food chemists[1] to discuss the impact of carbohydrates in health and disease, as well as to attempt to achieve consensus on what constitutes a high-quality carbohydrate source. Overall, the experts identified at least twenty nutritional

[1] Panelists were: Julie Miller-Jones, PhD, CNS, LN, CFS, FICC, Professor Emeritus, St. Catherine's Univ, St Paul MN; G. Harvey Anderson, PhD, Professor of Nutrition Science & Physiology, Univ of Toronto; John Sievenpiper, MD, PhD, FRCPC, St Michael's Hospital, Toronto; Bruce Hamaker, PhD, Distinguished Professor of Food Science, Director, Whistler Center form Carbohydrate Research, Purdue Univ.

and chemical factors they believed could impact carbohydrate quality, which they bucketed into three general categories: the context in which a food or meal is consumed; the chemical composition of the carbohydrate-containing food; and the physiological impacts of consuming a particular carbohydrate-containing food. All agreed that carbohydrate quality is a multifactorial issue, and that no one or two metrics accurately define the quality of a carbohydrate-containing food. There was overall agreement that several research gaps need to be filled if we are to develop a metric, equation or any tool or process for accurately assessing the overall quality of carbohydrate-containing foods.

State of the Science: Current Thoughts on Dietary Carbohydrates in Health and Disease

The importance of dietary carbohydrate as a key provider of energy for the body and the major source of energy for the brain is unequivocal (16). Clinicians and researchers often talk about the "protein sparing" effect of carbohydrate as well, and how inadequate carbohydrate intake results in the body metabolizing protein as a glucose source, with a concomitant rise in circulating ketones. Neither of these situations are metabolically optimal. In a fed state, the human body tends to hold protein degradation to a minimum and ketone production remains low. So, from an energetics perspective, adequate carbohydrate intake is important to maintain metabolic homeostasis.

Our understanding of the impact of various carbohydrates on the gut microbiome has increased greatly in recent years. In this regard, dietary carbohydrates must be viewed as a heterogeneous class of compounds, with very different chemical structures and biological functions. Different carbohydrates empty from the stomach and reach the intestine at differing rates, promoting diverse effects not only on the rate of appearance of glucose in the bloodstream and on appetite, but also on the gut microflora as undigested carbohydrates make their way through the intestinal tract (17). The amount of fiber, resistant starch, and degree of branching of starch molecules, as well as methods of food processing/preparation all affect gut bacterial production, which can ultimately impact health and disease indices in several ways. Regarding "optimal" macronutrient intake, there is general agreement that one's state of health, lifestyle, genetics, and other factors all impact carbohydrate/fat/protein needs, making a one-size-fits-all statement about carbohydrate intake difficult, if not impossible (18). That said, recent observational data suggest very low (<30% of kcals) carbohydrate intake is associated with increased mortality, and that subjects who consume 50-55% of kcals as carbohydrate lived four years longer on average than those who ate fewer carbohydrates (8).

From a body weight perspective, some data indicate that low carbohydrate diets can lead to greater weight loss than higher carbohydrate diets after six months. However, most studies show these differences disappear after a year of a lower carb diet (19-21). Further, as mentioned previously, data indicate that over a 50-year period commencing in 1970 Americans consumed on average about 700 more kcals per day in recent years than they did in previous decades, strongly suggesting that total food intake from all sources, and not any one macronutrient, has driven our obesity epidemic. Thirty-year (1980-2010) data on carbohydrate intake and obesity tend to bear this out. Over this time span, carbohydrate intake began to decline in 2000 and continued to drop until 2010, but total calories did not, and rate of obesity continued to rise more-or-less unabated (10).

Most data suggest there is no ideal percentage of macronutrients for people with Type II diabetes (22). Rather, it is generally recommended that people with diabetes focus on healthy eating patterns that include adequate dietary fiber, such as the Mediterranean or DASH diets, instead of focusing on specific macronutrients (23). Avoiding foods with excess calories and fewer nutrients (e.g., snacks/desserts, and sugar-sweetened beverages), and encouraging fiber, vegetables, fish, and low-fat dairy are seen as the best way to minimize risk or to control diabetes. And while data exist suggesting an association between high glycemic load diets, increased risk of Type II diabetes, and elevated fasting blood glucose levels (24), moderate carbohydrate intake (~100-200 grams digestible carbohydrate/day) appears to have a small positive or mixed effect, which may be confounded by whole grain or dietary fiber intake (25-27). Data exist suggesting that high intakes of carbohydrate-containing foods such as bread or rice are associated with increased risk of diabetes. This has led to the assumption that foods like white rice raise diabetes risk for everyone (28). However, risk appears greater only in those who are overweight, especially when

intakes of total carbohydrate or white rice is quite high, as occurs more in Asian compared to Western populations (28). Recent data from Iran indicates no association between boiled or fried potato intake and diabetes risk when data were adjusted for various lifestyle and dietary factors (29).

Historical Definitions for Characterizing Carbohydrates

As a prelude to a discussion on carbohydrate quality, it is instructive to consider terms that have historically been used to classify carbohydrates either by chemical structure, biological impact, or some other way. These terms include: simple vs. complex; processed vs. unprocessed; starch vs. sugar; digestible vs. non-digestible; refined vs. unrefined; and fiber vs. non-fiber.

Generally speaking, most terms of classification are lacking in one way or another. Some are too difficult for consumers and, in many cases, clinicians to understand or care about; others (i.e., complex vs. simple) connote benefits or deficiencies of carbohydrate sources that may not exist. Terminology which might resonate with a food chemist may have limited utility to a nutritionist or biological scientist, and vice versa. One clinician who participated on the panel indicated that when his patients sought diet advice, they discussed carbohydrates as a general entity – "I need to cut carbs from my diet." The notion that there are distinctions between carbohydrate sources did not resonate with many of his patients.

The lack of understanding regarding the physiological relevance of fiber, even among health professionals, exists as well. Most consumers think they ingest sufficient dietary fiber and have little awareness of how far below daily recommendations they may be. Further, both consumers and health professionals are often confused about what foods contain fiber (30).

For the most part, fibers are undigestible or incompletely digested carbohydrates; compounds that provide few if any calories and that largely pass through the digestive tract. Nevertheless, there are differences among fibers that confer varying physiological benefits. Soluble, viscous fibers (those found in oats and barley, and to a lesser extent legumes and potatoes) have been shown to lower serum cholesterol and possibly blunt the glycemic response. Some soluble fibers may be fermentable as well. Insoluble fibers (found mainly in wheat-derived products and various leafy vegetables) add bulk to the diet and contribute in varying degrees to fermentation.

Fermentable fibers (fibers that undergo fermentation in the large intestine) tend to have the greatest impact on the gut microbiome; non-fermentable fibers have less impact. But this issue is complicated because the gut microbiome can change from day-to-day based on diet and other factors. So, based on current science, conferring health benefits on a food that contains fermentable carbohydrate may be a bit premature. Further, processing can change the characteristics of starch and fibers as well, making them less digestible and more fermentable (e.g., heating and cooling can convert starch in the potato to resistant starch, a compound that acts like dietary fiber and is fermentable in the large intestine). Longer term studies are needed to more fully understand the effects of fermentable fibers on health and disease.

Many experts agree that sugar can have a place in the diet as a means of increasing palatability and providing energy, among other things. When considering sugar consumption, the issue of need state should be addressed; for example, athletes or people burning a significant number of calories through physical work can certainly consume sugar healthfully.

Finally, most nutrition experts have begun to advocate for a food-based approach that is not often considered in discussions of carbohydrate type and quality. When discussing healthy carbohydrate-containing foods, it is important we not think in reductionist terms; that we understand the context in which a food is eaten. For example, what foods are accompaniments in a carbohydrate-containing meal?; what does an individual's habitual diet look like?; what is the health of the individual consuming the food?; what is their need state (i.e., level of physical activity; BMI; age; are they pregnant?; malnourished?; etc.); what is their socioeconomic status?

All these issues should be considered when characterizing carbohydrate-containing foods, and ultimately factored into any definition of what constitutes a high-quality carbohydrate source.

Toward Establishing a New Criterion for Carbohydrates: How Should We Define the Quality of Carbohydrate-Containing Foods?

Despite the consensus that a definition of carbohydrate quality should consider numerous lifestyle factors as well as diet patterns rather than looking at individual foods as inherently good or bad, most panelists agreed that more clearly defining carbohydrate quality could be helpful in defining overall diet quality.

Identifying relevant metrics which may be used to rate carbohydrate quality, and that potentially can generate a score or equation to objectively grade the quality of carbohydrate-containing foods seems a worthwhile endeavor. Various nutritional attributes could affect carbohydrate quality, including fiber/resistant starch content of a food, sugar content, and rate of starch digestibility, as can food processing and preparation factors. Food chemists have identified ways of manipulating the starch composition of many carbohydrate-containing foods so that the rate of starch digestibility could be altered, which may impact the quality of a carbohydrate source. Cooking or hydrating a carbohydrate-containing food during preparation, or adding various toppings, oils, or proteins during or after preparation could also impact glycemic response, as can food form. Whether a carbohydrate-containing food is boiled, mashed, steamed, grilled, or fried may not only impact its nutritional content, but also how readily the body digests it, both of which can impact overall quality.

Also important is the physiological functionality of a food – its impact on satiety, blood glucose and serum lipid levels, insulin response, and blood pressure – and various other biomarkers that can serve as indicators of the quality of a carbohydrate-containing food. In this regard, one needs to tease out acute versus chronic biological effects. For example, a food that fed alone might transiently raise serum triglycerides following a meal might have no such impact or adverse health effects over time when consumed as a part of the chronic diet.

Nutrient density, a measure of the overall nutrition in a food and, thus, its implied health benefit tends to resonate more with nutritionists than food chemists, but it is an important factor when considering the quality of a carbohydrate food. Nutrient density is the metric that separates foods like rice, potatoes, and pulses, which contain vitamins, minerals, fibers, and proteins, from sugar-sweetened beverages or snack cakes, which offer fewer nutrients. To the food chemist, however, any discussion about carbohydrate quality tends to focus on the carbohydrate source(s) themselves, and not on other nutrients in the food, with the possible exception of protein, which as part of the food matrix could impact digestibility of the carbohydrates. To most chemists, carbohydrate quality is largely based on rate of digestion of the carbohydrate itself regardless of the overall nutritional value of the food.

In summary defining carbohydrate quality requires an acknowledgement of numerous nutritional, physiological, and chemical attributes, as well as certain socioeconomic considerations. In no particular order, diverse factors including food matrix, food/meal preparation, and physiological responses associated with food consumption, as well as cost and availability issues can all impact the quality of a carbohydrate containing food (Table 1).

When asked to rate the various metrics from most-to-least important, panelists had a difficult time reaching consensus. All agreed that winnowing down the list would be a necessary step in developing an algorithm or equation for assessing carbohydrate quality of a food or meal, and they proceeded to group the various criteria based on a) the context in which a food or meal is consumed (meal and dietary patterns; lifestyle/demographics); b) food composition/chemistry (food matrix; macro/micronutrient content; other factors that impact rate of carbohydrate absorption); and c) physiological endpoints associated with food consumption (postprandial glycemia and lipemia, satiety, etc.) (Table 1).

While developing an objective tool for measuring the quality of carbohydrate-containing foods is worth considering, a scale taking all criteria into account in weighted fashion would require much thought and effort. Clearly, carbohydrate quality is multifactorial. No one or two metrics define quality, and the context in which carbohydrate-containing foods are consumed can greatly affect the impact of a food on health and disease.

Glycemic Index as a Factor in Assessing Carbohydrate Quality

The glycemic index (GI) is often given an oversized role as a marker of carbohydrate quality. Generally speaking, carbohydrate-containing foods that generate a higher GI are deemed to be lower quality than foods that promote a lower GI. GI is certainly one determinant of the quality of a carbohydrate-containing food; however, numerous other criteria may be of equal or greater importance. Limitations of the GI outside of the laboratory setting have been discussed (31-33). In a free-living environment, where people generally eat varying amounts and types of foods at each meal, the GI of an individual food is difficult to replicate even in the same person following the same protocol (31). Slight variations in cooking/preparation methods can greatly impact the GI as well. Studies (32) have demonstrated that when oatmeal is over- or underhydrated, or heated for different amounts of time, the GI can be greatly altered, changing a food that under some conditions would be considered a low GI food into a high GI food, and vice versa. Heating and cooling foods like potatoes can alter the starch composition of the carbohydrate matrix, which can greatly impact GI as well (33), as can level of ripeness of a food item (e.g., a banana). Changes in physiological state – exercising prior to eating, the degree of stress one feels on a particular day, what one's prior meal consisted of, amount of sleep on the previous night – can also impact an individual's glycemic response to a food.

Limitations of GI in a laboratory setting exist as well. The GI is defined as one's glycemic response to a 50 g bolus of available carbohydrate in a food as compared to a 50 g standard (generally white bread). It might require three-and-a-half servings of whole wheat bread to consume 50 g of available carbohydrate, while one candy bar might easily deliver 50 g. Consequently, the GI of some foods (particularly those that deliver both digestible and undigestible carbohydrates) may be based on unrealistically high volumes necessary to attain a 50 g load.

The insulin response to a food or meal could have significant health implications as well, though many researchers who measure GI often neglect to measure insulin levels. Measuring glycemic response but not the insulin response only tells a partial story regarding the physiological implications of that food or meal.

This is not to suggest that glycemic response does not have utility as a marker of carbohydrate quality. In people with diabetes, or those with a particular metabolic phenotype, overall glycemic load of the diet can impact health and disease indices, though the effect is lower in individuals with normal glucose tolerance. Some experts suggest that GI ranges (low GI, moderate GI, high GI) would be preferable to scores. Focusing on a number (e.g., a GI of 92, or 45, etc.) may not be accurate, though specific GI values are often used as a cudgel to describe foods as "healthy" or "unhealthy." A recent review published in the Lancet regarding carbohydrate quality and human health corroborates this perspective (34). In studies using GI as a primary marker of carbohydrate quality, the certainty of evidence for a relationship between carbohydrate quality and various health/disease outcomes was graded "low to very low." This tends to bolster the idea that, as a stand-alone indicator, GI is not a valid marker of carbohydrate quality. It is clear from the literature that the GI can serve as one marker of carbohydrate quality, but as a stand-alone marker it is of limited utility.

Call out: Glycemic Index is a popular determinant of carbohydrate quality, but it is a poor marker of health outcomes. There are numerous other criteria of equal or greater importance in determining carbohydrate quality

Gaps in the Literature Regarding Carbohydrate Quality

Gaps exist in the current literature regarding the impact of carbohydrate quality on health and disease (Table 2). Potential study designs discussed by panelists included observational trials to assess traditional high carbohydrate diets around the world and their impact on health/disease endpoints; modelling exercises to look at addition or deletion of carbohydrate-containing foods on overall diet quality; experimental trials that assess long-term impact of high- or low-quality carbohydrate diets on health and disease; the impact of food processing and preparation on the quality of carbohydrate-containing foods;

and the socioeconomic implications of diets based on quality of carbohydrate-containing foods, among other issues.

Summary

A primary goal of the panel was to discuss the possibility of creating an algorithm or equation that could effectively assess quality of a carbohydrate-containing food. While no consensus was reached on the best way to achieve this goal, meeting participants agreed that such an effort was attainable. Convening a panel of experts, possibly under the auspices of a respected health/nutrition organization, would be a step toward generating such a tool. All participants agreed that carbohydrate quality is a multifactorial issue, and no one or two metrics accurately define the quality of a carbohydrate-containing food. Factors including meal/diet context, food chemistry and composition, and various physiological endpoints were identified as key components to rating overall carbohydrate quality.

From a practitioner perspective, it is important to avoid succumbing to reductionism when providing dietary advice or designing diet plans. While a greater understanding of the factors that may affect the overall quality of an individual food or an entire macronutrient class is important, it is ultimately more beneficial to view foods in the context of whole diet and lifestyle patterns, and refrain from thinking about individual foods as good or bad. Recent recommendations by some public health advocates, among others, to avoid starch-containing foods without considering the heterogeneity of starches as a class of compounds, the total nutrient package of a starch-containing food, or the context in which the food is eaten tends to breed this type of reductionist thinking that should be avoided.

Additional observational, pre-clinical, and clinical studies would advance our understanding of the quality of carbohydrate-containing foods. As is the case with many issues in the nutritional sciences, the concept of carbohydrate quality is far from settled, and the need for a more empirical definition of what constitutes a low- versus high-quality carbohydrate-containing food is warranted. As nutritional scientists endeavor to identify the “optimal” macronutrient blend, it is wise to refrain from removing or severely restricting entire food groups or categories. Further research on the factors that can be used to assess carbohydrate quality would be helpful in that regard.

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Table 1
Factors influencing the quality of carbohydrate containing foods

Context of Food/Meal Consumption	Food composition/chemistry	Physiological endpoints
Meal and dietary patterns	Food matrix/macronutrient content of food/meal	Post prandial glycemia and lipemia
Lifestyle; level of physical activity/stress/sleep; etc.	Fiber content/type (fermentable/non-fermentable; soluble/insoluble; etc.	Satiety
Age/state of health/other demographic considerations	Protein content/type	Relative glycemic response
Food form	Starch type/properties; amylose/amylopectin content	Glycemic index
Food preparation method (degree of heating/cooling; hydration status; etc.)	Resistant starch content (natural or generated via prep method)	Inflammatory markers
Cost/availability	Sugar content	Impact on gut microbiome
	Other micronutrients/ phytonutrients/nutrients of concern	Chronic impact on lipemia/glycemia/body weight/other biological markers
	Other factors that impact rate of carbohydrate absorption	Other biomarkers affected by food/diet intake

Table 2
Assessing Carbohydrate Quality: Research Gaps

Potential Study Type/Design	Possible Research Questions/Areas To Address
Observational trials assessing global impact of traditional high carbohydrate foods/diets and their impact on health/disease endpoints.	Historical role of carbohydrate-containing foods like potatoes and rice in different cultures; how they fit in the context of a native diet; impact on health & disease.
Diet modelling to assess impact of adding or deleting carbohydrate-containing foods on overall diet quality.	Are there unintended consequences associated with removal of nutritious high- or low-quality carbohydrate sources from the diet?
Pre-clinical and clinical trials on long-term impact of high- or low-quality carbohydrate foods/diets on indices of health and disease.	Effects of chronic consumption of high-quality carbohydrate foods on metrics including body weight, serum lipids, metabolic markers, and inflammatory markers
Impact of food processing and preparation on the quality of carbohydrate-containing foods	Impact of frying potatoes in healthy oils on short- and long-term indices of health & disease Effects of cooking/processing on starch composition, and its impact on carbohydrate quality
Socioeconomic implications of consuming foods/diets based on quality of carbohydrate-containing foods?	Health/nutrition implications of foods/diets fed to citizens in developing country vs. developed countries; in food desert areas in the US