Symposium proceedings

# Sugars and sweeteners: science, innovations, and consumer guidance for Asia

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**Background and Objectives:** Rising obesity in Southeast Asia, one consequence of economic growth, has been linked to a rising consumption of energy from added sugars. This symposium, organized by ILSI Southeast Asia, explored regional issues related to dietary sugars and health and identified ways in which these issues could be addressed by regional regulatory agencies, food producers, and the consumer. **Methods and Study Design:** Papers on the following topics were presented: 1) current scientific evidence on the effects of sugars and non-caloric sweeteners on body weight, health, and eating behaviors; 2) innovations by food producers to reduce sugar consumption in the region; 3) regional dietary surveillance of sugar consumption and suggestions for consumer guidance. A panel discussion explored effective approaches to promote healthy eating in the region. **Results:** Excessive consumption of energy in the form of added sugars can have adverse consequences on diet quality, lipid profiles, and health. There is a need for better surveillance of total and added sugars intakes in selected Southeast Asian countries. Among feasible alternatives to corn sweeteners (high fructose corn syrup) and cane sugar are indigenous sweeteners with low glycemic index (e.g., coconut sap sugar). Their health benefits should be examined and regional sugar consumption tracked in detail. Product reformulation to develop palatable lower calorie alternatives that are accepted by consumers continues to be a challenge for industry and regulatory agencies. **Conclusions:** Public-private collaborations to develop healthy products and effective communication strategies can facilitate consumer acceptance and adoption of healthier foods.

**Key Words: added sugar, Southeast Asia, indigenous sweeteners, consumers, healthy food choices**

## INTRODUCTION

The advent of the nutrition transition in South East Asia with the attendant shifts in food purchases and dietary patterns has had major consequences for regional food and nutrition policies and for population health. Increased economic development and urbanization has meant that the traditional Southeast (SE) Asian diets built around a staple grain crop, rice, have given way to more varied diets containing more animal proteins, vegetables and fruit, but also more processed and packaged foods containing substantial amounts of added sugar.[1]

It is the rapidly rising consumption of foods and beverages containing added sugars that is seen as a major factor contributing to rising obesity rates.[2] Added sugars refer to sugars and syrups added to foods and beverages when they are processed or prepared, as opposed to sugars that naturally occur in fruit, vegetables or milk.[3] Dietary patterns containing excessive amounts of added sugars tend to be energy rich but nutrient poor. Such dietary patterns, increasingly associated with lower income groups, have been causally linked to a variety of non-communicable diseases (NCDs), including obesity, diabetes, and the metabolic syndrome. International agencies including the World Health Organization (WHO) have

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Manuscript received 11 June 2018. Initial review completed 18 March 2019. Revision accepted 16 May 2019.
doi: 10.6133/apjcn.201909_28(3).0025

issued calls to limit the consumption of foods and beverages containing added sugars in an effort to improve global public health.

There are only limited observational data on the current consumption of total and added sugars in SE Asia. The ILSI Southeast Asia Region organized the present symposium to address the state of knowledge on added sugar consumption in the region and to propose ways by which both producers and consumers can address these issues. Identifying research needs and effective approaches to promote healthy eating in SE Asia was an important theme. Public-private partnerships were singled out as a potential approach and the risks and benefits were discussed. The symposium objectives were to 1) discuss current evidence on the effects of sugar and non-sugar sweeteners on eating behaviors, body weight, and health outcomes; 2) survey SE Asian countries for levels and sources of sugar intake; 3) explore the use of indigenous sweeteners; and 4) propose consumer guidance for consumption of sugar and non-sugar sweeteners. A panel discussion explored effective approaches to promote healthy eating in the region. The symposium presentations reported information from published studies, hence ethical approval was not required.

## CURRENT SCIENTIFIC EVIDENCE

### *Added sugars from cane and corn*

Added sugars in the global food supply largely come from sugar cane (sucrose), corn (high fructose corn syrup) and to a lesser extent from sugar beet (sucrose). Fructose and sucrose are naturally present in fruits and vegetables and lactose in dairy products. In the gut, sucrose (a disaccharide) is split into glucose and fructose; lactose is split into glucose and galactose. These two disaccharides are eventually absorbed into the blood as free glucose, fructose and galactose. In contrast, digested starch yields only glucose in the blood. Glucose is metabolized irrespective of its origin (starch or sugars). In many past studies, the adverse metabolic effects of added sugars, particularly from sugar-sweetened beverages, were mainly attributed to excessive levels of free fructose.

Fructose is metabolized in different ways from glucose. The conversion of glucose to pyruvate through a process known as glycolysis is closely regulated by insulin and by the energy status of cells. Phosphofructokinase (a key glycolytic enzyme), intracellular ATP and citrate are present in all cells. In contrast, fructose metabolism is not insulin dependent. Furthermore, the conversion of fructose into pyruvate requires specific enzymes, fructokinase and aldolase B, which are only present in the small bowel, liver, and kidney. As a consequence, all fructose absorbed from the gut is converted into trioses-phosphate (dihydroxyacetone phosphate and glyceraldehyde-phosphate) and pyruvate, mostly in the liver. When fructose intake is high, the liver becomes exposed to a high rate of trioses production, and further converts fructose carbons into lactic acid, glucose, and fatty acids, which are either temporarily stored in the liver or exported from the liver into the bloodstream.

Glucose and fructose are generally ingested together and each promotes storage of the other. Glucose enhances gut fructose absorption,[4] while fructose-1-phosphate (a metabolite of fructose) activates glucokinase and promotes the formation of hepatic glycogen.[5] As a result, post-prandial fructose concentration in the blood increase only slightly and shortly and the glycemic response is minimal. Excess consumption of free fructose has been reported to have adverse metabolic consequences; among them a rise in blood lactate concentration and loss of sensitivity to insulin. Daily fructose intakes above 50 g/day have been linked to higher hepatic secretion of very-low density (VLDL) triglyceride and to higher blood triglyceride levels.[6,7]

A persistently high intake of free fructose can have a significant impact on fasting and postprandial glucose levels and on lipid metabolism. First, an increase in liver glycogen can lead to a moderate hepatic glucose resistance. Second, de novo lipogenesis in the liver raises hepatic fat content[8] and raises hepatic VLDL-triglyceride secretion, which increases fasting and postprandial blood triglyceride.[9] These metabolic alterations may be normal adaptations to a habitual high fructose diet. They would most likely not be associated with adverse effects if sugar overconsumption were sporadic. However, in modern urban societies, energy and added sugar intakes are continuously high throughout the year. Prolonged consumption of excessive amounts of sugars has been linked to a higher risk of atherosclerosis, non-alcoholic fatty liver diseases, or even diabetes.

### *Added sugars and health in SE Asia*

Some leading international studies on the health effects of added sugars can be extrapolated to at-risk populations in SE Asia.

### Mortality

Two large US based studies (Nurses' Health Study and the Health Professional's Follow-up Study) examined the association between consumption of sugar-sweetened beverages (SSB) and low calorie beverages (LCB) with risk of total and cause-specific mortality (cardiovascular disease (CVD), cancer).[10] SSB consumption was associated with a higher risk of total mortality compared with LCBs. Hazard ratios with increasing number of SSB servings were: 1 to 4 servings/month (HR: 1.01, 95% CI: 0.98, 1.04), 2 to 6 per week (HR: 1.06, 95% CI: 1.03, 1.09), 1 to <2 per day (HR: 1.14, 95% CI: 1.09, 1.19), ≥2 per day (HR: 1.21, 95% CI: 1.13, 1.28). SSB intake was associated with increased risk for CVD mortality; the association was less pronounced for cancer mortality.

Added sugar may impact CVD and coronary heart disease (CHD) through insulin resistance and hyperinsulinemia.[11] DiNicolantonio and OKeefe[11] cited animal and human studies showing that isocaloric replacement of starch, glucose or combination of both with sucrose or fructose, increases fasting insulin levels, reduces insulin sensitivity, increases fasting glucose concentration as well as glucose and insulin responses to a sucrose load, reduces cellular insulin binding. Thus, overconsuming sucrose and high fructose corn syrup drive insulin resistance and hyperinsulinemia by increasing insulin levels. This abnormality is observed in CHD and CVD patients, and worsens when humans and animals are given a diet high in sugar.[11]

In contrast to U.S. studies, a study[12] among Chinese elderly (≥65 years; 2000 men, 2000 women) with an average of 11.1-years follow-up, found that the highest quintile of added sugar intake was associated with significantly reduced CVD mortality by 74.9% (HR: 0.251, 95%: CI 0.070, 0.899) compared with the lowest quintile, in a dose-response manner (*p* for trend=0.011) in both sexes. Further studies are needed to confirm these results in other Asian elderly populations and to understand the mechanisms underlying the different response.

**Cognitive function**

High fructose consumption and insulin resistance were linked to age-related cognitive decline and dementia.[13] Adult neurogenesis is an important component of brain maintenance and tissue remodeling in the central nervous system.[13,14] BDNF (brain-derived neurotrophic factor) is a vital mediator of neurogenesis and neuronal plasticity that is involved in normal brain development, learning and memory. Studies showed that diets high in refined sugar may reduce hippocampal BDNF.[13] Among newborn infants, glycemia at birth showed a strong inverse association with plasma BDNF.[14]

Brain hyperglycemia precedes the development of cognitive decline in humans.[14] A study among 27,971 older Chinese adults (50-96 years, mean age 61.5 years, 72% female) showed that a fasting blood glucose level indicative of type 2 diabetes mellitus was significantly associated with increased risk for cognitive impairment (measured using Delayed Word Recall Test).[15] Glycemia was continuously associated with cognitive impairment, suggesting that dysfunction is associated with increasing glucose levels even in the normoglycemic range.[15]

**Immune function**

*In vitro* evidence showed that processed simple sugars reduced white blood cell phagocytosis and increased inflammatory cytokine markers in blood.[16] Human whole blood cultures incubated with sugar cane molasses enhanced levels of the inflammatory biomarker IL-6.[17] In contrast, Della Corte et al's[18] review and meta-analysis of human intervention studies found no effect of dietary fructose on C-reactive protein, a marker of low-grade inflammation, compared with sucrose and glucose. Effects on immunity may occur through alterations in the gut microbiome. Brown et al[19] cited evidence showing refined sugars mediate the overgrowth of opportunistic bacteria (*C.difficile, C.perfringens*) at the expense of beneficial microbes by increasing bile output, resulting in diet-induced dysbiosis and inflammation.

Compared with Caucasians, it is known that Asians have a genetic predisposition towards abdominal obesity (increased visceral adipose tissue (VAT) stores).[20,21] VAT is the main culprit in inflammatory diseases of obesity.[22] West-Eberhard[22] explained that visceral fat is part of the immune system, providing multiple lines of defense against intraperitoneal pathogens and foreign matter, as well as pathogens and endotoxins (e.g. lipopolysaccharide (LPS)) translocated from the intestine into circulation. A high fructose diet affects immunity by reducing the number of intestinal symbiotic mucosal bacteria that regulate permeability of the intestinal membrane[22] resulting in hyperpermeability of the gut barrier ("leaky gut"). This leads to pathogen-induced endotoxemia (i.e., presence of LPS in blood) which activates inflammatory responses in VAT. Another way by which fructose might influence immunity is by increasing VAT stores.[21] Obese VAT induce a prolonged and low level immune response characterized by chronic inflammation and increased insulin resistance, typically seen in CVD and type 2 diabetes.[22] West-Eberhard[22] suggested that high fructose sugars may be toxic for vulnerable individuals (i.e., high VAT stores and hence Asian ethnicity), as CVD and diabetes in these people are both metabolic disorders and disorders involving inflammation rooted in the intraabdominal immune system.

**Neoplastic disease**

The Singapore Chinese Health Study is a prospective cohort study involving 60,524 middle-aged or older participants, with up to 14 years follow-up. Mueller et.al.[23] investigated the association between consumption of carbonated sugar-sweetened beverages and fruit juices with risk of pancreatic cancer. Individuals consuming ≥2 soft-drinks per week experienced a statistically significant increased risk of pancreatic cancer (HR: 1.87, 95% CI: 1.10, 3.15) compared with non-consumers, after adjustment for potential confounders (BMI, type 2 diabetes). There was no significant association between fruit juice consumption and risk of pancreatic cancer. The authors proposed that high insulin levels might be associated with pancreatic carcinogenesis. Chronically elevated glucose concentrations are directly associated with insulin insensitivity. Hyperinsulinemia resulting from insulin insensitivity is shown to increase cell division within the pancreas and increase concentrations of free insulin-like growth factor (IGF) in pancreatic cell lines. Overexpression of IGF and IGF receptors are found in human pancreatic cancer cells compared with normal cells. The authors suggested that dietary items that lead to hyperglycemia, and consequently hyperinsulinemia, might influence pancreatic carcinogenesis in this Asian population.

The role of hyperglycemia in pancreatic carcinogenesis is confirmed in another prospective study involving 512,000 adults aged 30-79 years from 10 diverse areas in China, followed up for 8 years.[24] Diabetes was associated with almost twofold increased risk of pancreatic cancer (adjusted HR: 1.87, 95% CI: 1.48-2.37), with excess risk higher in those with longer duration since diagnosis (*p* for trend=0.01). Among those without previously diagnosed diabetes, each 1 mmol/L higher random plasma glucose level was associated with higher risk (HR: 1.12, 95% CI: 1.04-1.21), suggesting that increasing blood glucose levels in both diabetic and non-diabetic individuals increases the risk for pancreatic cancer.

***Effects of non-sugar sweeteners on weight, eating behavior, and health***

**Effects on weight**

A comprehensive review by Rogers et al[25] examined the effects of low and non-caloric sweetener (LNCS) consumption on body weight in humans using evidence from multiple studies. Prospective studies among adults showed inconsistent results regarding the use of LNCS on body weight and obesity, with some studies suggesting increased body weight and others suggesting otherwise. A meta-analysis using the fixed effect model showed slightly lower BMI resulting from LNCS consumption (-0.008 kg/m$^2$ per year, 95% CI: -0.10 to -0.006) while use of the random effects model showed no change in BMI compared with sugar. Short-term intervention studies showed that consumption of LNCS consistently reduced short-term cumulative energy intake (comprising preload of sugar or LNCS plus ad libitum test meal) compared with sugar. Sustained intervention studies demonstrated a relative loss in body weight using LNCS products vs. sugar-sweetened products (-1.35 kg, 95% CI: -2.28 to -0.42). However, the authors acknowledged that a high degree of heterogeneity existed among studies and there was no information regarding the ethnicity of subjects.

**Effects on eating behaviour**

The sense of taste informs food choice and forms an important link between sensory aspects of a food and the nutrients it provides.[26,27] Individual taste sensations can influence food preference and shape dietary behaviors[28] and may be reflected in ethnic or cultural differences in dietary practices. An early study reported pleasantness ratings for sodium chloride and sucrose were higher in Chinese compared to European subjects.[29] However, linking individual taste ratings to dietary behavior is challenging and numerous studies have tried and failed to establish this relationship.[30] Sweetness intensity ratings have been found not to correlate with dietary intake of sugars and sweet foods recorded in two 24-hour recalls[31] or with anthropometry and dietary intakes.[32]

The looked-for association between sweetness intensity perception and dietary sugar intakes was reported in only one study of 13 subjects on a 3-month low-sugar diet.[33] At the end of 3 months, sweet detection and liking remained unchanged, but subjects rated the same concentration of sucrose as more intense. Perceived sweetness intensity dropped to the normal level again following a return to the usual diet, demonstrating for the first time a link between dietary intakes of sugar and subsequent perceptual response. Unlike sweet taste detection, sweet liking can predict consumption patterns. Study participants who preferred higher concentrations of sweet stimuli in a test beverage, also reported a liking for sweet foods.[34]

Asians are at higher metabolic risk of developing chronic conditions at lower levels of BMI. There is some urgency to cutting sugar calories through the use of LNCS and other methods that can meet the dual goals of sugar reduction and sustained consumer acceptance.[35,36] Despite some concerns that LNCS consumption may produce re-bound hunger and increase later energy intake,[37] several systematic reviews and comprehensive meta-analyses consistently support the use of LNCS for sugar and overall calorie reduction.[25,35,38,39] To date the U.S. Food and Drug Administration (FDA) has approved six LNCS as food additives (aspartame, neotame, acesulfame-k, sucralose, saccharin, advantame) and two natural LNCS extracted from plants: stevia (*rebaudoside A*) and monk fruit (*mogroside V*).

A series of recent studies compared the impact of sucrose to that of artificial (aspartame) and natural (monk fruit/stevia) LNCS on energy intake and 24-hour glycemic response.[40] Overall there were no differences in total daily energy intake regardless of whether participants consumed the caloric sucrose sweetened beverage (SSB), or the three zero-calorie versions sweetened with stevia, monk fruit or aspartame. Moreover, the type of LNCS (artificial or natural) did not affect postprandial glucose and insulin, with similar 24-hour glucose profiles across all non-nutritive and nutritive sweeteners. Although desire to eat, hunger and prospective consumption ratings were slightly higher following diet beverage preloads, there was no evidence of excess energy consumption following LNCS intake. In sensory matched, reformulated products it may therefore be possible to covertly reduce total sugar content to manage glycemia without prompting a rebound hunger response. Thus, a better understanding of sensory patterns within dietary intake behaviors, combined with ongoing advances in product reformulation, offers the potential to reduce dietary intakes of sugars and other public health sensitive nutrients while maintaining a pleasant and satisfying experience for the consumer.

**Effects on health and related issues**

A number of investigators[37,41,42] question whether LNCS can be used to prevent obesity, arguing that non-nutritive sweeteners are not physiologically inert (or metabolically inactive) compounds as historically claimed. Rather, these artificial sweeteners affect biological processes involved in regulating energy and glucose homeostasis, the mechanisms of which are not yet clearly understood. Hence, their long-term effects on body weight are unknown. Proposed physiological mechanisms by which LNCS consumption may impact energy balance and body weight include:[37,41,42] 1) extra-oral mechanisms such as the interaction of LNCS with sweet taste receptors in the gut, pancreas, and other extra oral tissues; 2) alterations in gut microbiota; 3) alterations in conditioned cephalic phase responses to sweet food due to uncoupling of sweet taste from caloric density.

*Interaction with extra-oral sweet taste receptors*

It is now known that sweet taste receptors (T1R2/T1R3) exist outside of the oral cavity (i.e., gut, pancreas) that play a role in glucose absorption and insulin secretion.[37,41,42] In the presence of glucose, these receptors are activated to release incretin hormones including glucagon-like peptide-1 (GLP-1) and glucose-dependent insulinotropic peptide (GIP), which stimulate pancreatic beta-cells to secrete insulin and reduce blood glucose levels.[37] Artificial sweeteners, like sugars, interact with sweet taste receptors and can influence glucose homeostasis. Chronic LNCS ingestion in humans increased glycemic response to an oral glucose load, with obese subjects being most adversely affected.[37] Pepino et al's[37] study among obese adults showed that sucralose ingestion prior to an oral glucose load increased peak plasma glucose concentration, glucose-stimulated insulin secretion, and plasma GIP concentration. Approximately 20% higher concentration of insulin was required to maintain the same level of glycemia as when water was consumed prior to glucose ingestion.[37] Similarly, studies in obese mice showed that dietary supplementation with LNCS induced hyperinsulinemia and insulin resistance.[37]

*Alterations in gut microbiota*

Changes in gut microbiota represent an unexplored mechanism by which LNCS can affect glucose homeostasis and energy balance.[41] In animals, LNCS consumption produced glucose intolerance via alterations to the gut microbiota.[43] In humans, gut bacterial populations in LNCS consumers were distinct from non-consumers independent of BMI, and LNCS consumption correlated with clinical parameters of metabolic syndrome including body weight, fasting blood glucose, impaired glucose tolerance.[41] Gut microbial inhabitants in Asian people differ from those in Europe and North America,[44] hence effects of LNCS may differ. No studies have yet been done to determine the effects of LNCS on the Asian gut microbiome and its accompanying health outcomes.

*Alterations in conditioned responses to sweet foods*

Cephalic phase responses (CPRs) are anticipatory pre-absorptive physiological responses (e.g., salivation and gastric acid secretion, secretion of metabolic hormones insulin, leptin and ghrelin, thermogenesis) that facilitate digestion, absorption and metabolism, and modulate appetite and satiety in a manner that serves to protect homeostasis.[41] Natural sweet taste predicts the presence of carbohydrates as an energy source, eliciting CPRs that signal and prepare for the arrival of carbohydrates in the gut.[41] Unlike sugar, LNCS provide the conditioned stimulus of sweet taste but without the matching caloric content. It is thought that chronic exposure to LNCS eventually diminishes the ability of sweet taste to predict calories, leading to suppression of conditioned CPRs.[41] Suppression may persist even when sweet taste is once again accompanied by caloric content, impairing the animal's ability to respond appropriately to sweet-tasting foods. This is demonstrated in LNCS-exposed rats which showed inability to compensate for additional calories consumed in a calorically-sweetened pre-meal by reducing intake at subsequent feedings.[41]

Consistent with these findings, a randomized crossover controlled trial in healthy humans[45] found that, when sucrose was given as a preload before an ad libitum buffet, participants ingested significantly less energy than when they were given water and artificial sweeteners (cyclamate, acesulfame-K, aspartame). Differential energy intake was accompanied by differences in brain responses to food viewing following LNCS, sucrose, and water preloads as measured using electroencephalography. Sucrose preload impacted activity in brain areas associated with cognitive control and food categorization (bilateral dorsal prefrontal areas and right insula), leading to reduced subsequent food intake suggesting adequate compensatory behavior. LNCS preload enhanced activity in ventral prefrontal regions (linked to inhibition of reward), did not change insular activity, and did not alter spontaneous food intake compared to water. The authors suggested that the differences in brain responses might reflect an initial stage of adaptation to taste-calorie uncoupling, indicating potential long term effects of habitual LNCS consumption on food intake behavior.

*Potential toxicity of specific LNCS (sucralose as an example)*

LNCS differ in their chemical structure and composition, and the effects of these different compounds in vulnerable groups need close examination. One example is sucralose, a synthetic trichlorinated disaccharide used more often than other sweeteners as a sugar substitute in food and beverage products, due to its amphiphilic (soluble in both lipid and aqueous media) characteristic.[46] The U.S. Acceptable Daily Intake (ADI) for sucralose is 5 mg/kg body weight/day, with no restrictions for vulnerable populations (i.e., pregnant women, nursing mothers, infants, children, elderly, persons with medical conditions, patients taking multiple medications).[46] Schiffman and Rother[46] discussed the following biological issues associated with sucralose ingestion that require further research, particularly among vulnerable groups:

1. Effects of sucralose on presystemic detoxification mechanisms. It is believed that sucralose is not absorbed in the gastrointestinal (GI) tract and passes from the body unchanged into feces. But animal studies showed that sucralose ingestion increases the expression of intestinal P-glycoprotein (P-gp) and cytochrome P-450 (CYP) proteins which are involved in the detoxification process (first pass metabolism). P-gp is an efflux transporter that serves as a barrier to harmful chemicals by transporting them out of enterocytes, back into the intestinal lumen. P-gp interacts easily with hydrophobic and amphiphilic compounds including organochlorine drugs and pesticides. CYP enzymes promote elimination of xenobiotics (foreign compounds e.g. therapeutic drugs, food additives) through oxidation and reduction reactions that render chemicals more polar and water-soluble. Activation of these detoxification proteins contribute to the "first pass effect" which decreases the concentration of a xenobiotic as it passes through the GI tract and liver, to limit their systemic bioavailability. The authors[46] stated that the increased expression of P-gp and CYP following sucralose ingestion is consistent with the physiological response to organochlorine pesticides and industrial chemicals, and that the body's efforts to reduce absorption may account for the low systemic oral bioavailability of sucralose.
2. Unidentified metabolites detected in feces and urine of rats and humans. Schiffman and Rothers[46] stated that recent findings do not support the claims that sucralose is "stable *in vivo*" and eliminated "unchanged" in feces. Oral administration of isotopically labeled sucralose showed the presence of metabolites in animal urine and feces. Similarly, thin layer chromatograms of fecal extracts from rats and humans following sucralose administration revealed the presence of metabolites whose identity and health effects are currently unknown.
3. Unknown safety of sucralose that has been heated. The authors[46] cited laboratory data showing thermal decomposition of sucralose with increasing temperature and pH. Chloropropanols were generated when sucralose was heated in the presence of glycerol (fat).[47] Chloropropanols are a group of contaminants that include known genotoxic, carcinogenic and tumorigenic

compounds. Other compounds that may be generated depending on ingredients of the food mixture include chlorinated compounds (e.g., dioxins, polychlorinated naphthalenes).

4. Effects on indigenous intestinal bacteria. The authors[46] cited animal studies showing that sucralose reduced the number of indigenous gut bacteria, with significantly greater suppression of beneficial bacteria. Significant alterations in the rat microbiome occurred at an equivalent dose of 1.1 mg sucralose/kg BW/day, significantly below the ADI level. Bacteria in soil samples were shown to metabolize sucralose generating an aldehyde 1,6-DCF, an alkylating agent that may possess antibacterial properties. The effects of sucralose on gut microbiome of groups with vulnerable colonic ecosystems, diarrhea, immune deficiencies and the elderly need to be determined.[46]
5. Potential for genotoxicity. Organochlorine compounds are shown to induce epigenetic events through alteration of DNA methylation patterns. It is not known if habitual use of organochlorine sweeteners or its hydrolysis product 1,6-DCF (an alkylating compound) induces epigenetic events.[46] Studies demonstrated that sucralose ingested by lactating mothers is passed on to their infants in breast milk.[48] Absorption of sucralose in infants may be greater due to their low expression of detoxifying proteins P-gp and CYP, and immature clearance mechanisms. The concentration of sucralose in breast milk was found to be 7-fold higher than the taste threshold for sweetness of sucralose. Rother et al[48] recommend more studies are needed to determine the consequences of early life exposure to LNCS – e.g., whether amplification of sweetness of breastmilk by sucralose might affect future food preferences and choices of children, the extent to which exposure through breastmilk alters the infant gut microbiota, and whether LNCS are appropriate for consumption by lactating mothers.

## PRODUCT INNOVATIONS TO REDUCE SUGAR AND ENERGY INTAKE IN THE REGION: ENHANCING THE SENSORY PROPERTIES OF FOODS AND USING INDIGENOUS SWEETENERS AS ALTERNATIVES

### *Enhancing the sensory properties of foods*

The use of LNCS to replace sugar calories in beverages is one good example of how calories can be reduced to zero, while palatability is maintained. However, the extent of calorie reduction that can be achieved in beverages is far more challenging for complex liquid, semi-solid and solid food items, where even small reductions of a specific nutrient, such as sugar or fat, can have a significant negative impact on the food's structure and sensory profile that are hard to combat. This means producing 'calorie reduced' foods is particularly difficult outside of the beverage category. Fortunately, maintaining palatability is not the only function of sensory cues from food.[49] An alternative approach is to consider how a food's sensory profle could be modified to improve the impact of its nutrients on appetite.[50]

Food texture has a unique capacity to influence eating behaviours in a way that can reduce energy intake and promote satiety. Numerous studies have consistently noted that viscous, harder and chewier foods are often consumed in smaller quantities (both in weight and calories) than softer or less viscous foods or beverages.[51] The first explanation for this comes from the simple mechanics of mastication. Based on their structure, foods naturally differ in the speed in which they are eaten, and consumers are required to adapt oral processing behaviours to process different textures, such as reducing bite size and/or increasing chewing frequency. Consequently, harder and chewier foods tend to require larger bites and more chewing and can reduce intake simply by spending longer in the mouth.[52]

However, texture can also influence energy intake regulation by modifying pre-meal beliefs about the potential satiating power of a food. Foods and beverages widely differ in the extent to which they are expected to be filling (expected satiation) and stave off hunger between meals (expected satiety), and this is based in part on their sensory profile.[53] Foods that are experienced as thicker, creamier and chewier are often expected to be more satiating, independent of their actual energy content. This has been noted across foods consumed in Europe and Asia.[27,54] What is more, consumer's memory for texture, in particular anticipated creaminess, can guide satiety-relevant beliefs without having to taste the product first,[55] implying that these beliefs are learned with experience and functional prior to consumption. Importantly, a foods expected satiety value appears to moderate pre-meal portion decisions and subsequent appetite sensations, meaning that a food that is expected to be more satiating tends to be selected in smaller portions and even experienced as more filling post consumption than a similar food of an equal caloric content that is expected to be less satiating.[53]

How can foods be designed for enhanced satiety? The role of food structure in oral processing and satiety-relevant beliefs means that foods and beverages can be created with textures that slow down the rate of eating and generate stronger satiety expectations. Recent studies used foods commonly consumed in Singapore with natural variations in food texture to design two equicaloric versions of a popular rice porridge breakfast meal. The two versions differed in the grinding of rice grains prior to cooking and the ratio of water to rice, pictured in Figure 1.[54,56] This produced a thin, less chewy 'fast' porridge and a thicker, chewier 'slow' version that was equally liked but consumed at a slower rate and consistently led to an 11-13 % reduction in intake. Importantly, these textural modifications meant that consumers expected the sensory enhanced porridge to be more filling, and actually felt more satiated despite a reduced meal size.

The sensory experience of eating can be viewed as a functional feature of the food itself. There is potential to promote stronger appetite sensations for the same or fewer calories consumed in a given meal, beverage or snack. However, this approach has its own challenges. Besides cost, a primary concern of any food company engaged in food (re)formulation is consumer acceptability. It is hard to remove nutrients from a food and instantly 'match' the sensory characteristics of the reformulated product to that of the original version. Any functional food texture applied to slow eating rate and/or enhance appetite

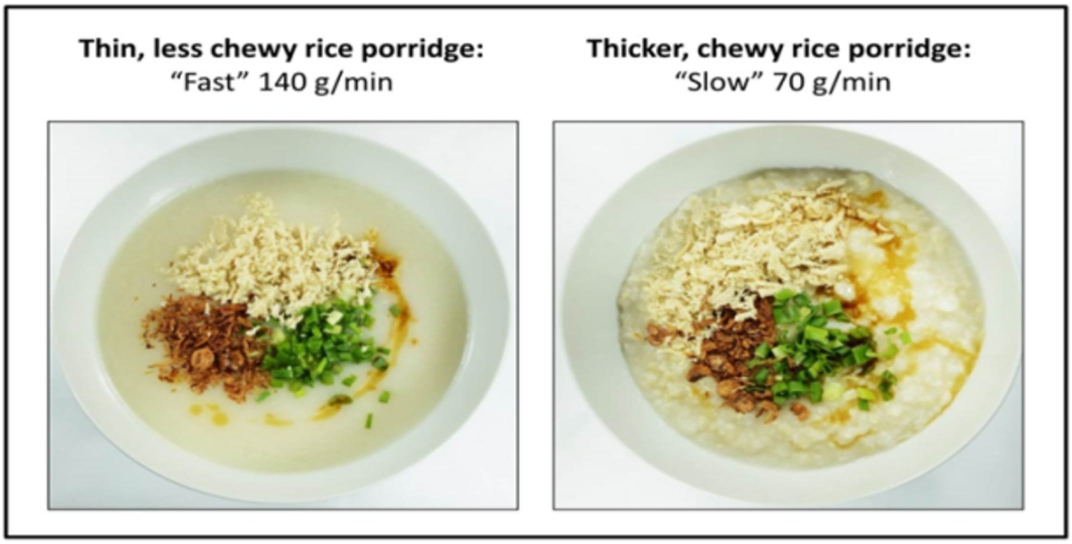


**Figure 1.** A 'fast' and 'slow' version of a rice porridge meal, popular for breakfast in Singapore.[56] The 'slow' porridge reduced intake by 11-13 %

sensations must be palatable and must fit within the specific context of a given product. For instance, enhanced chewiness in the context of a yogurt may be less palatable and harder to achieve than chewiness in porridge.

A second point of interest is the possible mismatch between consumer-generated expectations of satiety and nutrient based satiety signals experienced post-consumption. Early cues from the sensory experience of eating a product can moderate later nutrient-based physiological satiety signals.[57,58] To limit the possibility of later rebound hunger and increased energy intake at a later eating occasion, textural modifications that generate strong expectations of satiety should not overestimate the actual experience that is achieved post-consumption.[50] This implies that the success of combining sensory enhancements with energy dilution within the same product is likely to be dependent in part on maintaining a certain 'expected' baseline calorie content or energy density,[59] and will be an important consideration going forward.

Ultimately the success of any food-based innovation for satiety enhancing products is dependent on rigorous longer term assessments of their efficacy in weight management, within the right consumer groups. Yet it is important to acknowledge that there will be no one food product or technique that will drive this change wholesale. Instead, multiple small changes to the way many commonly consumed foods and beverages are presented and eaten, combined with careful energy density dilution is one strategy to be part of the solution.

***Southeast Asian indigenous sweeteners as potential sugar alternatives***

Glycemic index (GI) is based on the blood glucose response to a given food as compared to a standard glucose solution. The magnitude of the response can be classified as low (≤55), medium (56-69) and high (≥70). The GI method has been used for classifying carbohydrate foods and there are recommendations that it should be used in conjunction with food composition tables to guide food choices. In order to evaluate the potential use of indigenous sweeteners as sugar alternatives, the glycemic index of the following natural indigenous sugars from local sources was examined: coconut sap sugar and syrup, sorghum sugar, sugars obtained from various palm species (kaong sugar, nipa sap sugar, buri sugar), sugar cane granules, and muscovado (brown sugar).

Sweeteners were analyzed for proximate composition and dietary fiber using standard AOAC methods. Proximate composition of the sugars is shown in Table 1. Coconut sap syrup had the highest moisture content. Ash content was highest in sorghum, nipa, and buri sugar while sorghum and buri sugar were highest in protein. All sugars were high in carbohydrates. The amount of total carbohydrates was calculated based on the proximate composition of the sugar (Table 2), wherein total carbohydrates was calculated by difference [100 - (Moisture +

**Table 1.** Nutrient composition of indigenous sugars (g/100 g sample)

| Sugars | g/100 g sample | | | | |
|---|---|---|---|---|---|
| | Moisture | Ash | Protein | Fat | Carbohydrates |
| Coconut sap sugar | 1.8 | 2.2 | 1.2 | 0.1 | 94.9 |
| Coconut sap syrup | 18.4 | 1.7 | 1.0 | 0.1 | 79.0 |
| Sorghum | 1.1 | 3.9 | 2.0 | 0.1 | 92.9 |
| Kaong | 2.2 | 1.4 | 1.1 | - | 95.4 |
| Nipa | - | 3.8 | - | ND* | 85.2 |
| Buri | 7.6 | 3.3 | 2.0 | 0.3 | 86.9 |
| Sugar cane granules | 0.2 | 0.3 | 0.2 | <0.1 | 99.3 |
| Muscovado | 2.8 | 1.4 | 0.2 | 0.2 | 95.4 |

*Not detected; - Not analysed.

**Table 2.** Calculation of 25 g available carbohydrates (CHO) in sugar samples

| Sugar | Total CHO, g/100 g S | Dietary fiber/inulin g/100 g S | CHO (g) used in calculating 25 g available CHO | 25 g available CHO (g) |
|---|---|---|---|---|
| Coconut sap sugar | 94.9 | 4.6 | 90.3 | 27.7 |
| Coconut sap syrup | 79.0 | 1.0 | 78.0 | 32.0 |
| Sorghum | 92.9 | 1.0 | 91.9 | 27.2 |
| Kaong | 95.4 | 0.8 | 94.6 | 26.4 |
| Nipa | 85.2 | 0.0 | 85.2 | 29.3 |
| Buri | 86.9 | 0.0 | 86.9 | 28.8 |
| Muscovado (brown sugar) | 95.4 | 0.4 | 95.0 | 26.3 |
| Sugar granules | 99.3 | 0.0 | 99.3 | 25.2 |

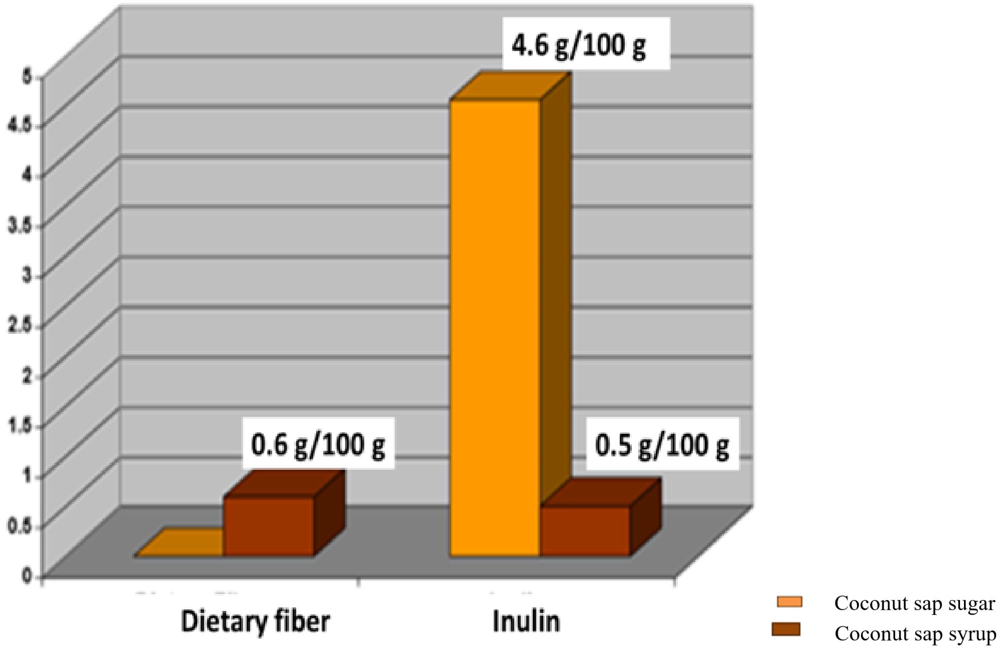


**Figure 2.** Dietary fiber and inulin content of coconut sap sugar and syrup

Ash + Fat + Protein) = Total Carbohydrates]. We did not use the sum of sugars in calculating total carbohydrates because of lack of data from other sugars.

Figure 2 shows the fiber content of coconut sap sugar and syrup. Coconut sap syrup contained both dietary fiber (0.6 g/100 g)) and inulin (0.5 g/100 g) while coconut sap sugar has no dietary fiber but has inulin (4.6 g/100 g) significantly higher than that of coconut sap syrup.

Mono- and disaccharides were analysed using gas chromatography (Table 3). Coconut sap syrup had the lowest sucrose content but the highest glucose and fructose content, followed by coconut sap sugar. Kaong sugar had the highest sucrose content.

A glycemic index study was conducted in ten apparently healthy humans. Inclusion criteria for all study participants were: 1) Age: 30-65 years; 2) Fasting blood glucose ≤6.2 mmol/L but not less than 3.5 mmol/L; 3) BMI: 20-25 kg/m$^2$; 4) No medication for glucose; and 5) Non-smokers. The participants were given 25 grams available carbohydrates of each sugar sample and a standard glucose solution after an overnight fast (Table 2). Finger-pricked blood samples were taken from each participant at 0, 15, 30, 45, 60, 90, 120 minutes. Serum was separated and analyzed for glucose levels on the same day using a clinical chemistry analyzer. The study protocol was approved by the Food and Nutrition Human Ethics Board.

Figure 3 shows the glycemic index of indigenous sugars. Coconut sap sugar, coconut sap syrup, and kaong sugar gave a GI of 42±4, 39±4, and 43±3, respectively and were classified as low GI (GI≤55). The other sugars were classified as medium GI (GI 56-69).

The inulin and fructose content of natural indigenous sugars may explain their lower GI. Coconut sap sugar contained inulin (4.6 g/100 g) while coconut sap syrup contained both dietary fiber (0.6 g/100 g) and inulin (0.5 g/100 g). Kaong has fructose content (0.8 g) two times higher than its glucose content (0.4 g). Natural indigenous sugars with greater amount of inulin and fructose than glucose resulted in low glycemic response. These sugars might help reduce the risk of overweight/obesity and type 2 diabetes mellitus, and thus require further investigation for potential health effects.

There is an increasing demand for coconut sap sugar as an alternative sweetener, both in the local and international markets. The global market for coconut sap sugar is now about US$1 billion, dominated by Indonesia, Thailand, and the Philippines. Currently there are 36 coconut sap sugar producers in the Philippines, mostly in Mindanao, and the rest in Luzon and Visayas. One of the most successful producers and exporters of coconut sap sugar and syrup and other coconut products is the Coconut Republic East Asia Outsourcing and Marketing, Philippines.

**Table 3.** Sugar composition of indigenous sugars (% w/w)

| Sugars | % w/w | | | |
|---|---|---|---|---|
| | Sucrose | Glucose | Fructose | Mannose |
| Coconut sap sugar | 83.1 | 11.4 | 3.7 | 2.8 |
| Coconut sap syrup | 36.0 | 14.0 | 15.4 | 3.9 |
| Kaong | 95.8 | 0.4 | 0.8 | - |
| Nipa | 85.2 | 0.1 | 0.2 | - |
| Buri | 87.5 | 0.6 | 0.3 | - |
| Muscovado | 89.2 | 2.8 | 1.9 | - |

- Not analysed.

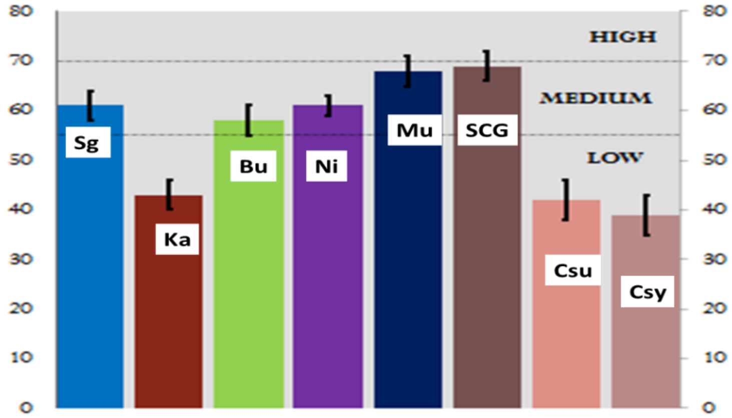


**Figure 3.** Glycemic index of indigenous sugars and its classification. Sg: Sorghum; Ka: Kaong; Bu: Buri; Ni: Nipa; Mu: Muscovado; SCG: Sugar cane granules; Csu: Coco sap sugar; Csy: Coco sap syrup

***Functional properties of indigenous sweeteners***

Various palm species (*Arenga pinnata*, *Borassus flabellifer*, *Cocos nucifera*, *Nypa fructicans*) have been used in Southeast Asia as a sweetener source for thousands of years.[60] Palm trees are indigenous in the forests of Southeast Asia, and benefit the environment ecologically as they restore damaged soil while using very little water.[60] Indigenous sweeteners are basic ingredients in local dishes, snacks and desserts across the region. Coconut sugar is an important ingredient in Indonesian sweet soya sauce (kecap manis) and Indonesian intermediate moisture meat (dendeng).[61]

Using *in vitro* methods, available studies showed that coconut sugar and palm sugar have high total phenolic content and good antioxidant activity using various tests (ferrous chelating assay, ferric reducing antioxidant potential (FRAP) test, DPPH radical scavenging test, total antioxidant test, β-carotene bleaching antioxidant test, ascorbing acid reducing equivalent).[60,62-65] In contrast, refined cane sugar showed low phenolic content and poor antioxidant activity.[63]

Phytochemical groups present in oil palm sugar include saponins, glycosides, flavonoids, alkaloids[64] while those in coconut sugar include polyphenols, flavonoids, anthocyanidin.[65] Micronutrients present are iron, zinc, calcium, sodium, potassium in coconut sugar,[65] vitamin C, calcium, iron, potassium in palm sugar.[64] Other potentially beneficial nutrients present are short chain fatty acids (acetate, propionate, small amounts of butyrate) in coconut sugar,[65] 5-hydroxymethylfurfural (a decomposition product of fructose which may function as an antioxidant) in palm sugar.[64] Palm sugar exhibited antimicrobial activity against clinical strains of *E.coli*, *P.aeruginosa*, *B.cereus*, *S.aureus*[66] and ACE (angiotensin 1-converting enzyme) inhibitory activity.[67]

**Use in functional food products**

Probiotic ice cream made with coconut palm sugar exhibited better microbial (*Lactobacillus acidophilus*) survival, higher antioxidant capacity, and higher consumer acceptability than that made with refined sugar.[62] Breads made with palm sugar and coconut sugar showed lower glycemic index (63.92±1.27, 65.67±0.12, respectively) than those made with refined sugar (81.34±0.96).[60] At present, no studies have been conducted to determine the contribution of these sweeteners to development of obesity and other chronic diseases in the region.

## ASSESSING LEVELS OF SUGAR CONSUMPTION IN SOUTHEAST ASIA: THE NEED FOR CONSUMER GUIDANCE

***Levels and sources of sugar intake in Southeast Asia***

Rising consumption of sweetened foods and beverages is thought to contribute to rising obesity rates in SE Asia.[68] In order to examine levels and sources of sugar intake in selected Southeast Asian countries, data were extracted from food balance sheets and nationwide nutrition surveys for Thailand, Malaysia, Indonesia, and Philippines (Table 4). Sales of sweetened foods and beverages were obtained from market research reports available online. While the nationwide consumption survey results varied widely in methodology and cannot be considered wholly reliable, they do identify the regional sources of added sugar, mostly comprising table sugar (white, brown, trad-

**Table 4.** Summary of information on sugar intake in selected Southeast Asian countries

| Source of information (y) | Study design | Sampling method | Sample size & characteristics | Method | Results |
|---|---|---|---|---|---|
| FAO food balance sheet data (2013)[104] | n/a | n/a | n/a | n/a | • Available supply of sugar & sweeteners (g/capita/day)<br>- Thailand: 277<br>- Malaysia: 121<br>- Philippines: 65<br>- Indonesia: 47 |
| Nationwide nutrition surveys | | | | | |
| Thailand | | | | | |
| Thailand Health Report Profile 2008-2010 (2012)[72] | Summary of results of various national surveys | --- | Population aged 6 y and over | Food frequency questionnaire (FFQ) | • 31.2 kg sugar consumed/person/y (approx.. 85 g sugar/person/day)<br>• In 2009, proportion of the population aged 6 y and above consuming the following foods weekly:<br>- Carbonated and sweetened drinks: 68.7%<br>- Snacks: 51%<br>• Proportion of primary school children regularly consuming carbonated drinks: 31.4%<br>• Amount of sugar used in industries 2008-2009 (% increase per 100 kg sack)<br>- Drinks: 4.91<br>- Milk products: 9.83<br>- Candies: 178.81<br>- Pharmaceuticals & others: 131.25<br>- Total: +8.96<br>• Food consumption behavior of Thais aged 35 y and over (% exhibiting such behavior)<br>- Adding sugar to foods when eating/cooking: 86.1<br>- Eating extremely sweet desserts such as egg drop sweet (thong-yod), sweet egg-serpentine (foi-thong), wax gourd in syrup: 75.8 |
| 2nd Thailand National Food Consumption Survey 2013-2015[73] | Cross-sectional survey | Stratified four-stage cluster sampling | 8478 individuals aged 1 y and older | Semi-quantitative FFQ; single 24 hr recall; 2nd recall in sub-sample of 10% | • Most popular sweetened food consumed daily by population aged ≥3 y<br>- Coffee (3 in one): 21 g/capita/day |
| Malaysia | | | | | |
| Malaysian Adult Nutrition Survey (MANS) 2014[74] | Cross-sectional survey | Multi-stage, stratified cluster sampling | 4000 adults aged 18-59 y | Semi-quantitative FFQ | • Sweet items consumed daily (g/capita/day)<br>- 25 g sugar (white, brown, melaka)<br>- 51 g condensed milk (approx. 27.5 g sugar)<br>- At least 0.76 cup sweet beverage (chocolate drink, pre-mixed drink, cordial) |

n/a: not applicable; --- no available data.

**Table 4.** Summary of information on sugar intake in selected Southeast Asian countries (cont.)

| Source of information (y) | Study design | Sampling method | Sample size & characteristics | Method | Results |
|---|---|---|---|---|---|
| Malaysia | | | | | |
| Malaysian Adult Nutrition Survey (MANS) 2014[74] | Cross-sectional survey | Multi-stage, stratified cluster sampling | 4000 adults aged 18-59 y | Semi-quantitative FFQ | • Top sweet foods consumed daily & weekly (g/capita/day)<br>- Daily — g/capita/day — % of population<br>Sugar (white, brown, Melaka) — 25.5 — 55.9<br>Condensed milk — 50.7 — 23.5<br>Cream crackers — 43.4 — 12.9<br>- Weekly — g/capita/wk<br>Local kuih (cakes) — 157.21 — 53.9 |
| Philippines | | | | | |
| National Nutrition Survey 2008[75] | Cross-sectional survey | Multi-stage stratified sampling | 36,634 households & their members | One-day household food weighing | • Per capita intake of sugars and syrups: 17 g/day<br>• Most commonly consumed foods by Filipino households<br>— % of households — Mean wt. (g/capita/day)<br>- Sugar — 81.1 — 12<br>- Chocolate milk drink, powder — 18.7 — 2<br>- Softdrinks — 17.8 — 26 |
| Indonesia | | | | | |
| National Socio-Economic Survey (SUSENAS) 2014[71] | Cross-sectional survey | Multi-stage stratified sampling | 75,000 households | Food consumption questionnaire (quantity of selected foods consumed daily & weekly | • Sweet foods contributing the most (2-4%) to per capita caloric intake/day<br>- Sugar (cane & brown): 19.92 g/capita/day<br>- Kueh (steam cake)<br>- Sweet liquid milk<br>- Roti manis (sweet bread)<br>- Kue kering (crisp bread)/biscuits/cookies |
| Total Diet Study | Cross-sectional | Subsample from | All members households | Single 24-h recall | • Percent of the population who consumed >50 g sugar/day by age group (%)<br>- 0-59 months: 1.3<br>- 5-12 y: 1.6<br>- 13-18: 2.0<br>- 19-55: 5.7<br>- >55: 6.8<br>- Total: 11.8<br>• Mean sugar intake (all ages): 25.51±23.15 g/day<br>• Mean per capita intake/day for sweet foods (all ages) (g/capita/day)<br>- Jelly, gelatin: 19<br>- Syrup: 18.5<br>- Honey: 14.1<br>- Jam: 11.2<br>- Chocolate: 11<br>- Sugar white: 9.9<br>- Candy: 8.6<br>- Brown & palm sugar: 7.9<br>- Sweeteners :4.5 |

n/a: not applicable; --- no available data.

tional such as Melaka and palm sugar), condensed milk, both traditional and modern sweets, cakes, desserts, and beverages.

The available data refer to both food availability and food consumption. The two are not necessarily the same. The FAO food balance sheet data showed that in 2013, the amount of sugar and sweeteners available for per capita consumption (mostly raw and cane sugar) in Thailand, Malaysia, and Philippines exceeded the WHO cut-off of 50 grams per day. Thailand and Malaysia had the greatest amounts of available sugar. In Indonesia, available sugar was below 50 but above 25 grams per day (WHO cut-off for additional benefits). Overall, the amount of sugar available for consumption in these countries was high, indicating that the respective populations were at potential risk for exposure to sugar intake levels exceeding recommendations aimed at preventing disease.

In contrast, the most recent nationwide surveys of food consumption showed varying results. Surveys in Thailand and Malaysia reported high levels of sugar intake that exceeded WHO recommendations, while those in Philippines and Indonesia reported low levels of sugar intake consistent with recommendations. Results for Thailand, Malaysia, and Indonesia have been reported in earlier papers.[69-71] None of the surveys were accompanied by biomarkers of sugar intake, which include 24-hour urinary sucrose and fructose, and the abundance of the carbon stable isotope $\delta\ ^{13}C$ in serum, fingerstick blood, and red blood cell alanine.

The Thailand Health Profile Report[72] showed that in 2008 to 2010, the sugar intake of the population aged 6 years and over was about 85 g/capita/day. Carbonated/sweetened beverages were consumed on a weekly basis by 68.7% of the population aged 6 years and above, and regularly by 31.4% of primary schoolchildren. In terms of health behavior, the report stated that 86% of Thais aged 35 years and over added discretionary sugar to foods, while 75.8% liked to eat extremely sweet Thai desserts such as egg drop sweet (thong-yod). Preliminary results from the second Thailand National Food Consumption Survey conducted in 2013 showed that the most popular sweetened food consumed daily by the population aged 3 years and above was sweetened (3-in-one) coffee mix.[73]

The 2014 Malaysia Adult Nutrition Survey (MANS),[74] covering adults aged 18 to 15 years, showed a daily per capita consumption of the following sweet foods: 25 g sugar (white, brown, Melaka), 51 g condensed milk (equivalent to approximately 27.5 g sugar), and 0.76 c sweetened beverage (chocolate drink/pre-mixed drink/cordial), containing approximately 10 g sugar. The top sweet foods consumed daily were table sugar, condensed milk, cream crackers, while that consumed weekly was local kuih (traditional cake).

Data from the Philippines' 2008 National Nutrition Survey based on household food weighing showed a daily per capita intake of 17 g sugar and syrup. The most commonly consumed sweet foods among Filipino households were table sugar (12 g/capita/day), chocolate milk powder (2 g/capita/day) and soft drinks (26 g/capita/day).[75]

Indonesia's National Economic Survey (SUSENAS) is a household socio-economic survey that includes a questionnaire on quantity and value of food and beverages consumed (purchased and own production or delivery), covering 215 commodities. SUSENAS 2014 showed per capita consumption of cane/brown sugar was 19.92 g/day, contributing approximately 4% of per capita caloric intake. A review of sugar intake in Indonesia[71] and SUSENAS results[76] concluded that reported consumption of sugar and sweetened foods was well below WHO cut-offs.

Using a single 24-hour recall, the Total Diet Study 2014 (a component of the National Basic Health Research (RISKESDAS) survey that collects data on health and nutrition variables) showed that mean sugar intake of all age groups was 25.6 g/day, and that 11.8% of the entire population consumed >50 g sugar/day. Frequently consumed sweet foods were jelly/gelatin, syrup, honey, jam, chocolate, white sugar, candy, brown & palm sugar, and sweeteners.[71]

Market reports consistently showed an increasing trend in sales of sweetened foods and beverages in all four countries. The Thailand Health Profile[72] report stated that the amount of sugar used by food and pharmaceutical manufacturers increased by 8.96% during the period 2008-2009, with the greatest increase in confectionery and pharmaceutical products (179% and 131% increase, respectively). From 1999 to 2012, Baker and Friel[1] showed that in Thailand, carbonated softdrinks exhibited the greatest increase in consumption among processed foods.

A 2016 report[77] showed that in Malaysia, the combined sales of sugared gums, sugar confectionery (boiled sweets, lollipops, mints, etc), chocolate confectionery, and sweet biscuits increased from RM 1224.4 million in 2009 to 1434.7 million in 2014. In the Philippines, imports of sugars and sugar confectionery grew by 28.8% from US$ 240.2 million in 2011 to $309.4 million in 2015.[78] A 2014 global analysis report[79] showed that retail sales for confectionery increased from US$ 863.2 million in 2009 to $925.8 million in 2013, representing 1.8% growth. Softdrink sales increased from US$ 3,407 million to 4,295.4 million during the same period, representing 6% growth.

In Indonesia, Rusmana and Listiyorini[80] reported that consumer expenditure on sugar and confectionery increased from US$ 3.2 billion in 2007 to US$ 3.6 billion in 2009. A 2014 EU-Indonesia Business Network report[81] showed that confectionery made up 9% of total retail sales for packaged foods during the period 2010 to 2012. It also stated that the non-alcoholic drinks industry in Indonesia was worth approximately US$ 8.5 billion in 2013, with a growth rate of 10%. From 2006 to 2011, various ready-to-drink beverages showed the following compounded annual growth rates: juice/juice drinks (16.3%), isotonic drinks (16.3%), dairy/soy (8.1%), coffee (7.5%), energy drinks (6.9%), tea (3%), carbonated drinks (2.1%).

While nationwide surveys showed inconsistent results, food balance sheet and market reports consistently suggested increasing levels of sugar consumption in these countries. Compared with food balance sheets, nationwide nutrition surveys provide a more precise and accurate representation of foods actually consumed by individuals.[82] However, dietary assessment instruments used in nutrition surveys (usually 24-hour recalls and food frequency questionnaires (FFQ)) are prone to measurement error. Twenty-four hour recalls are less prone to measurement error than FFQs.[83] At least two or more days of recall are needed to estimate the distribution of usual intakes in a population and to determine individual adherence to dietary recommendations.[83] None of these countries used 2 recall days. Dietary assessment methods consisted of FFQ (Thailand, Malaysia), household food weighing (Philippines), and single 24-hour recall (Indonesia). Underreporting of intake also appears to be an issue, having been observed in Malaysian[84] and Indonesian subjects.[76]

An online news report citing Euromonitor International data[85] stated that the "Asia Pacific region continues to emerge as the global confectionery industry's new growth engine. By 2015, the global sugar market is expected to surpass 177 million metric tons, and Asia Pacific is expected to lead in terms of annual growth at a rate of 6% yearly through 2015." Another report[86] suggested that the chocolate market in Asia Pacific is expected to grow 2% faster than Europe and North America up to 2019 and that "annual Asia Pacific chocolate sales will reach $18.23 bn by the end of 2019 from $12.24 bn in 2013, growing at a CAGR of 5.2% during the forecasted period, largely due to increasing availability of various chocolate brands and improving Asian economies." Given this magnitude of future increase in the sources of sugar in the region, it is necessary to know precisely what and how much people are eating in order to guide policy and effectively address the problem. This can be done by improving dietary assessment methods used in nationwide nutrition surveys, to include at least 2 days of recall in addition to FFQs, and biomarkers of sugar intake.

### *Consumer guidance in Southeast Asia – sugar and LNCS use*

#### Sugar

Excessive intake of added sugars may promote a positive energy balance,[2] leading to weight gain and obesity. Energy from sugars may displace micronutrient-dense foods, leading to diets of lower nutrient density and minimal nutritional value. Another concern is the association between intake of free sugars and dental caries. Although prevention and treatment of dental diseases are greatly improved, these problems persist in many Asian communities.

Food-based dietary guidelines (FBDGs) give dietary advice to the population on all diet-related conditions, i.e., nutrient deficiencies and nutritional excesses. Key messages in FBDGs touch on a variety of topics, such as eating a variety of foods, messages on specific food items, and food labelling. The FBDGs of six countries in Southeast Asia (Indonesia, Malaysia, Philippines, Singapore, Thailand and Vietnam) include recommendations to reduce consumption of sugar-rich foods and beverages.[87] However, there is no numerical recommendation in these national guidelines that clearly specifies the amount of reduction, such as that found in the most recent WHO guideline, i.e., reduce sugars to 10% or less of total energy intake.

Systematic approaches are needed to communicate FBDGs. These approaches should stress the need to reduce excessive intake of sugar-rich foods and beverages. The first step would be to convince consumers that excessive sugar intake is undesirable. Next, consumers need information on sugar content of foods and beverages from all sources, to enable them to opt for foods and beverages with no or less sugar. But data are presently not available, as the current food composition tables of Malaysia and other Southeast Asian countries do not include the sugar content of foods.[88] It is therefore important that the sugar content of commonly consumed foods and beverages be made available, including pre-packaged foods and ready-to-eat meals from hawkers, cafes, restaurants, etc. To this end, practical and feasible methodologies for determining sugar content in foods of various matrices need to be established. The sugar content of foods in food composition databases is also required in food consumption studies, to estimate a population's intake from various food sources.

Greater efforts are needed to help consumers understand the sugar content of pre-packaged foods and identify products with lower sugar content using the ingredient list and nutrition information panel (NIP). Consumers should be educated to recognize sugar as an ingredient, as sugars can be present in various forms, e.g., sucrose, brown sugar, corn syrup, fructose, maltose, molasses, etc. Besides energy, carbohydrate, protein, fat, saturated fat, and sodium, total sugars should also be declared in the nutrition information panel (NIP).[89] Codex Alimentarius has published a set of guidelines related to nutrient content claims on labels, which includes claims related to total sugars.[90] National authorities should strive to enact regulations that are harmonised with Codex. These regulations can be utilized to inform consumers of sugar content of packaged foods and to identify foods high or low in sugars. In Southeast Asia, only Thailand adopted the requirement of declaring sugar content of foods on the NIP. Malaysia only requires labelling of sugar content of ready-to-drink beverages.

Many consumers in Southeast Asia purchase ready-to-eat meals, widely available in hawker stalls, coffee-shops, café, restaurants and other eateries that are ubiquitous in countries in the region. The contribution of energy and nutrients from such foods and beverages can be greater than those of pre-packaged foods. Many of these local meals, desserts and beverages have high sugar content, and they can contribute significantly to the intake of total sugars. It is therefore important to help consumers identify ready-to-eat meals that are high in sugar. However there are no regulatory requirements to label the sugar content of street foods and beverages, making this difficult to achieve.

It cannot be assumed that the same foods and beverages are the main contributors of sugar intake for all population groups. For effective and targeted implementation of sugar reduction programs, the main sources of sugar and the amount consumed by various communities should be identified. This will enable targeting of appropriate foods and population groups for intake reduction, and requires both nationally representative food consumption data and sugar content of foods. As pointed out earlier, it is urgent that the sugar content of a wide variety of foods and beverages be analysed. In addition, methods used in dietary surveys, i.e., 24-hr recalls and food frequency questionnaires, are known to have many limitations. Thus the use of objective methods to accurately determine sugar intake should be investigated.

Identifying the main contributors of sugar intake will allow consumers to make appropriate choices and the government to establish measures to reduce the sugar content of these foods. Food manufacturers in the region are encouraged to produce lower sugar alternatives of pre-packaged foods and so far they have responded positively. But countries also need to find ways to reduce the sugar content of ready-to-eat meals and street foods. Reaching out to many food vendors of diverse backgrounds is a challenge. Ultimately, consumers should be empowered to seek and demand for lower sugar varieties of foods and meals.

In summary, there is general consensus that populations should avoid excessive intake of total fat, trans fat, sugars and salt to reduce risk of obesity and related NCDs. To successfully reduce sugar intake in the region, some practical considerations should be kept in mind. First, it is necessary for all stakeholders to increase their efforts to effectively implement FBDGs. Effective ways to communicate FBDG messages to consumers, including reduction of sugar intake, are needed to ensure improved understanding and adherence to these recommendations. Second, serious efforts must be made to help the public identify foods and beverages with high sugar content. To this end, the sugar content of commonly consumed foods and beverages needs to be clearly labeled. Third, there is a need to identify the main foods and beverages that contribute to the sugar intake of specific population groups.

**Food structure as an additional component of Southeast Asian FBDGs**

Regulation of energy balance and prevention of chronic disease can be achieved by consuming a biodiverse diet which retains much of its original food structure (textural properties) for nutrient delivery.[91] Wahlqvist[91] pointed out that food structure makes a major difference to biological and health outcomes, based on evidence showing differences in macronutrient handling by the gut depending on the physical form of food. For instance, it was shown that fruit eaten intact reduced risk of diabetes, but ingestion of fruit juice increased the risk. Thus, food matrix is important for health maintenance as whole foods provide less health risk than extracted single components.[91] The natural food structure itself regulates energy by providing satiety and reducing glycemic load, and maintains a healthy gut microbiome.[91] Wahlqvist[91] recommends that dietary guidelines should take account of food structure, and that food composition tables should provide information on structural properties such as degree of processing, texture, particle size, viscosity, etc. In addition to reducing sugar intake to prevent disease, Southeast Asian FBDGs should consider including food structure by adopting the Brazilian FBDG: "Make natural or minimally processed foods the basis of your diet."

**Low and non-caloric sweeteners**

The worldwide increase in obesity and diabetes has increased the use of LNCS globally.[92] In Southeast Asia, little is known about consumers' views regarding the different types of LNCS, and hence their potential use. Thus, a qualitative study in Singapore and a questionnaire survey in Malaysia (both unpublished and funded by ILSI Southeast Asia) were undertaken to determine how local adult consumers perceived LNCS (artificial vs. natural or plant-based), and if these perceptions were positive or negative.

In Singapore, focus group discussions were conducted among 48 male and female consumers aged 18 to 45 years from different income groups. Subjects had no background in food and nutrition, and did not work in these fields. Each focus group consisted of 6 respondents (4 Chinese and 2 Indian/Malay). In general, sugar and sweeteners were regarded as "bad" for health and most subjects tried to limit consumption of these products. Subjects were concerned about the safety of both artificial and natural sweeteners. Examples of statements regarding sweeteners were:

- "Just a little bit of sweetener can already be so sweet so it cannot be good."
- "If it's low calorie, it should have some side effects."

Other concerns were that sweeteners "may lead to addiction, (subjects were) unsure of what is a safe intake level," and (subjects) "do not know side effects e.g., may have toxins and may affect kidneys." Participants believed that even if LNCS are approved by regulatory agencies as being safe for consumption, it does not necessarily mean that these are "healthy".

In Malaysia, a survey was carried out using a structured questionnaire. Opinions regarding risks and benefits of intense sweeteners were measured on 5 point Likert scales. The questionnaires were administered to 151 health, food and nutrition professionals (considered opinion leaders) in the Klang Valley region. Respondents considered natural intense sweeteners as having the lowest health risks, followed by sugar, while artificial sweeteners were thought to have the highest health risks. Natural intense sweeteners and sugar were considered safe for consumption of pregnant women and children below the age of 12, while artificial sweeteners were not. Respondents agreed with the statement that "it is healthier to consume products sweetened with natural intense sweeteners than those sweetened with artificial sweeteners."

In summary, Singapore respondents viewed sugar and sweeteners (whether artificial or natural) negatively, and expressed their belief that these are not healthy products. In contrast, Malaysian respondents viewed natural sweeteners positively, believing that these were healthier products than white sugar and artificial sweeteners. They also viewed natural sweeteners as having the lowest health risk, followed by sugar, and lastly artificial sweeteners which had the highest health risk.

The Malaysian results are consistent with the worldwide positive perception regarding natural sweeteners.[93] This is shown by the global increase in the use of natural intense sweeteners particularly stevia which experienced a 39 CAGR% growth over the 2011-2015 period.[94] In the U.S., one report[95] stated that "trends in wellness and awareness of natural and artificial sweeteners are affecting consumer attitudes. This trend includes growing consumer avoidance of artificial sweeteners, with high fructose corn syrup (HFCS) and aspartame perceived as artificial and unhealthy while honey is associated with health benefits. Granulated sugar was near the middle of a spectrum in consumers' view of good for health or bad for health, with honey at the top and coconut sugar, agave, monk fruit and stevia in the top half. On the bottom half of the spectrum were sucralose, erythritol, xylitol, saccharin, aspartame and HFCS."

**Limitations of the evidence regarding LNCS**

The US Academy of Nutrition and Dietetics stated that "consumers can safely enjoy a range of nonnutritive sweeteners when consumed within an eating plan that is guided by current federal nutrition recommendations, such as the Dietary Guidelines for Americans and the Dietary Reference Intakes, as well as individual health goals and personal preferences."[39] In a scientific statement regarding the use of LNCS, the American Heart Association (AHA) and the American Diabetes Association (ADA) stated that "when used judiciously, LNCS could facilitate reductions in added sugars intake, thereby resulting in decreased total energy and weight loss/weight control, and promoting beneficial effects on related metabolic parameters. However, these potential benefits will not be fully realized if there is a compensatory increase in energy intake from other sources."[96]

The joint scientific statement issued by the AHA and ADA[96] concluded that while LNCS may be a tool to reduce energy intake and maintain body weight, "data are insufficient to determine conclusively whether the use of LNCS to displace caloric sweeteners in beverages and foods reduces added sugars or carbohydrate intakes, or benefits appetite, energy balance, body weight or cardiometabolic risk factors… There are few well-designed human trials exploring the potential role of LNCS in achieving and maintaining a healthy body weight and minimizing cardiometabolic risk factors."

Mosdøl et al[97] examined the hypotheses, research approaches and features of the evidence on non-caloric intense sweeteners and their effects on appetite and body weight, identifying gaps where new systematic reviews or primary research are needed. The authors concluded that:

- Current reviews of the evidence present several hypotheses on how intense sweeteners may be associated with weight changes, but do not review a specific hypothesis and whether included studies are suitable to illuminate this.
- The evidence is dominated by small studies with short follow-up and limited number of participants.
- The reviews combine results for multiple compounds and omit considerations of doses used.
- There is a lack of appropriate compound-specific analyses, given different properties of each intense sweetener.
- The risk of bias is not accounted for in a number of reviews.
- The following hypotheses have not been examined:
  - The notion that intense sweeteners will substitute sugar consumption. In the US, evidence shows that people consume products with intense sweeteners in addition to rather than instead of sugar.
  - Reverse causation to explain health effects. There is a need to understand behavioral patterns related to dieting, indulging, or restrained eating in different groups and cultures.
  - Choosing low energy products may lead to a "licensing" effect wherein people who consume a low energy food feel entitled to indulge in high energy foods. This attitude will counteract any effects on weight.

Some reviews have concluded that evidence is insufficient to prove that consumption of nonnutritive sweeteners as sugar substitutes is beneficial in terms of weight management, regulation of blood glucose or type 2 diabetes.[98-101] Fowler[102] noted RCT results showing that, within the context of a healthy diet and consumption within acceptable daily intake (ADI) levels, LNCS showed no deleterious impact on weight and other cardiometabolic factors. However the author also noted that long term prospective observational studies in humans showed that daily exposure to high intensity sweeteners was associated in a dose response manner with increased cardiometabolic risk, increased weight gain, general and abdominal obesity, incidence of overweight and obesity, and worsened glucose homeostasis even after controlling for a wide range of confounders. In some cases, cardiometabolic risk escalated in LNCS-exposed subjects in the absence of significantly increased weight gain.[102]

For results of an RCT to be directly applicable to the general population, Fowler[102] pointed out that it should represent as faithfully as possible those population subgroups identified by animal and observational studies as most likely to show adverse effects from LNCS exposure – these include individuals genetically disposed to diabetes and obesity (e.g., ethnic minorities, low income groups, those consuming Westernized diets, or already overweight or obese). Southeast Asian populations readily fall within this high-risk category, due to their increased risk for metabolic disease at lower levels of BMI.[20,21,103] This underscores the need for studies among Southeast Asian subjects regarding the effects of LNCS.

Additional recommended research[100,102] which are relevant for the region, include the following: 1) Conduct experimental studies that confirm the associations between LNCS consumption and chronic disease shown in long-term studies; 2) Compare the effects of different types and formulations of nonnutritive sweeteners, 3) Evaluate the net effect of substituting specific and combined nonnutritive sweeteners for sugar, 4) Address confounding bias such as adiposity, and 5) Use improved assessment tools and biomarkers to accurately capture consumption of nonnutritive sweeteners. Factors to be considered include subjects' sex, ethnicity, genetic predisposition to obesity, timing of initiation of exposure to LNCS (prenatal or neonatal vs.adulthood), environment of origin, differences in gut microbiota prior to initiation of LNCS.[102] Regardless of consumer perceptions, the long-term risks and benefits of LNCS need to be fully characterized in Southeast Asian populations before dietary recommendations for the region can be made. Similar approaches may be considered when examining the health effects of indigenous sweeteners in local populations.

## PANEL DISCUSSION

The following research needs to promote healthy eating in the region were suggested:

1. Develop effective communication strategies with respect to sugar, sweeteners, and healthy lifestyle through public-private partnerships. Stakeholders can work together through public-private partnerships, to jointly develop the content of messages pertaining to sugar and sweeteners. Messages should be comprehensible to ordinary consumers, improve their caloric literacy, and empower them to make informed choices. These messages should focus on balancing the entire lifestyle and encourage people to not simply reduce food intake (i.e., cutting sugars) but also increase physical activity. A coordinated, multi-disciplinary approach, with inputs from psychology, anthropology, and fields other than nutrition would be needed to facilitate behavior change.
2. For each country in the region, identify best practices that overcome the challenges facing public-private partnerships with respect to promotion of healthy eating. One example is the Singapore experience. In Singapore, the Health Promotion Board (HPB) collaborates with food sellers to supply healthy meals. Health officials embarked into this whole of supply chain approach to work with partners in the retail sector and food & beverage sector. When food sellers were approached to include healthier meals in their menu, they asked – what if those healthy meals do not sell, is HPB going to subsidize me? To overcome that, HPB worked with them very closely, e.g., to come out with a recipe, etc., that level of detail. HPB worked with several partners and accumulated experience along the way. The program started off with the quick service restaurants, then moved to communal dining, and now to food courts and the most common eateries. The take-up rate for healthy meals in commercial establishments has so far been good. In fact HPB has done business reviews with their partners and the trend is positive. Unlike when sellers started off thinking that healthy meals do not sell, actually numbers do show that the healthy meal is gaining traction. Consumers are now more informed and when the choices are out there, they try these and say healthy meals are just as tasty so why not. When HPB shares this positive data to partners, more partners are coming back so that the two parties can work together. Therefore, so far so good. The program is on a positive trend and definitely moving forward.
3. Develop effective digital dietary data collection methods for the region, to enable collection of spontaneous, timely consumption data that are useful for industry, regulators, and the health sector. In Singapore, we no longer just give out leaflets to promote health. We have actually launched an app – Healthy 365 – available in stores. It tracks the number of steps and incorporates some behavioural science. It gives incentive for consumers to be physically active. The information is collected in real time and we use this information to measure the effectiveness of the program. In Thailand, the National Center for Information Technology, Nektek, has a project with Mahidol University Institute of Nutrition to create an app for mobile phones that people can download. It calculates calories eaten during the day and can be used for planning meals. It's not yet widely disseminated but in the pipeline. Thailand is still on 3G communication system, but using electronic questionnaire to collect data is becoming more frequent, particularly in the social sciences. The method can be applied to nutrition and food science in the future, particularly in dietary data collection which forms the basis for understanding how people eat and how behaviors change.

It should be noted that countries are aspiring to go online with respect to dietary data. NHANES aspires to move online by 2018. The validity of implementing the multi-pass method over the internet, or linking photographs to online food composition data (to improve accuracy of estimating portion size and nutrient content), needs to be assessed. There's a huge scope for error there but nevertheless online use is increasing, and problems regarding validity, accuracy, and precision of traditional methods when transferred to an online platform need to be examined and addressed.

## ACKNOWLEDGEMENTS

The authors wish to acknowledge the Singapore Health Promotion Board for co-organizing the symposium.

## AUTHOR DISCLOSURES

The symposium was supported by ILSI Southeast Asia Region which is funded primarily by its industry members.

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