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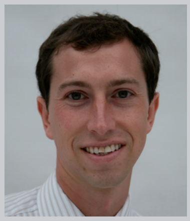

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ABSTRACT: Low energy dense diets (<1.6 kcal g^{-1}) are recommended for weight management. Self-assembled, water-filled, edible nanotubes that self-organise into a more complex structure, possibly a 3D network of nanocellulose, may be used to lower the energy density of many processed foods to <1.6 kcal g^{-1}. Durethan® KU2-2601 packaging film enables the water content of processed foods to be increased without reducing their shelf life. Food and drinks can be sweetened by adding calorie-free Purefruit™ monk fruit *(Siraitia grosvenorii)* extract to them. PUREFRUIT™ is approximately 200 times sweeter than sugar and has exceptional stability. The energetic cost of the assimilation of processed and farmed foods, including sugar-sweetened liquids can be increased by increasing their protein and fibre content.

INTRODUCTION

The combined effect of sedentary lifestyles and availability of energy dense food in modern societies is undeniable. Once considered a problem only in high-income countries (World Bank classification: http://data.worldbank.org/about/country-classifications), the prevalence of overweight and obese people is now dramatically on the rise in low- and middle-income countries, particularly in urban settings where exercise is optional and high energy dense (>2 kcal g^{-1}) (1) fast food is now plentiful. Degenerative non-communicable diseases are rare or non-existent in hunter-gatherers eating a late Palaeolithic diet i.e. a low energy dense diet with a wild plant-to-animal energy intake ratio ~1:1, with fish and shellfish providing a significant proportion of the animal component (2). Nearly all the genes and epigenetic regulatory mechanisms humans carry today were originally selected for behaviourally modern humans who appeared in Africa between 100,000 and 50,000 years ago (2). Thus, it has been argued that the typical diet, physical activity patterns, and body composition of late Palaeolithic humans remain normative for contemporary humans and models for disease-prevention recommendations (2). Indeed, an article in Nature highlighted "It is difficult to refute the assertion that if modern populations returned to a hunter-gatherer state then obesity and diabetes would not be the major public health threats that they now are" (3). There are more humans on Earth than can be sustained by the natural World. Thus, the food industry needs to use the principles of the optimal Palaeolithic diet to help prevent diet induced disease because unbiased observers agree that nutritional advice from conventional sources, whether based on epidemiologic or mechanistic findings, has not affected complex degenerative disease incidence/prevalence as much as hoped (2).
Late Palaeolithic humans ate wild foods and cooking them increases food safety and improves diet quality (4).
The largest single constituent of many cooked wild foods is water and increasing the water content of a processed food lowers its energy density (5). Low energy dense diets (<1.6 kcal g^{-1}) are recommended for weight management because a relationship exists between the consumption of an energy dense diet and obesity (1). Further, modern humans consuming low energy dense diets have the lowest total intakes of energy, even though they consume the greatest amount of food (1). The energy density of some liquid and some spreadable solid emulsion-type processed foods has been reduced by increasing water content. Further, amorphous cellulose, which has a high water content, has successfully been used to reduce fat levels and hence reduced the energy density of cheese, hamburgers, sausages and baked goods (6-8).
Cellulose is the major structural component of plant cell walls and the cellulose molecule is insoluble in water, tasteless and odourless. It occurs in plants as microfibrils 2-20 nm diameter and 100 - 40 000 nm long. These cellulose microfibrils form a structurally strong framework in the cell walls. The human digestive system can only partially breakdown cellulose into smaller components for absorption into the bloodstream and thus it is often referred to as dietary fibre (dietary fibre consists of non-starch polysaccharides such as cellulose, arabinoxylans, and many other plant components such as resistant dextrins, inulin, lignin, waxes, chitins, pectins, beta-glucans, and oligosaccharides that are not digested by human pancreatic or intestinal enzymes). Amorphous cellulose is not a natural constituent of meat. Using cellulose as a meat additive highlights an attempt to treat a symptom of modern animal husbandry; modern animal husbandry caused the rise in the production of high fat meat with a low nutrient density and it will have to be corrected because of its negative effects on animal welfare and human nutrition (9-12).
Processed food products of plant origin such as chocolate bars, biscuits, fruit bars and cereal bars have a high energy density principally because they have a low water content (5). Self-assembled, water-filled, edible nanotubes that self-organise into a more complex structure, possibly a 3D network of nanocellulose, may be used to lower the energy density of many processed foods to <1.6 kcal g^{-1}(5). Nanocellulose is composed of nanosized cellulose fibrils (fibre diameter: 20-100 nm), has a water content of up to 99 percent and the same molecular formula as plant cellulose (13). The water inside the nanosized cellulose fibrils could contain flavour with few calories e.g. a cup of tea without milk = 0.01 kcal g^{-1}. The shape and supramolecular structure of the nanocellulose can be regulated directly during biosynthesis to produce fleeces, films/patches, spheres and tubes (14). Other edible materials can strongly adhere to the surface and the inside of nanocellulose structures such as fleeces to form edible composites (15). Taste sensation per mouthful could be improved by adding flavouring substances processed on the

nanoscale (increased surface area in contact with taste and smell receptors) to edible composites (Ultrafine food technology: Eminate Limited, Nottingham, United Kingdom).

Durethan® KU2-2601 packaging film produced by Bayer Polymers, Germany, is a nanocomposite film enriched with silicate nanoparticles which is designed to prevent the contents from drying out and prevent the contents coming into contact with oxygen and other gases. Durethan® KU2-2601 can prevent food from spoiling (16) and thus the water content of dehydrated plant-based food products may be increased without reducing product shelf life. Thus, nanocellulose is expected to be widely used a as a nature-based food additive (14, 15).

A reduction in liquid calorie intake has been found to have a greater effect on weight loss than a reduction in solid calorie intake (17). Sugar sweetened liquids require little digestion. Glucose and fructose can be directly absorbed into the bloodstream without digestion. Reducing the energy density of processed foods, including sugar-sweetened liquids and simultaneously increasing the cost of their assimilation makes them more akin to foods consumed by late Palaeolithic humans. The energetic cost of the assimilation of processed foods can be increased by increasing their protein and fibre content (2, 5). The typical modern diet has a fibre content of 15.1 g day^{-1} (18) which is considerably lower than the estimated ancestral intake of >70 g day^{-1} (2) and nanocellulose may be used to increase the fibre content of processed foods. Indeed, chocolate (e.g. dark chocolate (19904) containing 10.9 g of fibre per 100 g) may appear to be high in fibre but is not when its energy density is reduced to a level similar to a typical fruit or vegetable (hot chocolate (14194) 55 kcal and 0.5 g versus raspberries (35202) 62 kcal and 7.5 g of fibre per 100 g (USDA National Nutrient Database for Standard Reference, Release 24 (2011) 5-digit nutrient database number in parentheses). Protein has more than three times the thermic effect of either fat or carbohydrate (19) and protein has a greater satiety value than fat or carbohydrate (19, 20). A high protein diet (protein and carbohydrate intake both being approximately one third of total energy intake (2)) is of vital importance as a weight-loss strategy for the overweight or obese and for weight maintenance (21, 22). Clinical trials have shown that calorie-restricted, high-protein diets are more effective than are calorie-restricted, high-carbohydrate diets in promoting (23,24,25) and maintaining (26) weight loss in overweight subjects, while producing less hunger and more satisfaction (27). Furthermore, high protein diets have been shown to improve metabolic control in patients with type 2 diabetes (28-30). Food-grade protein based nanotubes (31) may be used to increase the protein content of processed foods that are currently high in fat or high in carbohydrate. Functional foods and drinks are required to simultaneously satisfy the human "sweet tooth" and almost completely remove added sugars such as glucose, fructose and sucrose from the diet (2). Savoury food and drinks can be sweetened by adding fruit to them or adding calorie-free Purefruit™ (Tate & Lyle) monk fruit (*Siraitia grosvenorii*) extract. PUREFRUIT™ is approximately 200 times sweeter than sugar and has exceptional stability.

THE BIGGER PICTURE

Obesity should not be considered in isolation, it is one of many non-communicable diseases linked to the modern diet and a sedentary lifestyle (22, 32). The modern diet has adversely affected the following dietary indicators 1) fatty acid composition, 2) energy density, 3) macronutrient composition, 4) micronutrient density, 5) acid-base balance, 6) sodium (as NaCl) - potassium ratio and 7) fibre content (22, 32). Diet induced disease is a situation out of control. The causes are preventable, but it is a global epidemic. Human food production must be linked to human nutritional requirements as its first priority, as was the aim of Professor Sir Jack Drummond during World War II. The nutritional value of processed and farmed foods should be based on the nutritional value of the late Palaeolithic human diet to help reduce obesity and other postprandial insults (5, 9, 33-35). Emergent technologies will change society beyond anything that has gone before. This should, but not with any certainty, eventually slow down the spiralling increase in diet induced healthcare costs (36).

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