Food nanotechnology: water is the key to lowering the energy density of processed foods.

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FOOD NANOTECHNOLOGY: WATER IS THE KEY TO LOWERING THE ENERGY DENSITY OF PROCESSED FOODS

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ABSTRACT

It is crucial that emergent technologies create foods that help prevent the causal mechanisms of the diet induced disease epidemic. Food nanotechnology could create modern convenience foods that mimic and improve on the nutritional value of the most nutritious cooked wild foods for humans. Structuring a solid processed food similar to a celery stalk using self-assembled, water-filled, edible nanocells or nanotubes would substantially lower its energy density (<1.6 kcal g^{-1}). Food technologists could harness the natural turgor force to produce a firm chocolate bar, biscuit or breakfast cereal with a good bite, without altering the appearance or taste of the product. Water carries flavour with few calories, and taste sensation per mouthful could be improved by processing food on the nanoscale to increase the surface area that is in contact with taste and smell receptors. The bioavailable nutrient content (including cofactors) of processed foods could be increased by existing bioactive nanoencapsulation. This would allow people to continue to consume modern convenience food on a mass scale, while simultaneously and significantly increasing nutrient intake and reducing energy intake per day. Thus, helping to reduce mental ill health, obesity and other postprandial insults

Key words: nanotechnology, self-assemble, molecular recognition, nanocells, nanotubes, diet, disease, water, obesity, food, energy, nutrition

High energy density and low nutrient density which characterise the modern diet must be overcome simultaneously. Overweight and obese people can develop paradoxical nutritional deficiency from eating high energy dense foods with a poor nutrient content. The finding that people with a low energy dense diet (<1.6 kcal g^{-1}) have the lowest total intakes of energy, even though they consume the greatest amount of food has important implications for promoting compliance with a healthy diet (Ledikwe *et al*. 2006). A processed food which is not both low energy dense and high nutrient dense dilutes the diet of the low energy dense foods of high nutrient density that humans should eat: the most nutritious cooked wild plant and

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animal foods for humans (e.g. Robson 2006; Marean *et al*. 2007; Robson 2009; Eaton *et al*. 2010; Robson 2010; Wang *et al*. 2010). Many foods consumers may consider natural are not due to agriculture, animal husbandry and food processing. Furthermore, the focus on just reducing dietary fat e.g. Farhang (2007) and Hsieh and Ofori (2007), must be refocused on reducing the imbalance between the intake and the expenditure of energy. Cereals – a food group humans are not yet fully adapted to provides 56% of humanity's food energy (Cordain 1999) and low fat, high carbohydrate cereal based products are often of high energy density (>2 kcal g^{-1} – see Ledikwe *et al*. 2006). For example a Masterfoods Twix® chocolate biscuit bar (56% carbohydrate) is 2.2% water = 5.5 kcal g^{-1}, Kellogg's Special K® (71% carbohydrate) is 3% water = 3.8 kcal g^{-1}, white bread (51% carbohydrate) is 36% water = 2.7 kcal g^{-1}, while roasted chicken meat from Cornish game hens (0% carbohydrate) is 72% water = 1.3 kcal g^{-1}, shrimp cooked in moist heat (0% carbohydrate) is 77% water = 1.0 kcal g^{-1} and boiled celery (4% carbohydrate) is 94% water = 0.2 kcal g^{-1} (c.f. Table 1 and Figure 1).

Molecular recognition is biology's building strategy and key to nanotechnology: biomolecules e.g. self-assembled, water-filled, edible nanocells and nanotubes that self-organise into more complex structures (Graveland-Bikker and De Kruif 2006). Using molecular recognition

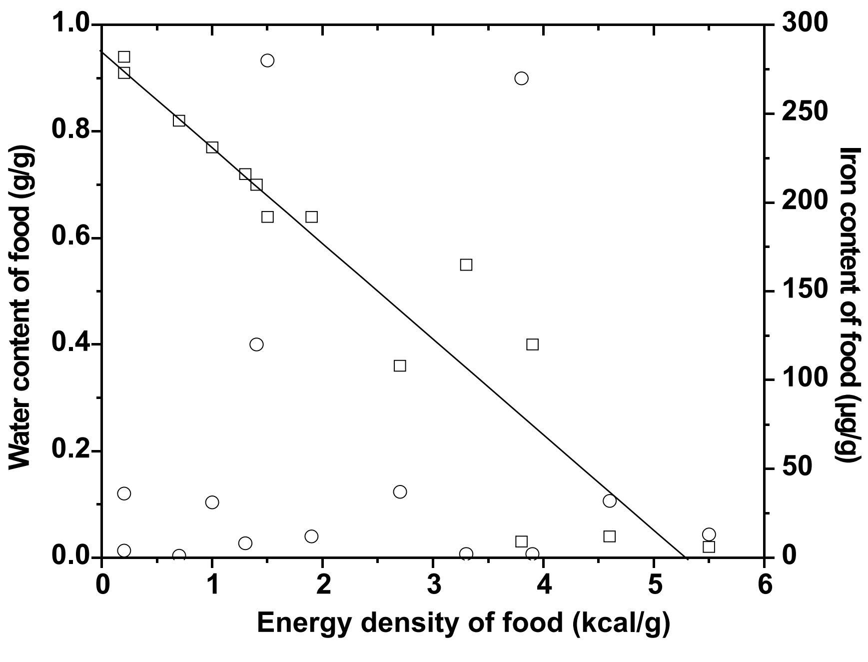

Figure 1. The significant relationship between the energy density of food and its water content (denoted by squares) using data from Table 1 (best-fit regression line: $y = -0.180x + 0.949$, $F_{1,12} = 102.0$, $P < 0.001$, $R^2 = 0.9$). Also using data from Table 1, the lack of relationship between the energy density of food and its iron content (denoted by circles, $P = 0.895$).

TABLE 1

Energy, water and iron content of a selection of foods

	Energy (kcal/g)	Water (g/g)	Iron[1] (µg/g)
Masterfoods Twix® bar (42183)	5.5	0.02	13
Oat breakfast bar (43100)	4.6	0.04	32
Regular mayonnaise (04018)	3.9	0.4	2
Kellogg's Special K® (08067)	3.8	0.03	270*
Light mayonnaise (04011)	3.3	0.55	2
White bread (18069)	2.7	0.36	37
Roasted chicken meat (05013)	1.9	0.6	12
Cooked clams (15159)	1.5	0.64	280∞
Cooked wild eastern oyster (15169)	1.4	0.70	120∞
Roasted meat from Cornish game hens (05310)	1.3	0.72	8
Cooked shrimp (15151)	1.0	0.77	31
Extra light mayonnaise (04013)	0.7	0.82	1
Boiled spinach (11458)	0.2	0.91	36
Boiled celery (11144)	0.2	0.94	4

Entries retrieved from the USDA National Nutrient Database for Standard Reference, Release 22 (2009) and are identified by a 5-digit nutrient database number in parentheses.
[1]Two billion people, over 30% of the World's population are anaemic, many due to iron deficiency (World Health Organization 2009).
*fortified with iron, ∞food with a high natural iron content and a low energy density.

processed foods could be created in a more natural, low energy dense way i.e. with high water content. For example, a new and effective way to use molecular recognition would be to structure a chocolate biscuit bar (solid processed food) similar to a celery stalk, to increase its water and fibre content which would substantially lower its energy density (<1.6 kcal g^{-1}). This would allow the same amount of food to feed more people, increasing food security. Celery stalk cells are pressurised with water causing the entire plant to become turgid and stiff. Food technologists could harness this natural turgor force to produce a firm chocolate bar, biscuit or breakfast cereal with a good bite, without altering the appearance or taste of the product. Water carries flavour with few calories e.g. a cup of tea without milk = 0.01 kcal g^{-1} and taste sensation per mouthful could be improved using the principles of Ultrafine food technology (Eminate Limited, Nottingham, UK); processing food on the nanoscale to increase the surface area that is in contact with taste and smell receptors. The bioavailable nutrient content (including cofactors – Das 2006; Robson 2009) of processed foods could be increased by existing bioactive nanoencapsulation.

It is important to consider not only the energy content of a diet but also the energetic cost of its assimilation. A reduction in liquid calorie intake has been found to have a stronger effect on weight loss than a reduction in solid calorie intake (Chen *et al*. 2009). Sugar sweetened beverages (SSBs) require little digestion. Glucose and fructose can be directly absorbed into the bloodstream without digestion. Functional foods are required to simultaneously satisfy the 'sweet tooth' that the modern diet has created, and have a significantly higher energetic assimilation cost compared to today's sugar sweetened foods. This could be achieved by adding protein and fibre to e.g. SSBs, honey, syrup, jam, cereal products and ice cream (Table 2). Protein has more than three times the thermic effect of either fat or carbohydrate (Crovetti *et al*. 1998) and because it has a greater satiety value than fat or carbohydrate (Crovetti *et al*. 1998; Stubbs 1998), increased dietary protein is an effective weight-loss strategy for the overweight or obese. Calorie-restricted high-protein diets are more effective than calorie-restricted high-carbohydrate diets in promoting (Baba *et al*. 1999; Skov *et al*. 1999; Layman 2003) and maintaining (Westerterp-Plantenga *et al*. 2004) weight loss in overweight subjects while producing less hunger and more satisfaction (Johnston *et al*. 2004). Furthermore, high protein diets have been shown to improve metabolic control in patients with type 2 diabetes (Seino *et al*. 1983; Odea 1984; Odea *et al*. 1989). Some protein based nanotubes are food-grade materials (Graveland-Bikker and De Kruif 2006) and could increase protein consumption at the expense of lowered carbohydrate.

Cooking has obvious beneficial effects by increasing food safety and improving diet quality (Carmody and Wrangham 2009). However, cooking can reduce the water content of a high energy dense processed food. Thus, further increase its deleteriously high energy density, especially if it is cooked twice. For example, toasting whole-wheat bread increases its energy density from 2.5 kcal g^{-1} to 3.1 kcal g^{-1} as water content decreases by 14% (data calculated from USDA National Nutrient Database for Standard Reference). Nanoscale science and technology are now enabling us to understand many

TABLE 2

Sugar, protein and fibre content of a selection of sweet foods and drinks

	Sugar (g/100g)	Protein (g/100g)	Fibre (g/100g)
Granulated sugar (19335)	99.8	0.0	0.0
Brown sugar (19334)	97.0	0.1	0.0
Honey (19296)	82.1	0.3	0
Boiled sweets (19107)	62.9	0.0	0.0
Maple syrup (19353)	59.5	0.0	0.0
Apricot preserve (19719)	43.4	0.7	0.3
Kellogg's frosted flakes® (08069)	38.7	4.3	1.8
High fructose corn syrup (19351)	26.4	0.0	0.0
Vanilla ice cream (19089)	20.7	3.5	0.0
Cola drink (14148)	10.6	0.0	0.0
Red Bull® drink (14154)	10.1	0.3	0.0

Entries retrieved from the USDA National Nutrient Database for Standard Reference, Release 22 (2009) and are identified by a 5-digit nutrient database number in parentheses.

natural and unnatural processes. Studying nanostructures at the cell and DNA level, gives us insight in to the working of these processes and how to manipulate, prevent and/or enhance them for the benefit of mankind. Emergent technologies can and must help correct the food system by creating modern convenience foods on a mass scale that mimic and improve on the nutritional value of the most nutritious cooked wild foods for humans. Thus, helping to reduce mental ill health, obesity and other postprandial insults (Robson 2009; Robson 2010).

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