Resurrection Sugar™ – the Rejuvenating and Functional Properties of Trehalose

An overview of the benefits of trehalose by Vic Cherikoff B.App.Sc.

What is trehalose?

Trehalose is a disaccharide made from two tightly bonded glucose molecules and giving it the biochemical descriptor: α-d-glucopyranosyl α-d-glucopyranoside. The difference of this di-glucose structure compared to the two glucose molecules bound together in maltose is simply the way they are linked. Trehalose is described as a 1–1 link and maltose is a 1–4 link. This relates to the numbers assigned to the carbon atoms in the glucose molecules.

The USFDA and European regulators class trehalose as GRAS and it is now available in over 40 countries. It is made commercially for the food and pharmaceutical industries by a patented enzymatic process using tapioca or corn starch as a base carbohydrate. It is only now beginning to appear in foods, beverages and dietary supplements as it catches up to its well accepted use in cosmetics, vaccines and other pharmaceuticals. Interestingly it is used in eye drops, stem cell research and IVF cell storage and the US Department of Defense has an interest in using trehalose-stabilized blood powder as a replacement for chilled transfusion fluids in battlefield medical units.

In nature, trehalose plays a key role in anhydrobiosis or the survival of plants, micro-organisms and insects in environments where prolonged desiccation is a challenge. The sugar is thought to form a gel phase as cells dehydrate, which prevents disruption of internal cell organelles by effectively anchoring them in position. Rehydration then allows normal cellular activity to be resumed without the major, generally lethal damage that would normally follow a dehydration/rehydration cycle. This protective role (amongst many other functions) justifies the branding of this amazing carbohydrate as Resurrection Sugar™.

A snapshot of some benefits of trehalose use

mild sweetness	stabilizes proteins and biological systems
non-reducing sugar	suppresses lipid acidification/oxidation
high glass transition temperature	supplies energy w/o excessive insulin release
chemical and thermal stability	sustained energy release
very low hygroscopicity	low cariogenicity (dental health)
protects starches from ageing	extends shelf life in some frozen products

The protective roles of trehalose

This is a unique sugar capable of protecting a wide range of other biological molecules against environmental stress including heat shock. These molecules include enzymes and other proteins; lipids and membranes they form; other sugars and their conjugated products such as glycoproteins, glycolipids and glycans. The latter are important in cellular communication and the support by trehalose of these macromolecules may be the mechanism by which it is able to suppress vasospasm, inflammatory responses and lipid peroxidation in subarachnoid hemorrhage studied in Tokyo University veterinary research (Echigo R, 2012).

A stable, colorless, odor-free and non-reducing disaccharide, trehalose is widespread in nature. It is found in mushrooms (the reason dried shiitake mushrooms rehydrate so well is due to the trehalose), honey, lobster and foods produced using bakers and brewer's yeast. It also appears that trehalose is found in many wild foods in Australia and possibly in arid zone wild food plants of other countries too.

Non-reducing sugar

The fact that it is a non-reducing sugar is a consideration for food scientists in that it resists the formation of Maillard products which are those roasted, toasty notes we love so much in cooked foods and which are important flavours in baked goods and meat marinades. However, the downside of Maillard product formation as hundreds of flavour compounds are created from the reaction of sugars with proteins is that they are steps towards the production of AGEs (see boxed text) and their deleterious health effects. The use of trehalose to sweeten foodstuffs and avoid Maillard product formation during dry cooking may provide health benefits, particularly for pre-disposed individuals eg those with diabetic retinopathy.

Maillard products are different to products of sugar caramelization although the two reactions can look the same in food (browning) and even confuse the palate in many instances. Other sources of Maillard products (soy sauce, yeast spreads, coffee, chocolate, Wattleseed, amino extracts, etc) are used in pre-prepared foods along with extended time cooking eg sous vide at low pH, to form Maillard products or caramelized sugars are added. Trehalose combined with caramelized sucrose, glucose or fructose may play a mitigating role in reducing Maillard reactions and help us to have both, taste and better health.

Stabilizing potential

The high stability of trehalose even after heat processing or prolonged storage benefits flavour and color retention in food. It reduces starch ageing in chilled or frozen flour products (breads, doughs, noodles, sauces, etc) and increases frost resistance in many other food products. The ability to stabilize proteins and intact biological systems also protects against damage caused by drying as much as freezing.

Low hygroscopicity

Crystalline trehalose remains free-flowing up to 94% relative humidity and can reduce product caking and water absorption in dry mixtures eg seasonings and coatings on food components. Compared with other disaccharides, trehalose has a high glass transition temperature and combined with its low hygroscopicity and process stability, it is ideally suited as a carrier for spray-dried flavours, proteins and other functional actives.

Mild sweetness

Trehalose provides energy with a clean taste with similar time of onset and persistence of sweetness to sucrose. It has zero after-taste and around 45% of the sweetness of sucrose, the sugar which is more typical in conventional fruits bred for sweetness and produced in 'pampered paddocks' with irrigation and fertilization. Few wild foods are as sweet as say, a modern-breed mango with its 15% total sugar content at a staggering 3% more sugar than is found in popular cola drinks.

The softer sweetness of trehalose enhances rather than masks the natural flavors in different types of foods. For example, Wattleseed is the Maillard-rich, roasted acacia seed product which has become a basic ingredient in our contemporary Australian cuisine. It exhibits its full flavour profile of coffee, chocolate and hazelnut when either used with dairy products or with trehalose as a sweetener. Add sucrose and the flavour diminishes markedly. Interestingly, add milk or cream and a delicate, natural sweetness appears, probably as the lactose in the dairy product is unmasked.

Fruit flavours and some of the more delicate aromatics of herbs can be more easily masked by sucrose than trehalose and thus quality products can deliver a better flavour when the right sugar is used.

Micro-sugars – Good Sugars vs Bad Sugars

Micro-sugars may be termed 'good sugars' analogous to good fats while sucrose, high fructose corn syrup and rich sources of fructose as in agave nectar might well be considered the bad sugars.

Trehalose appears to be one of around 20 important micro-sugars in Australian wild foods, particularly in several leafy flavourings (tree-herbs such as lemon myrtle and mountain pepper). Other micro-sugars include mannose, rhamnose, raffinose, ribose, xylose and arabinose for example and these are present in wild fruits and tubers that were variably important to the 600 Aboriginal nations in traditional times.

Current research suggests that micro-sugars assist in regulating the permeability of our cell walls enhancing the bioavailability of antioxidants, sugar-conjugates (glycans, glycoproteins, glycolipids), minerals and other beneficial phytonutrients. Mixtures of micro-sugars are used in therapeutic protocols to over-come multi-drug resistance in cancer cells and to assist anti-cancer drugs move through the cell wall.

Glycobiology, Glycation and AGEs

A relatively new science is that of glycobiology which considers the implications of the reaction of sugars with other sugars, proteins and lipids in processes of glycation or glycosylation.

Exogenous or external glycation and the formation of advanced glycation end-products (AGEs) are the result of the non-enzymatic reaction of sugars with proteins and lipids. In our body, enzyme-controlled addition of sugars to protein or lipid molecules is termed glycosylation which occurs at defined sites on the target biomolecule and is required in order for the resultant sugar-conjugate to function. In comparison, without the controlling action of enzymes, glycation is a haphazard process that impairs the functioning of the molecules involved. It is a process that is analogous to the formation of free radicals and other reactive intermediates. Glycation can happen within the body (endogenous glycation) and also during food processing (exogenous glycation) forming dietary AGEs.

AGEs are implicated in many age-related chronic diseases such as: Type II diabetes mellitus (pancreatic beta cell damage); cardiovascular diseases (the endothelium, fibrinogen, and collagen are damaged); Alzheimer's disease (amyloid proteins are side-products of the reactions progressing to AGEs); cancer (acrylamide and other side-products are released); peripheral neuropathy (the myelin is attacked, and other sensory losses such as deafness (due to demyelination); and blindness (mostly due to micro-vascular damage in the retina).

http://en.wikipedia.org/wiki/Glycation

Glycation and trehalose

The endothelial cells of the blood vessels are damaged directly by glycations, which are implicated in atherosclerosis, for example. Atherosclerotic plaque tends to accumulate at areas of high blood flow (such as the entrance to the coronary arteries) due to increased presence of sugar molecules, glycations and glycation end-products at these points. Glycation can lead to stiffening of the collagen in the blood vessel walls leading to high blood pressure or it can cause a weakening of the collagen which may lead to micro- or macro-aneurisms; this may cause strokes if in the brain.

The good news is that trehalose reduced AGEs and nanofibril formation of human serum albumin under in vitro glycation conditions and improved its helical structure (Sharifi E, 2009). Trehalose itself appears to be resistant to glycation (Motomiya Y, 2003) so its contribution to AGE formation is not significant. By comparison, fructose and galactose are glycated 10 times more than glucose. Additionally, high circulating sugars in the blood as in diabetes, increases the likelihood of AGEs. This means that trehalose replacement of sucrose in more foods may protect against AGE formation by inhibiting glycation and not contributing to the process as a component sugar itself.

Dietary AGEs and their accumulation over time are implicated in the progress of a wide range of conditions, from age-related and diabetic disorders to aged skin and chronic tiredness. Blocking or reducing AGE formation may be a novel therapy for some of these conditions and present new opportunities for the food industry.

Beverages sweetened with trehalose are now entering the market and their functionality puts them into the superfood category along with high antioxidant fruit beverages. Preliminary research indicates that trehalose elicits a lower blood sugar rise and a lower insulin response than glucose (Maki KC 2009, van Can JG, 2011). This effect is due in part, to the resistance to digestion until trehalose is exposed to the enzyme trehalase in the intestine as well as some antioxidant effect on insulin resistance.

Additionally, there is some research that suggests that trehalose inhibits protein plaque buildup that causes neurodegenerative diseases like MS, Alzheimer's and Parkinson's diseases, motor neurone disease and Huntington 's chorea (M. Tanaka 2004).

Trehalose appears to inhibit fat cell enlargement and may play a role in preventing metabolic syndrome (initial results from Hayashibara Biochemical Labs Japan 2013).

One of the most interesting recent discoveries is the possible role of trehalose and telomeres. Telomeres are the DNA-protein complexes at the ends of chromosomes and which are essential for maintaining genomic stability. In the human body, the telomeres get shorter with age and when they reach a certain length, the cells cannot divide creating senescent cells. This compromises immunity and organ function and reduces tissue elasticity. Trehalose appears to protect telomere flexibility and maintains its length in cryopreservation and possibly in vivo as well (Spinelli 2011).

Conclusion

It is early days for trehalose in the food industry and the body of research on its benefits in human health is less than a few decades old. However, from the existing indicators, the term Resurrection Sugar™ appears to be well earned and as a result the food and nutrition industries will certainly continue to explore this natural sweetener as a substitute for at least some of the 80g of sucrose we each consume in an average day in Australia (and 120g a day in the USA). We can be confident of seeing more super food supplements and products enhanced with Resurrection Sugar™ entering the marketplace as we pursue the dream of living well past our four score and ten years with the health of a 16 year old (but with better judgment).

A comprehensive scientific review encompassing clinical uses of trehalose can be found here: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3102588/