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Sustainable Agriculture: Nutrition of Indigenous American 3 Sisters Garden Compared to Monoculture Corn Production and a Cool Old Squash

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Authors' contributions

This work was carried out in collaboration among all authors. All authors designed the study. Author GH performed the statistical analysis. Author DP wrote the protocol and author PAT wrote the first draft of the manuscript. All authors managed the analyses of the study. Authors PT and GH managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Balancing productivity, profitability, human health, and environmental health is a key challenge for agricultural sustainability. After WW2, however, U.S. government agricultural subsidies have created cheap corn that the processed food industry has infused into virtually every aspect of the American diet. As a result, rates of diabetes, heart disease, hypertension, kidney disease, obesity, and metabolic syndrome have increased significantly in the past forty years, especially among low socio-economic groups and non-Western peoples, due to the low cost of processed foods. Additionally, industrial monoculture corn production depletes soil nutrients and increases weeds and insects, requiring fertilizer and pesticide inputs that contaminant water, reduce biodiversity, and contribute to eutrophication. Multi-cropping, in particular growing corn, squash, and legumes in an Indigenous American Three Sisters garden provides significantly improved nutrition per mass of

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plant compared to corn. Squash is very high in carotenoids that have been shown to reduce rates of chronic diseases, such as cancers, diabetes, hypertension, and cardiovascular disease. It also promotes eye health and improves immune function. Agricultural practices of multi-cropping also replenish soil nutrients and suppress weeds and insects, requiring fewer fertilizer and pesticide inputs. Finally, in an exciting opportunity, the ancient Indigenous American squash *Gete Okosomin*, "Cool old squash," was grown and a complete nutritional analysis was obtained and compared to common modern squashes. Different stories of its origin are also discussed.

Keywords: 3 sisters garden; Gete Okosomin; diet and nutrition; sustainable agriculture.

1. INTRODUCTION

It is estimated that about sixty percent of the current world food supply originated in the Americas. By the time Europeans arrived, Indigenous Americans had already developed many varieties of corn, beans, and squashes and had an abundant supply of nutritious food. It was not long until corn, potatoes, new varieties of beans and squash, peppers, tomatoes, cacao, chocolate, black raspberries, blueberries, cranberries, strawberries, pineapple, wild rice, peanuts, pecans, cashews, sugar from sugar cane, allspice, and vanilla were introduced around the world and integrated into cuisines of the entire world [1]. Crosby [2] stated: It is in plants that America has made its really positive contribution to the Old World… the food plants developed by the American Indian proved to be an enormously valuable acquisition for the Old World farmer. The dependence of Old World peoples on American crops in some instances [continue to] be increasing today.

Indigenous American crops were often planted in a sustainable polyculture crop, known as the Three Sisters Garden, in which corn, beans, and squash were planted together [3]. This was a staple for much of Indigenous American agriculture that provided a sustainable balance of soil chemistry and a nutritionally balanced food supply that can be sun dried and stored for an extended time [4,5]. The maize served as a tall food grass for the beans to climb, the beans functioned as nitrogen fixing legumes replacing nitrogen removed by corn, and the squash preserved the soil moisture with its low-lying vegetation while sheltering the corn and beans from pests and weeds [6,7]. The prickly vines of the squash may also deter raccoons, deer, and other pests [3]. This farming technique, therefore, reduces the need for watering, fertilizers, herbicides, pesticides and weeding. The Three Sisters is also grown in a mound system that helps retain soil water and encourages plant growth by minimizing soil compaction. Finally, when eaten together, corn, squash, and beans provide a balanced nutritious meal complete with vitamins, minerals, carbohydrates, and protein [8].

Corn is now the world's largest grain crop. Its widespread success is largely because it adapts to where it is planted, can be stored for a long period of time, and is easily manipulated [9,4]. The United States is the number one corn producing country and in addition to providing a food crop for humans, it is used for animal feed, ethanol fuel production, and many commodities. Over thirty-two million hectares of land is dedicated to corn production, most of which is used for animal feed. U.S. Government subsidies have made corn so inexpensive that food manufacturers invent ways to push corn into more products [10].

Corn in the U.S. boomed during and after World War 2 (WW2). During WW2, the U.S. government bought food commodities in surplus and shipped them to the allies in Europe. A huge expansion in corn production came after WW2, when production facilities that were making ammonium nitrate for explosives used in munitions switched to making nitrogen fertilizers for agriculture in a government attempt to convert the war machine to peacetime purposes [11]. Corn requires the most nitrogen of major crops and new hybrid strains, that were dependent on nitrogen fertilizers saw huge increases in yields in the 1950s as domestic fertilizer use skyrocketed [11,12]. At the same time, pesticides and herbicides also contributed to increased crop yields.

Today the majority of American farmland is dominated by large-scale, industrial agriculture, the system of chemically intensive food production featuring enormous single crop farms and animal production facilities. At its core is monoculture, the practice of growing single crops intensively on a large scale. Monoculture farms rely heavily on chemical fertilizer and pesticide inputs because single plant crops quickly deplete nutrients. Pesticides are needed because monoculture crops are highly attractive to specific insects and weeds [11]. Most crop systems in the U.S. are characterized by low species diversity, extensive use of fossil fuel energy and agricultural chemicals, and negative impacts on the environment [13]. Because of this industrial agriculture, inexpensive corn and corn by-products have permeated the American diet, and contributed to many negative human health impacts [14].

Monoculture corn production causes soil nitrogen and other nutrients to be diminished and it attracts weeds and insects that are increasingly resistant to herbicides. Because excess nitrogen destroys the organic matter in soil, nutrient deficient soil can also be dry and susceptible to erosion, a concern since the Earth's soil is currently depleting at a faster rate than it can be replaced [15]. When chemical fertilizers are used, unused synthetic nitrogen evaporates, contributing to acid precipitation and global warming through nitrous oxide emissions, which are three hundred times more potent than carbon dioxide [12]. It seeps into water tables, such that people in rural areas may have well water with excessive nitrates. At high enough levels, this causes methemoglobinemia which impacts both humans, especially infants and small children, and farm animals. Pesticides also impact the health of farm workers and people who live in agricultural regions. Excess nitrates run off into surface waters, leading to eutrophication. In the U.S., excess nitrates from farm fields flow into the Mississippi River and are transported to the Gulf of Mexico, where deadly algae blooms have smothered fish and created a large dead zone where the river discharges into the Gulf [11,12].

Post WW2, petroleum, much of which was imported from Middle Eastern countries, was the feedstock for fertilizers. More recently, the synthetic fertilizer industry in the U.S. increasingly relies on cheap natural gas as a feedstock because natural gas is now relatively abundant in the U.S. through the hydraulic fracturing industry, which is documented to have negative environmental impacts. This has created a concern that "If Big Agriculture becomes hooked on cheap fracked natural gas to meet fertilizer needs, the fossil fuel industry will have a powerful ally in efforts to steamroll regulation and fight opposition to fracking projects" [12].

Corn production in the U.S. has been subsidized since the 1930s, when a reduced demand from post-World War I Europe caused a glut and prices crashed. Subsidies have been criticized as disincentivizing crop diversification and harming public health by supporting more meat and processed food consumption. Use of corn for ethanol has only added to lack of crop diversification. Dumping of excess corn in the developing world also contributes to the destruction of the livelihoods of farmers [10].

U.S. government agricultural subsidies have made corn so cheap that food manufacturers have invented new ways to incorporate it into processed foods. It is used directly in breakfast cereals, crackers, and chips and indirectly as high fructose corn syrup used to sweeten soda and juice, pasta and other sauces, salad dressings, baked goods, and many other products. It is added to foods, like tomato-based pasta sauces and breads, that previously had no added sweeteners. It is also used as animal feed, so that poultry, beef, and even farmed fish products are negatively impacted [16]. High fructose corn syrup made its way into the American diet in the 1970s. It is not a naturally occurring sugar, and its use rapidly increased throughout the food supply, because it is cheap, easily amenable to numerous processed food applications, and, as a liquid, it can be easily transported. Annual consumption of high fructose corn syrup nearly tripled between 1970 and 2000. This is of concern because a high fructose diet is associated with hypertension, obesity, diabetes, heart disease, kidney disease, and metabolic syndrome [14]. Clinical studies have confirmed that fructose can induce weight gain and metabolic syndrome. In humans, diets high in fructose cause insulin resistance and impaired glucose tolerance. Even as low-fat diets have been promoted, obesity rates in the U.S. have increased as high fructose corn syrup, consumption has increased [17,18].

With rapid addition of high fructose corn syrup into processed foods, the prevalence of hypertension has been increasing globally. The greatest increase has been in groups with low socioeconomic status as processed foods are less expensive and more accessible than fresh fruits and vegetables. It is also now seen in non-western peoples, including Native Americans Indigenous peoples, particularly those living on reservations receiving government food aid which disproportionately consists of processed foods. A rise in obesity and diabetes have paralleled the rise in hypertension. In addition, obesity affects more than one-third of adults and one-sixth of children in the U.S. Likewise, hypertension impacts nearly one-third of the U.S. population, diabetes impacts seven percent, and kidney disease continues to rise at an alarming or disturbing rate such that nearly twenty million Americans have stage 1 kidney disease or greater [18].

1.1 Literature Review

Balancing productivity, profitability, human health, and environmental health is a key challenge for agricultural sustainability. There is increasing concern that intensive, monoculture industrial corn production has negative impacts and is not a sustainable process. Polyculture systems, with characteristics of the Native American Three Sisters garden have potential to produce a more varied, nutritious food supply with reduced environmental impacts.

Intercropping, the practice of growing more than one crop together, has been practiced around the world for centuries and has been shown to increase crop yields [19]. It has been shown to suppress weeds and disease [20]. Olasantan [21] showed that increased ground cover from low growing plants led to greater soil moisture through infiltration. Legumes are known to fix soil nitrogen and the practice of growing grains with legumes has been practiced in Ghana to reduce the need for fertilizer [22]. In addition, small-scale farmers who plant legumes with grain crops have seen improved soil fertility with added complete protein (i.e., providing all essential amino acids necessary for human health) to their diets [23].

A 2012 Iowa State University study found that by shifting to more diverse crop rotations, Midwest farmers could radically reduce reliance on added nitrogen, while maintaining overall levels of food production. A field study in Iowa from 2003 to 2011 compared a conventionally managed two year rotation of maize-soybean with fertilizers and herbicides applied at rates comparable to nearby farms to more diverse three and four year rotations (maize-soybean-small grain + red clover) and (maize-soybean-small grain + alfalfa-alfalfa) with lower synthetic nitrogen fertilizer and herbicide inputs plus periodic applications of cattle manure. It was found that grain yields, mass of harvested product, and profit in diverse systems were equal to or greater than those in the first conventional system. Weeds were suppressed and freshwater toxicity of more diverse systems was two orders of magnitude lower than in conventional systems [13].

Many gardeners have demonstrated that the Three Sisters system produces higher yields than the same crops grown separately in the same land area [8,24]. Cornell University agronomist and member of the Tuscarora Nation in New York, Jane Mt Pleasant, has focused on Indigenous American planting techniques, particularly the Three Sisters Garden of the Iroquois. Her work has shown that the Three Sisters is important for conserving soil, reducing pesticide use, increasing overall crop yield, and improving nutrition [25]. Mt Pleasant has also shown that the mound system of the Three Sisters helps improve root growth by reducing compaction, and because organic matter accumulates on the top when crop residues decompose, soil fertility increases. When eaten together, the corn, squash, and beans of the Three Sisters is a balanced meal of carbohydrates and protein with needed fiber, vitamins, and minerals [8].

With a growing global need for sustainable agriculture, coupled with the many poor health impacts of a diet rich in corn-based processed foods, alternative cropping systems are needed. The goal of this particular research study was to compare the overall dietary nutrient content obtained from a Three Sisters Garden to the nutrient content found in a monoculture corn crop. A second goal of comparing total food biomass production was abandoned when racoons managed to get through the fencing put up to protect the garden and ate significant amounts of corn. Fortunately, previous studies have demonstrated the high yields of the Three Sisters.

A third objective emerged when, through Indigenous American connections, seeds from *Gete Okosomin,* which is Indigenous American for “cool old squash,” whose origins will be discussed below, were obtained, and this squash was grown along with flint corn and pole beans. Because of the unique opportunity to grow and analyze this ancient Indigenous American squash, this work has provided a thorough nutritional analysis, which can be compared to more modern squashes.

1.2 *Gete Okosomin*, "Cool Old Squash"

In the course of this project, seeds from a uniquely Indigenous American squash, *Gete Okosomin,* which means cool old squash*,* were provided by a traditional Menominee farmer in Wisconsin and an *Anishinaabe* member of the Pinaymootang First Nation in Manitoba, Canada. The ancient squash has been cultivated as far north as Manitoba and the surrounding First Nation Reserves in Canada, the U.S. Native American reservations in Minnesota, Wisconsin, and other states, as well as urban community centers, such as Chicago's American Indian Center [26,27,28]. There are two stories on the origins of *Gete Okosomin*. The first was provided by renowned indigenous orator, Winona LaDuke, an enrolled member of the Mississippi Band *Anishinaabe* from the White Earth Reservation, Minnesota. La Duke is a highly recognized Indigenous author on writings ranging from indigenous economy, environmental issues, human rights, sovereignty practice, and reclamation of lands, resources, and entitlement. Her story was that an archeological dig took place somewhere in the northern region of Wisconsin/Minnesota around 2008. At the excavation site, a pottery container was unearthed and inside the container were squash seeds estimated to be over 800 years old. The seeds were donated to LaDuke for cultivation and the production of an ancient squash began on the White Earth Reservation.

The alternative story came from a University of Wisconsin-Stevens Point emeritus professor, David R. Wrone. In his story, he and another colleague were visiting a museum in the state of Indiana in 1995. Indigenous women from the Miami Nation showed them their garden with "the squash growing on the edge of the plantings". The women said that the "squash had been in the tribal economy for many generations, time out of mind, perhaps one or two thousand years" and that "each year they were planted to keep them from cross pollinating with any other type of squash". The seeds were later shipped to Wrone and his colleague in Wisconsin. Wrone states that "the Indians [i.e., people of the Miami Nation] had obviously carefully developed the squash — much I suppose like they did corn".

The first story may have been a misinterpretation of information possibly due to its exchanges from one person to another until it was ultimately delivered to LaDuke. Quite possibly, a series of different stories crossed; thereby, creating a merged tale of the 800-year-old 'clay-ball' containing ancient Indigenous heirloom squash seeds. More recently, the people of the Miami Nation are the seed keepers of *Gete Okosomin* and the squash remains an Indigenous American food plant. Nevertheless, throughout the Great Lakes region, communities have embraced *Gete Okosomin* in gardens as part of a healthy Indigenous food diet for at least hundreds of years [26,27]. Although the story of *Gete Okosomin* remains speculative, its existence is a gift of connection with traditional Indigenous American food diets and organic agricultural practices.

2. PREPARATIONS AND METHODS

At the beginning of the 2014 growing season, a plot of land on the University of Wisconsin – Green Bay campus, was plowed for planting and divided into 6 sections, three of which were planted with flint corn following mono-culture row agriculture and the other three were planted with Native American Heirloom varieties of flint corn, pole beans, and *Gete Okosomin* in an Indigenous American Three Sisters Garden. Organic fertilizer was applied. Plants reached full maturity and were harvested late September 2014. Seeds from the squash were collected and dried for future use.

Four squashes were selected for nutritional analysis. Raw samples were collected and separate samples were cooked in a conventional oven at 177-degrees Celsius (350-degrees Fahrenheit for thirty minutes. Two different types of samples were obtained: one sample having flesh and skin, the other sample having flesh without skin. Both types of squash samples were cut into thin strips, and stored at – 80 degrees Celsius in food vials that were nitrogen flushed. Cooked samples were sent to Northland Laboratory to attain a macro- and micronutrient analysis, and the raw squash samples were sent to Craft Technology laboratory to obtain a phytochemical analysis of various carotenoids. Analysis of the pole beans and flint corn were not obtained, as these have been previously documented.

3. RESULTS AND DISCUSSION

Table 1 includes the macronutrient analysis of the crop components of the Three Sisters - flint corn, pole beans, and *Gete Okosomin* squash. As the table shows, corn is relatively high in calories, most of which are carbohydrates. The overall amount of fiber and protein is relatively low and the amino acid (lysine and tryptophan) profile of the protein component is incomplete. The pole beans have a higher percentage of their calories from protein, yet are limiting in the essential amino acid methionine. The dietary combination of corn and beans demonstrates the nutritional value of the Three Sisters garden, as it provides all nine essential amino acids necessary for human health.

The vitamin and mineral content of the Three Sisters crops is seen in Table 2. The Three Sisters diet provides a more complete array of macronutrients and vitamins and minerals. For example, a number of B vitamins (i.e., B_1, B_2, B_3 and B_9) are obtained from the corn and beans, the beans provide more vitamins A (in the form of vitamin A yielding carotenoids) and C on a per calorie basis, and the squash and beans provide more vitamin E and calcium.

A phytochemical analysis of various carotenoids, Table 3, shows *Gete Okosomin* is relatively high in certain carotenoids, which are considered to be beneficial in the prevention of cancer, cardiovascular disease, diabetes, osteoporosis, and eye disease [29,30] and play an important role in health and nutrition [31]. Epidemiological studies demonstrate an association between higher dietary intake of carotenoids and lower risk of chronic diseases [29]. For example, lutein and zeaxanthin selectively accumulate in the macula of the eye's retina, and appear to protect against the development of age-related macular degeneration (AMD) [29,32]. In another example, β-carotene, lycopene and dietary intake of carotenoid-rich fruits and vegetables are inversely related to the risk of cardiovascular disease and cancers [31]. Finally, the carotenoids β-carotene and α-carotene are pro-vitamin A molecules that are metabolized into retinal, which is vital for vision and immune function. Overall, the biological actions of carotenoids ranging from immune response to antioxidant function highlights their importance for maintaining optimal health and in the prevention of human diseases [30,31,33].

Finally, *Gete Okosomin's*, carotenoid and vitamin and mineral composition was compared to a variety of modern yellow-orange squashes, including acorn, pumpkin, hubbard, butternut, and crook-/straightneck squash in Table 4. Data for the squashes was obtained from the United States Department of Agriculture, Agriculture Research Service, Food Data Central [34]. The vitamin and mineral profile of Gete Okosomin is comparable to the other modern squash varieties. As is expected, the profile of carotenoids varies among the types of squash. Among the six squash, pumpkin and Gete Okosomin had the highest amounts of total lutein and zeaxanthin, acorn, and crook/straightneck squashes had considerably smaller amounts, while butternut and hubbard had non-detectable levels of lutein and zeaxanthin. Butternut was the only squash among the six that contained cryptoxanthin. Pumpkin and butternut squashes had the highest α and β-carotene content, followed by hubbard, acorn, Gete Okosomin and crook/straightneck squash with the lowest. *Gete Okosomin*, pumpkin, and butternut squashes have a wider array of carotenoids (lutein, zeaxanthin, and pro-vitamin A α and/or β-carotene) than acorn, hubbard, and crook-/straightneck.

Table 1. Macronutrient analysis of three sisters

Nutrient per 100 grams edible portion	Flint Corn	Pole Beans	Gete Okosomin Squash
Calories	384	31	29
Protein (g)	9.85	1.83	0.4
Fat (g)	5.88	0.22	<0.1
Saturated Fat (g)	1.04	0.34	<0.01
Carbohydrates (g)	72.9	6.97	7
Dietary Fiber (g)	9.4	2.7	1 g
Total Sugars (g)	1.56	3.26	3.35
Cholesterol (mg)	0	0	0

Table 2. Micronutrient (Vitamin and Mineral) analysis of three sisters

Nutrient per 100 grams edible portion	Flint Corn	Pole Bean	*Gete Okosomin* Squash
Vitamin A (mcg RAE)	0	35	16.6
Vitamin C (mg)	0	12.2	1.09
Vitamin E (mg*)	0.37	0.41	0.44
Vitamin B_1 (thiamin) (mg)	0.3	0.082	nd
Vitamin B_2 (riboflavin) (mg)	0.09	0.104	nd
Vitamin B_3 (niacin) (mg)	2.47	0.734	0.28
Vitamin B_9 (folic acid) (mcg)	34	33	nd
Calcium (mg)	6	37	11.1
Magnesium (mg)	107	25	7.64
Potassium (mg)	322	211	382
Sodium (mg)	4	6	<1
Iron (mg)	2.99	1.03	0.16
Manganese (mg)	0.64	0.216	<0.05
Copper (ppm)	0.24	0.069 mg	0.48

**reported as mg alpha-tocopherol*

Table 3. Carotenoid profile of *Gete Okosomin*

Carotenoid	mcg/100 g
Trans Lutein	853.5
Trans Zeaxanthin	90.5
Cis-Lutein/Zeaxanthin	70
Total Lutein+ Zeaxanthin	1014
Total Lycopene	nd
a/b cryptoxanthin	nd
a-carotene	nd
b-carotene	199.5

Table 4. Comparison of *Gete Okosomin* to common squashes

Nutrient per 100 gram edible portion	*Gete Okosomin* Squash	Acorn	Pumpkin	Hubbard	Butternut	Crook/ Straightneck
Vitamin A (mcg RAE)	16.6	18	426	68	532	8
Vitamin C (mg)	1.09	11	9	11	21	19.3
Vitamin E (mg*)	0.44	0.12	1.06	0.16	1.44	0.13
Vitamin B_1 (thiamin) (mg)	nd	0.14	0.05	0.07	0.1	0.05
Vitamin B_2 (riboflavin) (mg)	nd	0.01	0.11	0.04	0.02	0.04
Vitamin B_3 (niacin) (mg)	0.28	0.7	0.6	0.5	1.2	0.45
Vitamin B_9 (folic acid) (mcg)	nd	17	16	16	27	19
Calcium (mg)	11.1	33	21	14	48	21
Magnesium (mg)	7.64	32	12	19	34	20
Potassium (mg)	382	347	340	320	352	222
Sodium (mg)	<1	3	1	7	4	2
Iron (mg)	0.16	0.7	0.8	0.4	0.7	0.44
Manganese (mg)	<0.05	0.17	0.13	0.18	0.2	0.17
Total Lutein+ Zeaxanthin (mcg)	1014	42.5	1500	nd	nd	290
β-carotene	199.5	230	3100	820	4226	90

4. CONCLUSION

Industrial monoculture agricultural practices, especially corn production, depletes soil nutrients and requires inputs of nitrogen and other fertilizers, herbicides, and insecticides to suppress weeds and insects that selectively thrive with these crops. This has led to contaminated wells in rural areas, eutrophication of surface waters, and a dead zone in the Gulf of Mexico where the Mississippi River discharges. Fertilizers and pesticides are also fossil fuel based, contributing to global climate change. Post WW2 corn production has significantly contributed to a less healthy diet for many people as inexpensive corn products, such as high fructose corn syrup, have been infused into many processed foods. As a result, rates of diabetes, heart disease, hypertension, obesity, and kidney disease have increased significantly in the past forty years, especially among low socio-economic groups and non-Western peoples. Agricultural practices, such as multi-cropping, replenish soil nutrients, require fewer fertilizer inputs; suppress weeds and insects, reducing the need for pesticides; and provide a more complete and balanced diet of macro- and micro-nutrients. The Indigenous American Three Sisters technique can increase crop yields and also provide a more comprehensive array of nutrients and phytochemicals that promote human health.

Seeds from *Gete Okosomin*, the ancient Indigenous American 'cool old squash' were obtained and included in a Three Sisters Garden on the University of Wisconsin-Green Bay campus. A nutritional analysis shows that this ancient squash is high in carotenoids which are important in human health as carotenoid intake is associated with lower risk of chronic diseases, such as cancers, diabetes, hypertension, and cardiovascular disease. The carotenoids lutein and zeaxanthin, in particular are associated with lower risk of macular degeneration. Comparison of *Gete Okosomin* to common squashes shows that, while each has a unique profile, all contain phytochemicals beneficial to human health. Previous studies also show that Three Sisters multi-cropping agriculture produces crop yields that are equal or higher than those in monoculture crops, delivering a sustainable agriculture system that provides a healthy, balanced diet for populations.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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