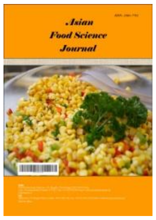

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Proximate Composition and Phytochemical Properties of Fresh and Boiled *Solanum torvum* Consumed in East of Côte d'Ivoire

Kouakou Kouadio[1], Kouassi Martial-Didier Adingra[1,2*], Martin Kouadio[1], William Kwithony Disseka[1], Oscar Jaures Gbotognon[1] and Eugène Jean Parfait Kouadio[1]

[1]Laboratoire de Biocatalyse et des Bioprocédés, Université Nangui Abrogoua (Abidjan, Côte d'Ivoire), 02 BP 801 Abidjan 02, Côte d'Ivoire.
[2]Laboratoire de Biochimie des Aliments et de Transformation des Produits Tropicaux, Université Nangui Abrogoua (Côte d'Ivoire), 02 BP 801 Abidjan 02, Côte d'Ivoire.

Authors' contributions

This work was carried out in collaboration among all authors. Authors EJPK and MK designed the study, author KK performed the statistical analysis, author KMDA wrote the protocol and the first draft of the manuscript. Authors WKD and OJG managed the analyses of the study. Authors KK and KMDA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The study aimed to evaluate the nutritional and anti-nutritional factors composition of the *Solanum torvum* fruit.
Place and Duration of Study: Department of Food Sciences and Technology, Biocatalysis and Bioprocessing laboratory of Nangui Abrogoua University (Côte d'Ivoire), between June 2019 and March 2020.
Methodology: Proximate composition, mineral element profile and phytochemical composition of fresh and boiled *S torvum* berries were investigated. The *S torvum* fruit were harvested fresh. One part was cooked in boiling water for 25 min while the other part did not undergo any treatment. These two samples were dried in an oven at 45°C for 72 hours, ground and analyzed according to

**Corresponding author: Email: maxadingra@gmail.com;*

official analytical method.
Results: The results indicated that the boiling caused the loss of nutrients except moisture, fibers and lipids. It was noted a significant reduction of nutrient and anti-nutrients content of berries after boiling. Boiled berries showed a higher energy value (57.07 Kcal) than fresh ones (53.12 Kcal). Despite the boiling, *S torvum* berries showed high levels of polyphenols (142.54 mg GAE/100g DW (dry weight)), carotenoids (12.96 mg βCE/100g DW), vitamin C (12.03 mg/100 g FW), fibers (6.88%) and ash (7.23%). Minerals analysis of *S torvum* berries indicated that it is rich in potassium (2046.77 mg/100 g DW), calcium (340.92 mg/100g DW), phosphorus (238.71 mg/100g DW) and magnesium (234.97 mg/100g DW) with high predicted bioavailability for calcium, magnesium and zinc. *S torvum* fruit contains also iron (7.97 mg/100g DW) and zinc (8.10 mg/100g DW) which are essential for organism.
Conclusion: These data indicated that this *Solanum torvum* fruit consumed in East of Côte d'Ivoire could constitute a potential good source of nutrients for local population.

Keywords: Solanum torvum berries; nutritional composition; anti-nutritional factors; mineral bioavailability.

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1. INTRODUCTION

The Solanaceae family represents one of the main plant families that includes many nutritionally important plant species [1]. Solanum is the largest and the most complex genus of the Solanaceae family which include 2000 plant species, many of which are economically important [2]. *Solanum torvum* commonly known as turkey berry is an edible plant for humans; it is a traditional vegetable for the natives [3]. It is well adapted to different agro-climatic conditions. More suitably it's ideal for the development of genomic resources targeted for domestication and commercial cultivation [4]. Indeed, it is gaining popularity in West Africa as a vegetable, especially in Ghana. As a crop, *S. torvum* is very tolerant to biotic diseases and abiotic stresses [5]. It is a very robust plant that grows without much care. Several studies have shown that *S. torvum* exhibits high levels of resistance to pests, nematodes and pathogens [6]. Alternatively, *S. torvum* is used for grafting with eggplant and tomato. It is also an ideal rootstock plant for improved environmental and climatic stress tolerance in tomatoes [7].

Solanum torvum is widely used in traditional medicine as an antihypertensive, antioxidant, analgesic and anti -inflammatory [8]. In many parts of Ghana, traditional healers usually prescribe juice made from the fruit of *S. torvum* for the treatment of anemia and other illnesses [9].

Pharmacological studies on this plant have demonstrated cytotoxic activities, antimicrobial and antiviral activity [10]. Plant parts are used as sedative, diuretic and digestive [11].

In human food these fruit are often eaten as vegetables. In African countries edible wild plants are used as food and contribute significantly to the nutritional needs of the population [12].

Solanum species are identified as the good source compounds like phenols and flavonoids with high antioxidant activities, as revealed from recent few studies in Malaysia [13].

The share of wild edible plants in the diet and even in poverty reduction of african populations is very important. In Côte d'Ivoire, most edible wild plants have not yet been recognized and biochemically characterized. However, a few local or regional studies have been conducted in certain parts of the country [14]. At the nutritional level, the biochemical studies of Herzog et al. [15] and Bédiakon [16] revealed the richness of nutrients and the importance of these wild plants in meeting the nutritional requirement of the population. In the region of V-Baoulé (Center) and Agboville (South) in Côte d'Ivoire, these researchers [15] and [16] noted that the diet of populations predisposes children to various nutritional deficiencies. The contribution of these wild plants is important for supplementing towards nutritional balance of children in this area but probably in all rural areas of Côte d'Ivoire.

It would therefore be opportune to ensure the nutrient profile after cooking for a better valorization of this fruit. The objective of this study was to analyze the proximate principles, minerals, vitamins and other phytochemicals in *S. torvum* fruit consumed by the indigenous populations of Côte d'Ivoire.

2. MATERIALS AND METHODS

2.1 Sample Preparation

2.1.1 Fresh turkey berry

The plant material consisted of fresh, mature and green *Solanum torvum* berries. These berries were collected from Tanda plantation located in the eastern part of Côte d'Ivoire. The fruits were transported directly to the Biocatalysis and Bioprocessing laboratory of Nangui Abrogoua University (Côte d'Ivoire). The selected fruits were washed with sterilized water thoroughly to free from mud, ferns and other extraneous material, dried on blotting paper. They were then manually cut with stainless steel knives and dried on stainless steel trays and after cutting, they were dried in an oven at 45°C for 72 hours. The dried samples were mechanically milled into powder with flat-hammer grinding mill and sieved through a 60 mesh screen and then stored in airtight containers for analysis [17].

2.1.2 Boiling turkey berry

The berries were cooked as described by Parkouda et al. [18]. One hundred (1000) ml of water was brought to a boil in a clean stainless steel saucepan. Five hundred grams of *Solanum torvum* berries were boiled for 25 minutes at 100°C. Then, the berries were drained, cooled for a few minutes at room temperature before being dried in a portable hot air oven at 45°C for 72 hours and powdered for analysis.

2.2 Proximate Analysis

The methods used for sample treatment and analysis (moisture, proteins, ash, fibers, lipids) were carried out following official analytical method recommended by AOAC [17]. Moisture was determined by drying in an oven at 105ºC during 24 h to constant weight. Total nitrogen was determined according to the Kjeldahl method and converted into proteins, using factor 6.25. Ash was determined by gravimetric of incinerated sample, in muffle at 550°C. Fibers were determined according to the technique described by AOAC [17] using sulfuric acid. Lipids were extracted by the Soxhlet technique with hot solvent (hexane) and afterwards were determined by gravimetric. Total sugar was determined by method of Chow & Landhäusser [19] and reducing sugar was analyzed according to the method of Garriga et al. [20] using 3,5 dinitrosalycilic acids (DNS). The total carbohydrate content was calculated by using the equation: 100 - (% moisture + % proteins + % lipids + % ash) [21]. The energy value of samples was calculated using the Atwater & Rosa [22] conversion factor: 9 $kcal.g^{-1}$ of lipids, 4 $kcal.g^{-1}$ of carbohydrate and 4 $kcal.g^{-1}$ of proteins.

2.3 Minerals Analysis

The determination of the minerals was carried out according to the method described by CEAEQ [23] using argon plasma ionizing source mass spectroscopy (ICP-MS). The minerals were atomized and ionized in argon plasma and the ions produced were analyzed by the spectrometer. The concentration of minerals in the sample was determined by comparison with standard solutions.

2.4 Phytochemical Composition

2.4.1 Extraction of phenolic compounds

Extraction of phenolic compounds was carried out according to the method described by Singleton et al. [24]. A sample (10 g) of fine dried of *S torvum* berries flour from each fresh and boiled sample was extracted by stirring with 50 mL of methanol 80% (v/v) at 25°C for 24 hours and filtered through Whatman no 4 paper. The residue was then extracted with twice additional 50 mL portions of methanol. The methanolic extracts of each sample were evaporated at 35°C (rotary evaporator HEILDOLPH Laborata 4003 Control, Schwabach, Germany) until 25 mL volume was obtained, prior to phenolic compound contents determination.

2.4.2 Total phenolic compounds

Polyphenols content was determined by spectrophotometric determination, using the Folin Ciocalteu's method described by Singleton et al. [24].

2.4.3 Carotenoids compounds

Carotenoids content was analyzed according to method described by Rodriguez-Amaya [25] using petroleum ether.

2.4.4 Vitamin C compounds

Vitamin C content was measured by titrimetric assay with 2,6-dichloroindophenol as described by Pongracz et al. [26].

2.4.5 Flavonoids compounds

The flavonoids content was evaluated using the method reported by Meda et al. [27].

2.4.6 Tannins compounds

The tannins assay was performed according to the method described by Bainbridge et al. [28] using vanillin reagent.

2.4.7 Oxalates compounds

The oxalates content was determined using the method of Day & Underwood [29] using potassium permanganate.

2.4.8 Phytates compounds

Phytate contents were determined using the Latta & Eskin [30] method.

2.5 Statistical Analysis

All chemical analyses and assays were performed in triplicate, unless otherwise indicated. Results were expressed as mean values ± standard deviation (SD). Analysis of variance (ANOVA) was done. If necessary, Duncan test was done to determine significant differences at 5% probability between means. Statistical differences with a probability value less than 0.05 ($P < 0.05$) are considered significant.

3. RESULTS AND DISCUSSION

This study on the berries of *S. torvum* made it possible to quantify its biochemical composition. The results of the proximate composition analysis of *S. torvum* fruit were presented in Table 1. These parameters differed significantly ($p<0.05$) between fresh and boiled.

The moisture content of fresh fruit was 87.86% while that of boiled fruit was 88.55%. This high moisture content of the berries of *S. torvum* shows that this fruit is highly perishable. This excessive moisture in *S torvum* berries may cause quick deterioration of these fruits when stored for a long time. This value was similar to result obtained by Akoto et al. [31] for *S. torvum* fruits from Ghana (86.23%).

The lipids content of boiled berry (2.79% DW) was significantly ($p<0.05$) higher than fresh berry (1.52% DW). The increased in the fat content of boiled when compared with the fresh fruit may be attributed to the increase of the contact surface between the sample and the extraction solvent. The method used for the determination of fat is linked to the accessibility of the solvent to the sample. Thus, the boiling made it possible to increase the contact surface between the sample and the solvent, thus leading to an increase in the lipid level. Bediakon [16] also showed that boiling (20 min. of cooking) increased the lipids content of *S. americanum* from 1.18% to 1.41%.

Crude proteins (CP) content of fresh berries of *S. torvum* was 2.07% DW, after boiling at 100°C for 25 min; it decreases to reach the value of 1.86% DW. This reduced protein content could be attributed to diffusion of certain soluble proteins in the cooking water [32]. On the other hand, Dan et al. [33] found higher CP value for *Solanum anguivi* (13.44%).

The ash content of fresh *Solanum torvum* berries was 11.76% DW, which is significantly higher than that of the boiled berries which was 7.23%. The boiling resulted in a drop in the ash of the of *S. torvum* fruit. The reduction in ash may be due to leaching of mineral compounds into the boiling water [34]. However the ash content of berries shows that it could be an excellent source of minerals. The high ash content reported in the *S. torvum* fruit may be due to high levels of minerals such as potassium, phosphorus, calcium, iron and magnesium in both types of berries (fresh and boiled) [35].

Regarding the fibers content of boiled berries (6.88% DW), it increased significantly ($p <0.05$) compared to that of fresh berries (4.09% DW). Boiling plant tissue alters the physical and chemical properties of plant cell walls, which affects their performance as dietary fibers [36]. The increase in temperature during cooking leads to the breaking hydrogen bridge and Van der Walls bonds between polysaccharides and to the cleavage of glycosidic linkages, which may result in solubilization of the dietary fibers [37]. They could play a role in the prevention of certain diseases such as constipation, appendicitis and colon cancer. The fibers present in a diet facilitate the intestinal transit.

Values of carbohydrates and reducing sugars also decreased with boiling, except for the caloric value which increased. This increased energy is partly linked to the increase in crude lipids during boiling. The amount of carbohydrates was significantly ($p < 0.05$) decreased during boiling compared to the control (fresh berry carbohydrates). This can be related to diffusion of soluble compounds in the cooking water. In a similar study conducted by Akoto et al. [31] in Ghana, lower carbohydrates percentage of fresh *S. torvum* berries (7.04% DW) than present study (7.79% DW) was found.

The mineral content of fresh and boiled *Solanum torvum* are shown in Table 2. The content of minerals after 25 min of boiling were: potassium (2995.76 - 2046.77 mg/100g DW), calcium (586.14 - 340.92 mg/100g DW), phosphorus (449.31 - 238.71 mg/100g DW), magnesium (375.57 – 234.97 mg/100g DW), copper (13.76 – 10.47 mg/100g DW), zinc (12.78 – 8.10 mg/100g DW), iron (10.82 - 7.97 mg/100g DW) and manganese (9.97-7.87 mg/100g DW). These observed reductions may be due to leaching of the mineral compounds into the boiling water.

S torvum berries have high levels of macro elements like K, Ca, P and Mg. Standard mineral requirements for human are: potassium (2 - 4 g/day), calcium (500-1000 mg/day), magnesium (360 mg for an adult woman and 420 mg for an adult man/day), iron (8 mg/day) and zinc (6 mg/day) [38,39]. The mineral content of *S. torvum* berries show that their regular consumption could fulfil these daily needs. Minerals play a vital role in human health. They are implicated with several body functions such as enzymatic reactions, energy production, transmission of nerve impulses, and multiple biological reactions. In addition, *S. torvum* berries contain trace elements such, iron (10.82 in fresh, 7.87 in boiled), copper (13.76 in fresh, 10.47 in boiled), manganese (9.97in fresh, 7.87 in boiled) and zinc (12.78 in fresh, 8.10 in boiled) (Table 2). These trace elements participate in metabolic reactions. The daily requirements of the human body in trace elements such as iron (Fe) are 16 mg for an adult woman and 9 mg for an adult male [39]. Daily consumption of foods containing *S torvum* could cover Fe needs and thus prevent the risk of anemia. Iron is an essential constituent of hemoglobin and is also involved in many enzymatic reactions [40]. Particularly, *S. torvum* berries could be recommended in diets for reducing anemia which affects more than one million people worldwide.

Table 1. Proximate composition of fresh and boiled *Solanum torvum* berries

Parameter (g/100g DW)	*Solanum torvum* berries	
	Fresh	Boiled
Moisture	87.86±0.22^{a}	88.55±0.10^{b}
Crude protein	2.07±0.03^{a}	1.86±0.05^{a}
Ash	11.76±0.04^{a}	7.23±0.03^{b}
Fiber	4.09±0.04^{a}	6.88±0.04^{b}
Lipid	1.52±0.01^{a}	2.79±0.01^{b}
Totals sugar	1.69±0.03^{a}	0.62±1.44^{b}
Reducing sugar	0.71±0.48^{a}	0.23±0.04^{b}
Carbohydrate	7.79±3.40^{a}	6.13±2.05^{b}
Caloric value (Kcal)	53.12±0.89^{a}	57.07±0.54^{b}

Tests: n = 3; the means ± standard deviation, assigned different letters on the same row indicate are significant difference at 0.05 level of significance according to Duncan's test

Table 2. Mineral contents of fresh and boiled *Solanum torvum* berries

Minerals content	*Solanum torvum* berries	
	Fresh (mg/100 g DW)	Boiled (mg/100 g DW)
Mg	375.57±0.36^{a}	234.97±0.17^{b}
P	449.31±0.38^{a}	238.71±0.12^{b}
K	2995.76±0.21^{a}	2046.77±1.15^{b}
Ca	586.14±0,41^{a}	340.92±0.35^{b}
Mn	9.97±0.09^{a}	7.87±0.08^{b}
Fe	10.82±0.14^{a}	7.97±0.13^{b}
Cu	13.76±0.22^{a}	10.47±0.10^{b}
Zn	12.78±0.14^{a}	8.10±0.14^{b}

Tests: n = 3; the means ± standard deviation, assigned different letters on the same row indicate are significant difference at 0.05 level of significance according to Duncan's test

Total phenolic, carotenoids, vitamin C, flavonoids, tannins, oxalates and phytates were evaluated in fresh and boiled *S torvum* and results are presented in Table 3. Statistical analysis showed that there is significant difference ($p< 0.05$) between the values of phytochemicals obtained for fresh berries and boiled berries.

The boiling significantly reduced the content of phytochemicals.

The total phenols content of fresh *S torvum* berries (356.70 mgGAE/100g DW) decreases during boiling to reach a value of 142.54 mgGAE/100g DW after 25 min. This loss was about 60% after 25 min of boiling.

Phenolic compounds include phenolic acids, flavonoids, tannins, and less common compounds such as stilbenes and lignans [41]. Polyphenols are water-soluble organic molecules comprising at least one phenolic group in their structure and generally have a high molecular weight widely found in the plant kingdom. They have anti-inflammatory, urinary antiseptic, anti-free radical, hepatic-protective, immune stimulant, anti-thrombotic and anti-carcinogenic effects [42].

These reductions are either due to diffusion of soluble compounds in the cooking water or enzymatic hydrolysis by activation of enzymes on cooking. The thermal degradation of these molecules, as well as the changes in their chemical reactivity or the formation of insoluble complexes, could also explain their significant reduction by cooking. Since these compounds are known to be substances which inhibit or slow down the oxidation of a substrate, they play an important role in the body.

The carotenoids content of fresh *S torvum* berries (35.31 mg βCE/100g DW) decreases during boiling to reach a value of (12.96 mg βCE/100g DW) after 25 min. Cooking in water caused huge losses of vitamin C and carotenoids. These losses are evaluated at 63% for carotenoids and 78% for vitamin C. The work of Bediakon [16] indicated that boiling led to a more or less marked decrease in nutritional value, either by diffusion of water-soluble constituents in the cooking water, or by destruction of thermolabile and / or oxidizable substances in vegetables.

Levels of anti-nutritional factors such as tannins, oxalates and phytates are also shown in Table 3. Boiling reduced also the level of tannins, oxalates and phytates in *S torvum* berries.

These losses are evaluated at 60% for tannins, 76 % for oxalates and 66% for phytates. The loss can be attributed to the water soluble compounds leaching into the cooking water as well as the breakdown of these compounds during cooking.

Knowledge of the tannins oxalates and phytates content of a food is necessary because a high level of these anti-nutritional compounds can have deleterious effects on digestibility [34]. Phytates and oxalates form complexes with essential minerals, making minerals unavailable to the body. These low levels of anti-nutritional factors caused by boiling allow a safe consumption of *S torvum* berries, since the lethal dose of oxalates is between 2000 and 5000 mg of oxalates/100 g of food [43] and that of phytates between 250-500 mg of phytates/100 g of food [44].

Tannins contents recorded in this work were 685.83 mg TAE/100g DW for fresh berries and 276.02 mg TAE/100g DW for boiled berries. The tannins content in the fresh fruit is similar to recorded by Pramodini and Uday [45] as 6700 mg/100g TAE/100g DW. This value is however higher than value recorded for *Solanum aethiopicum* by Eze and Kanu [46]. Boiling brought significant reductions in the tannin contents from the fresh one. Arinola et al. [47] also observed significant decrease in tannins contents when African walnuts were boiled.

Phytates is known to decrease the bioavailability of minerals, especially calcium, magnesium, iron and zinc. To predict the effect of phytates on the bioavailability of calcium, magnesium, iron and zinc, phytates to nutrients ratios were calculated. Also, to predict the effect of oxalates on the bioavailability of calcium, magnesium, oxalates to nutrients ratios were calculated. The molar ratios between anti-nutrients and minerals of *S torvum* berries are shown in Table 4. The results indicated that molar ratio of [Oxalate]/[(Ca+Mg)], [Oxalate]/[Ca], [Phytate]/[Fe], [Phytate]/[Ca] and [Phytate]/[Zn] for *S torvum* berries were 0.51, 0.84, 21.20, 0.39 and 17.95 respectively. After boiling these ratios decreased. The molar ratios of [Oxalate]/[(Ca+Mg)], [Oxalate]/[Ca], Phytate]/[Fe], [Phytate]/[Ca] and [Phytate]/[Zn] for boiled *S torvum* berries were 0.20, 0.34, 9.72, 0.23 and 9.56 respectively. The critical ratios reported are as follows: Phytates / Fe: 1.0 [48], Oxalate / (Ca + Mg): 2.5 and Oxalate / Ca: 2.5 [49], Phytates / calcium: 0.24 [50], Phytates / zinc: 15 [51].

Table 3. Phytochemical contents and anti-nutritional *factors* of fresh and boiled *Solanum torvum* berries

Parameters (mg/100 g DW)	*Solanum torvum* berries	
	Fresh	**Boiled**
Polyphenols (mg Gallic Acid Equivalent /100g)	356.70±0.02[a]	142.54±0.01[b]
Carotenoids (mg βeta Carotene Equivalent /100g)	35.31±0.10[a]	12.96±0.01[b]
Vitamin C (mg/100 g FW)	56.82±0.32[a]	12.03±0.21[b]
Flavonoids (mg Quercetin Equivalent /100g)	7.88±0.01[a]	2.70±0.02[b]
Tannins (mg Tannic Acid Equivalent /100 g)	685.83±0,01[a]	276.02±0.04[b]
Oxalates (mg Oxalic Acid /100g)	494.79±0,29[a]	115.91±0.15[b]
Phytates (mg Phytic Acid Equivalent /100g)	229.44±0.04[a]	77.44±0.15[b]

Tests: n = 3; the means ± standard deviation, assigned different letters on the same row indicate are significant difference at 0.05 level of significance according to Duncan's test

Table 4. Numerical ratio between anti-nutritional factors and minerals in fresh and boiled berries of *Solanum torvum*

Parameters	*Solanum torvum* berries		
	Fresh	**Boiled**	**Critical value**
Oxalates /(Ca+Mg)	0.51	0.20	2.5
Oxalates /Ca	0.84	0.34	2.5
Phytates /Fe	21.20	9.72	1
Phytates /Ca	0.39	0.23	0.24
Phytates /Zn	17.95	9.56	15

*The critical values are shown below: Phytates / Fe: 1.0 [47], Oxalate / (Ca + Mg): 2.5 and Oxalate / Ca: 2.5 [48], Phytates / calcium: 0.24 [49]***,** *Phytates / zinc: 15 [50]*

The molar ratios of anti-nutrient to minerals were low compared to their corresponding critical value except that of the [Phytate]/[Fe] which was higher than critical value.

These results indicate that absorption of calcium, magnesium and zinc may not be adversely affected by phytates and oxalates. Although cooking lowers the berry's phytate levels, iron is chelated by phytates, reducing its bioavailability. Acho et al. [34] reported that *S. melongena* had higher molar ratio of [phytates]/ [Fe] than the critical level indicating that the phytates of these leafy vegetables may hinder iron bioavailability.

4. CONCLUSION

This study has revealed that *S torvum* berries consumed in East of Côte d'Ivoire could help to cover the nutritional needs of the populations. They are very rich in polyphenols, carotenoids, vitamin C, fibers and ash. The minerals analysis of *S torvum* berries indicated that it is rich in most mineral elements with high expected bioavailability for calcium, magnesium and zinc.

Boiling caused a significant reduction of nutrient and anti-nutrients content of berries after 25 min. The losses in anti-nutrients (oxalates, phytates) might have beneficial effect on bioavailability of minerals like zinc, calcium, magnesium and iron.

The consumption of this plant berries could therefore provide several health benefits. As a spontaneous food plant, this plant deserves to be popularized. Thus, it could contribute to populations' food security.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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