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Nutritional Value of *Spirulina platensis* (Oscillatoriaceae), an Algae Produced and Consumed in Côte d'Ivoire

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Abstract

Spirulina platensis (Oscillatoriaceae) commonly called Spirulina or blue algae is a cyanobacteria traditionally used for hundreds of years worldwide for its nutritional and pharmacological virtues. In Côte d'Ivoire, these microscopic algae produced and used as a nutritional supplement did not undergo many scientific studies, therefore an investigation to ascertain its nutritional properties which could justify its empirical use was carried out. For this purpose, analysis of minerals was performed by an atomic absorption spectrophotometer and revealed the presence of Calcium, Sodium, Magnesium, Phosphorus, Potassium, Iron, Fluorides, Iodine, Manganese, Selenium, Zinc and Copper. Extraction and determination of vitamins were done according to standard methods (AOAC, NF) and demonstrated the presence of liposoluble vitamins (Beta carotene, vitamin A, vitamin E and vitamin D3) and water-soluble vitamins (vitamin C and those from group B) vitamins.

The extraction by Soxlhet method with petroleum ether and the determination of fatty acids by gas chromatography revealed the presence of saturated, monounsaturated and polyunsaturated fatty acids. Our findings demonstrated that *Spirulina platensis* produced in Côte d'Ivoire has proven nutritional properties.

Keywords: *Nutritional Value; Spirulina platensis; Algae; Côte d'Ivoire*

Introduction

Malnutrition is thought to be a public health issue [1-3]. It therefore causes many diseases such as kwashiorkor, stagnation, thyroid gland tumor, obesity, diabetes, anaemia, cancer and cardiovascular diseases [4,5]. According to FAO, 842 million people suffer from malnutrition in the world with 798 million in developing countries [6,7]. In 2006, more than 36 million people died from hunger or diseases basically related to food insufficiencies [8]. According to WHO, malnutrition is the greatest cause of youth mortality, in half percent of the cases [9]. Six millions of children die of hunger every year [10]. In Côte d'Ivoire, the nutritional state of vulnerable people was strongly affected during the decade of socio-political crisis. Furthermore, the most current form of these nutritional disorders remains chronic malnutrition with a prevalence reaching 30% to 40% in some areas of the country. As for acute malnutrition, the situation remains appalling with a prevalence rate reaching 7.1%, with regional disparities and rates close to the emergency case of 10% [11]. UNICEF is struggling to prevent the worst effects of malnutrition by granting funds and assistance to countries, by distributing essential micronutrients,

deworming tablets to improve the health of vulnerable people during vaccination campaigns or through fortified food [12]. It is in this context that ANTENNA Technologies a Swiss foundation committed to research and diffusion of adapted technologies to tend to the bare needs of developing countries by framing tools and trainings to locally and sustainably produce an exceptional food supplement: Spirulina, resulting from a microalga which can locally be cultivated and provides essential nutrients such as vitamin A, essential amino acids, iron. In collaboration with local structures, ANTENNA Technologies has developed in various countries of Africa and Asia a Spirulina production area which gain financial autonomy by selling approximately 60% of its production and the rest being distributed in schools, dispensaries, hospitals [13]. Indeed, *Spirulina Platensis* (Oscillatoriaceae) commonly called Spirulina or blue algae is a cyanobacteria traditionally used for hundreds of years and known for its food protein properties [14]. In developed countries, Spirulina is consumed as a health beneficial food supplement. It is sold with products known as "Bio" [15]. According to Falquet and Hurni, Spirulina contains a wide range of vitamins, minerals and trace elements [16]. In addition, the studies of Kambou., *et al*. showed that Spirulina has antianemic and immunostimulatory properties in rabbit [17,18].

The nutrient values contained in Spirulina are mean values because its nutritional composition varies from one production area to another and depends on the culture medium implemented by producers [19]. Moreover, due to the scarcity of scientific research on Spirulina produced in Côte d'Ivoire, it appears convenient to us to determine and to evaluate the nutritional value of *Spirulina platensis* produced in Côte d'Ivoire in order to assess whether its consumption can be an alternative for nutritional deficiency problem.

Specifically, it was to:

- Determine the contents of the main nutritional compounds of *Spirulina platensis*;
- Compare the different nutritional values of *Spirulina platensis* from the production areas between them and with the values of some countries on the one hand, and with the recommended nutritional intake on the other hand.

Materiel and Methods

Plant material

The plant material was made up of dry powder of *Spirulina platensis* provided by SAP (Société Agro-Piscicole) of Lamé in the Department of Adzopé (Côte d'Ivoire) where the production unit is settled. In fact, SPIRULINA is produced in ponds covered with greenhouses. The harvest consists of filtering a part of the culture on a linen cloth (mesh diameter of 40 µm) after opening the valves connecting the ponds to the laboratory. The biomass obtained is drained, dewatered, pressed, weighed, extruded and then dried in a dehumidifier at 45°C. Once dried, SPIRULINA is ground using a grinder to obtain a powder. This powder is also used for manufacturing tablets and capsules.

Energetic value and fatty acids contents

The extraction of fatty acids was done by using a soxhlet and was converted to methyl ester by saponification and then by esterification. Quantification of fatty acids was carried out by gas chromatography (GC).

Minerals contents

Determination of minerals rate was done according to the method described by Clément and Françoise [20]. The samples were mineralized by calcination in a muffle furnace set at 550°C for 5 hours. Determination of minerals was carried out after preparation of samples and standard solutions. Calibration solutions were used for the calibration of the flame atomic absorption spectrophotometer. P was assayed by colorimetry while Fe, Mn, Na, Cu, Mg, Ca, Zn and K was performed by the atomic absorption spectrophotometer (AAS 20 type VARIAN, Australia). The following steps were used to determine the different quantities of stock solution (mL) to be taken: Results of optical densities (OD) read at the wavelength corresponding to each mineral helped to determine the quantities of minerals contained in Spirulina samples. The minerals contents were determined as follows: OD readings by atomic absorption spectrophotometer was done at different wavelengths: 766.5 nm; 422.7 nm; 285.2 nm; 248.3 nm; 279.5 nm; 589 nm; 285.2, respectively for K, Ca, Mg, Fe, Mn, Na, Mg and 24.7 nm for Cu and Zn.

The tests were done in single for samples resulting from the combination of Spirulina ponds and in duplicate for samples from different ponds and the means calculated.

Extraction and dosage of vitamins

The extraction and dosage of vitamins were performed according to the following standard methods: AOAC 938.04, NF EN 12823-1, NF EN 14122, AOAC 75.92, NF EN 15652, AOAC 992.07, NF EN 14166, NF EN 15607, NF EN14131, AOAC 986.23/Elisa, ISO 6867 and NF EN 12821 respectively for vitamins A, B1, C, B2, B3, B5, B6, B8, B9, B12, E and D3 approved by the French Committee of Accreditation (COFAC).

The water-soluble vitamins B1, B2 and B9 were extracted enzymatically. The enzymes used were amylase for thiamine, a mixture of takadiastase and pajanin for riboflavin, for the extraction of folic acid, dog kidneys and fowl pancreas were used. Vitamins B3, B5, B6, B8, B12 and B6 were chemically extracted.

Lipo-soluble vitamins have been extracted using organic solvents in which they are soluble. Vitamin A was extracted using solvents such as NaOH 50%, ethyl alcohol, hydroquinone, water and petroleum ether. Vitamin D3 was extracted using pyrogallol, ethanol, KOH 50% and petroleum ether as solvents. As for vitamin E, methanol, ascorbic acid and KOH 70% were used for its extraction [21,22].

The method used for extracting vitamins was high performance liquid chromatography (HPLC). Each solution was therefore subjected to a retention force and a mobility force [23]. The test samples were performed in triplicate and means calculated.

Statistical analyses

Statistical analyses of data were performed using the software Graph Pad Prism 5.01 (San Diego California, USA).

The results were expressed as means ± standard deviation. Changes of parameters subjected to our study were observed by performing comparison tests of means by an analysis of variance (ANOVA ONE WAY), using a post hoc Tukey test. A probability level $P < 0.05$ was chosen for the significance of all analyses.

Results

Nature and contents of fatty acids

The nature and the contents of the evaluated fatty acids are indicated in table 1 and 2. The fatty acids concerned were: saturated fatty acids, monounsaturated fatty acids, polyunsaturated fatty acids. These last two have included omega 3, omega 6 and omega 9, then trans and cis fat acid. The fatty acids quantified were C4, C6, C8, C10, C11, C12, C13, C14, C15, C16, C17, C18, C20, C21, C22, C23 and C24.

Fatty acid	Obtained values
Saturated	50,7
Butyric acid C4: 0	< 0,02
Caproic acid C6: 0	< 0,02
Caprylic acid C8: 0	< 0,02
Capric acid C10: 0	< 0,02
Lauric acid C12: 0	1,28
Myristic acid C14: 0	0,69
palmitic acid C16: 0	32,91
Stearic acid C18: 0	3,80
Arachidonic acid C20: 0	10,09
Behenic acid C22: 0	< 0,02
Lignoceric acid 24: 0	< 0,02
Undecanoic acid C11: 0	0,38
Tridecanoic acid C13: 0	0,35
Pentadecanoic acid C15: 0	0,23
Margaric acid C17: 0	0,25
Heneicosanoic acid C21: 0	0,76
Tricosanoic acid C 23: 0	< 0,02
Lignoceric acid 24: 0	< 0,02

Table1: *Values of the saturated fatty acids of Spirulina platensis (g/100g of fatty matter).*

Unsaturated	**49,2**
Monounsaturated fatty acid	9,2
Polyunsaturated fatty acid	40
Fatty acid Omega 3	0,2
Fatty acid Omega 6	39,6
Fatty acid Omega 9	5,1
Fatty acid trans	< 0,05
Myristoleic acid C14: 1	< 0,02
Palmitoleic acid C16: 1	3,25
Oleic acid C18: 1 n 9 cis	4,24
Erucidic acid C 22: 1 n9	< 0,02
Linoleic acid C18: 2 n 6 cis	19,21
α-linolenic C18: 3 n 3 cis	< 0,02
α-linolenic C18: 3 n 3 trans	< 0,02
γ-linolenic acid C18: 3 n 6	20,04
Pentadecanoic acid C15: 1	< 0,02
Heptadecanoic acid C17: 1	0,90
Elaidic acid C18: 1 n 9 trans	0,83
Linolelaidic acid C18: 2 n 6 trans	< 0,02
Eicosénoic acid C20: 1	< 0,02
Eicosadienoic acid: C20:2	0,23
Eicosatrienoic acid C20: 3 n 3	0,16
Eicosatrienoïc acid C20: 3 n 6	< 0,02
Eicosapentatonic acid C20: 5n 3	< 0,02
Docosadienoic acid 22: 2	< 0,02
Decosatétraenoic acid 22: 4	< 0,02
Clupanadonic acid C 22: 5	< 0,02
Docosahaexenoic acid C 22: 6 n3	< 0,02
Nervonic acid C 24: 1	< 0,02

Table 2: *Values of unsaturated fatty acids of Spirulina platensis (g/100g of fatty matter).*

Minerals contents

The macronutrients and trace elements are presented in table 3. These minerals were quantified in Spirulina samples from each pond on one hand and in samples of combined SPIRULINA ponds on the other hand.

	P1	P3	P4	P5	P6	P8	AP	P	ANC [33]
Macro-elements									
Calcium	1159,83 ± 5,64c	1064,45 ± 3,97d	1142,32 ± 7,52b	1153,2 ± 8,00bc	1002,06 ±3,91a	1008,08 ± 1,88a		1.10-7	500-1200
Magnésium	272,79 ± 4,86ab	277,36± 4,47ab	228,33± 6,91c	286,16 ± 9,54a	283,96 ± 8,18a	267,09± 3,86b		7.10-6	80-400
Phosphore	287 ± 2,00b	280,42 ± 1,41b	383,73 ± 9,1c	235,86 ± 1,86a	233,38 ± 6,43a	392,51 ± 2,8c		1.10-7	360-800
Potassium	2093,05 ± 5a	2090,67 ± 6,02a	2104,13 ± 45,8a	2083,22 ± 7,32a	2074,04 ± 5,94a	2077,47 ± 12,71 a		0.58	2000*
Sodium	1499,70 ± 9,96d	1443,53 ± 6,22c	1340,28 ± 15,42b	1356,39 ± 5,42b	1245,95 ± 6,62a	1252,27 ± 8,4a		1.10-7	5000*
Trace elements									
Iron	24,08 ± 1,1a	24,32 ± 0,2a	23,38 ± 1,1a	25,13 ± 1,2a	24,18 ± 1,2a	24,03 ± 1,5a	27,61 ± 2,96b	0.002	7-30
Manganese	4,03 ± 0,24a	4,08 ± 0,38a	3,04 ± 0,24b	5,05± 0,42c	4,17 ± 0,62a	3,11 ± 0,32b	3,65 ± 0,21ab	5.10-4	2-3
Zinc	2,10 ± 0,13a	2,12 ± 0,02a	2,14 ± 0,02a	2,19 ± 0,04a	3,22 ±0,03b	3,25 ± 0,17b	1,19 ± 0,13c	1.10-7	6-19
Copper	0,017 ± 00a	-	-	0,21 ± 0,01e	0,14 ± 0,01c	0,17 ± 0,02d	0,09 ± 0,01b	1.10-7	0,8-2
Fluor	NGV	NGV	NGV	NGV	NGV	NGV	0,38 ± 0,01		0,5-2.5
Iode	NGV	NGV	NGV	NGV	NGV	NGV	3,35 ± 0,04		0,08-0.20
Selenium	NGV	NGV	NGV	NGV	NGV	NGV	1,19 ± 0,21		0,02-0.08

***Table 3**: Content of minerals in Spirulina platensis compared to ANC and RNI (mg/100g).*

The affected means of the same letter on the same line are not significantly different at P = 5%

**: Values indicating the RNI (Recommended Nutrient Intake) of the microelement, ANC: Advised Nutritional Contribution; NGV: Non-given value; AP: All ponds. Daily administrated product: 3-5 grams.*

As for macro-elements, significant differences (P < 0.05) were registered between the content of the different production areas except for potassium, for which contents were statistically equal (P = 0.58) to all production ponds. In the same way, some trace elements such as iron, manganese, zinc and copper, showed a statistically significant differences (P < 0.05) between the contents of the different production ponds. The measured fluorine and iodine samples derived from a combination of Spirulina from all production ponds.

Vitamins contents

Vitamins contents of SPIRULINA are indicated in table 4. Analyzed samples derived from a combined SPIRULINA of all ponds. High contents of vitamins were obtained with vitamins C, B1, B2, E and beta carotene. As for the low contents, they were obtained with vitamins B3, B5, B6, B8, B9, B12, A and D3.

Water-soluble vitamins	
Vitamin C (mg/100g)	46,80 ± 6,51
Vitamin B1 (mg/100g)	3,10 ± 0,70
Vitamin B2 (mg/100g)	5,60 ± 2,54
Vitamin B3 (mg/100g)	9,50 ± 1,83
Vitamin B5 (mg/100g)	0,87 ± 0,08
Vitamin B6 (mg/100g)	0,58 ± 0,01
Vitamin B8 (µg/100 g)	3,05 ± 1,34
Vitamin B9 (µg/100 g)	17,52 ± 4,72
Vitamin B12 (mg/100g)	0,01 ± 00
Liposoluble vitamins	
Beta-caroten (mg/100g)	55,50 ± 4,72
Vitamin A (µg/100 g)	1,00 ± 0,28
Vitamin E (mg/100g)	36,60 ± 4,99
Vitamin D3 (µg/100 g)	0,60 ± 0,14

***Table 4**: Vitamins composition of Spirulina platensis.*

Discussion

The aim of this study is to determine and assess nutritional value of *Spirulina platensis* produced in Côte d'Ivoire.

Determined fatty acids include saturated, monounsaturated and polyunsaturated fatty acids, omega 3, omega 6, omega 9, the trans and cis fatty acids. Our findings are in agreement with the quantities of palmitic, palmitoleic, stearic and gamma linoleic acids determined in SPIRULINA containing a higher content of active ingredient (HCAI) [24] on the one hand and similar to the values indicated by other authors (Falquet and Hurni, 2006; Fox, 1999) in addition [16,25]. As for the quantity of linoleic and oleic acid, our values are higher than those of HCAI Spirulina (13.7%). However, the value of the oleic acid found in HCAI SPIRULINA (2.7%) is lower than ours, which is in accordance with the results of Fox (4.70%) [25]. Our value is lower than the values indicated by Falquet and Hurni which vary from 5 to 16% [25].

The value indicated by Pascaud., *et al.* (1993) which is 40.1% for the linoleic acid quantity is higher than ours [26].

As for the acid α-linolenic, Falquet and Hurni (2006) [16] and Pascaud [26] indicated that there exist in the form of traces, which is in agreement with our results but different from those of Fox [25] which brought back a value of 7.30%.

The contents of lauric and heptadecanoic acids determined were higher than those indicated by Fox which were respectively 0.38% and 0.22% [25]. This author indicated a value of myristic acid (01.1%) higher than our value.

The contents of oleic and palmitoleic acids obtained were comparable to those of SPIRULINA from Burkina Faso, except for linoleic, gamma linolenic, stearic acids where we had an higher contents. However, contents of myristic and behenic acids determined in Spirulina from Burkina Faso were higher than the values we obtained [27].

These results confirm the study of Deborah [19] which demonstrated that the values of nutrients in Spirulina vary from one farm to another and depend on the cultivation area set up by farmers. Indeed, saturated, monounsaturated and polyunsaturated fatty acids determined represent 50.7%, 9.2% and 40%, respectively. Among the unsaturated fatty acids, omega 3 (0.02%) and omega 6 (39.6%) were essential because they cannot be synthesized by human body. In addition to energy intake like all lipid, omega-6 are also used as precursors (mainly arachidonic acid) to a number of molecules such as prostaglandin E2, prostacyclin, thromboxane A2 or leukotriene B4. These molecules play a key role in inflammation, smooth muscle of blood vessels (vasomotricity) or platelet aggregation involved in clot formation [28].

Considering the nutritional intake indicated by Martin [29] about saturated fatty acids (15-20%), monounsaturated fatty acids (38-50%), C18: 2 n-6 polyunsaturated fatty acids (7.5 to 10%), C18: 3 n-3 (1.5-2%), our results gave satisfactory values for saturated, polyunsaturated and omega 6-series fatty acids. Apart from gamma linolenic acid, our results also indicated a low content of omega 3 and A higher content of linoleic acid, which could play on the ratio of omega 6/omega 3 which must be 5 for adults [28]. Indeed, linoleic acid reinforces body defense and prevent against diseases [30].

Differences observed between the minerals content in the different production areas could be explained by the fact that all fields did not undergo the same treatments.

The rates contents of calcium, magnesium and manganese determined are in agreement with values indicated by some authors [31,32]. Those rates contents are also in accordance with values obtained in the Chinese and American Spirulina [24]. These values are integrated into the Recommended Nutrients Intake (RNI) [33]. As for phosphorus and iron, our values are lower than the values indicated by the former authors [24,31,32]. However, apart from iron, they satisfy the RNI [33].

With regard to potassium and sodium, our values are higher than the values indicated by the above-mentioned authors. however, the value of sodium is lower than the RNI which is 5000 Mg. On the other hand, the quantity respects the RNI [33].

The contents of fluorides and copper determined in Spirulina are below the RNI, ranging from 0.5 mg to 2.5 mg, and then from 0.8 mg to 2.5 mg, respectively [33]. As for iodine and selenium, their rates are higher than the RNI [33].

Indeed, the recommended daily amounts of Spirulina vary between 3 and 5 grams. Although this dosage does not allow to reach the Recommended Nutrients Intake (RNI) or the Advised Nutritional Contribution (ANC) of macro-elements and trace elements [33], it still seems necessary to emphasize in view of our results that the intake of minerals of this alga is not negligible and could be complementary to daily food sources.

In short, we can say that Spirulina produced in Côte d'Ivoire is a good source of calcium, magnesium, phosphorus, potassium, iodine, manganese and selenium. Though it does not cover all the body's daily needs in sodium, iron, fluorides, zinc and copper, its contribution to these minerals is not inconsiderable.

The determined vitamins are water-soluble and lipo-soluble vitamins. The levels of vitamins B1, B2, B3, B5, B6, B8 and C are comparable to the levels reported by some authors [31,32,34]. Moreover, the levels of vitamins B1, B2 and B5 are in agreement with those of Chinese Spirulina and in HRAI Spirulina. However, vitamin B5 exists in a form of trace in HRAI Spirulina [24].

As for beta carotene, precursor of vitamin A, mean value determined (55.5 ± 41.72 mg/100g) was lower than those indicated by Falquet [31] and Babadzhanov., *et al.* [34] which were 140 mg/100 g and 64 mg/100g to 200 mg/100 g, respectively. However, it was higher than that of HRAI Spirulina which was 14 mg/100g [24]. Our results indicated a value of vitamin A (1 µg/100 g) much lower than the value indicated by Vidalo (2012) for Chinese Spirulina (100 mg/100 g with 200 mg/100 g) [24].

Concerning vitamin B3, the mean content is in agreement with that of Chinese Spirulina (10 mg/100g to 14 mg/100g), but remains lower than that indicated by Falquet [33], then Otten [32] and in HRAI Spirulina [24] which are respectively 140 mg/100g and 64 mg/100g to 200 mg/100g. However, it is still higher than the values reported by Babadzhanov., *et al.* [34] and Vidalo [24] in the American Spirulina, which are 5.3 mg/100g and 1.2 mg/100g respectively. The rate of vitamin B9 measured was higher than that reported by some authors which was 10 µg/100g, but lower than those of the American, Chinese and HRAI Spirulina Which were 100 mg/100g, 50 mg/100g to 100 mg/100g and 10 mg/100g, respectively [31,32].

The rate of vitamin B12 was lower than the value indicated by the above-mentioned authors. Likewise, the rate of vitamin A was much lower than the Chinese Spirulina [24]. As for vitamin D3, the rate was significantly higher ($P < 0.05$) than that indicated by Babadzhanov., *et al.* [34].

The rate of vitamin E (36.60 ± 4.99 mg/100 g) is much higher than the values indicated by the above-mentioned authors, which were 5 mg / 100 g to 19 mg / 100 g, 10 mg / 100 g to 19 mg / 100 g, 1 mg / 100 g, 5 mg / 100 g to 10 mg / 100 g and 12 mg / 100 g. It was the same for vitamin C which content was in agreement with the quantities mentioned by Babadzhanov., *et al*. however, this vitamin was not present in HRAI Spirulina [35].

Indeed, variations of vitamins rate recorded from one author to another and from one production area to another could be due to production conditions and treatments implemented by the producers [19]. Vitamin C, for example, which is a heat-volatile compound, is practically absent in Spirulina because of the drying methods that use heat. However, our analyses showed a high presence of vitamin C which could be explained by the dehumification method through a dehumidifier used for drying for which the principle is to extract water from Spirulina. Vitamins B1, B2, E and beta carotene (vitamin A precursor) are in great quantity in the analyzed Spirulina samples. In fact, the contents of these vitamins correspond to the recommended nutrients intake (RNI) for all age groups and for both sexes.

As for vitamins C, B3 and B6, the contents determined in Spirulina only satisfy the nutrient intake of infants and children [32,35,36]. Though, the content of beta-carotene was high, we noticed a low rate of vitamin A. For vitamins B5, B8, B9, B12 and D3, the contents quantified in our samples were low. Basically, contents of these vitamins are low in Spirulina, which give them values below recommended nutrients intake [24,31,32,34,35-36]. In spite of the unbalanced vitamins content in the Ivorian SPIRULINA, this study showed that it contained a well-diversified range of vitamins.

Conclusion

Spirulina comes from *Spirulina platensis* which is a microscopic alga consumed around the world and sold in Côte d'Ivoire by pharmaceutical firms as a nutritional supplement in forms of capsules, tablets and powder. Through this study, our aim was to investigate and assess the nutritional properties that highlight the use of this cyanobacteria.

Our study revealed that Spirulina contains all the series of fatty acids, water-soluble and liposoluble vitamins, many trace elements and macro-elements.

This study also outlines that Spirulina produced in Côte d'Ivoire has a proven nutritional value which could handle the daily nutritional deficiencies of population in particular children, pregnant women, breast feeding mothers in the developing countries.

However, it seems necessary to pursue our investigations:

- On its antioxidant activity;
- To determine its bactericidal and fungicidal activities on some germs wreaking havoc in tropical areas;
- To evaluate the bioavailability of the assessed nutrients.

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Conflict of Interest

The author(s) did not declare any conflict of interest.

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