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ARTICLE

Application of a Functional Mathematical Index for Antibacterial and Anticarcinogenic Effects of Tea Catechins

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Tea leaves produce secondary metabolites that are involved in the defense of the plants against invading pathogens. In the case of green teas, these metabolites are polyphenolic compounds called catechins. Previous studies developed a mathematical formula called functional mathematical index (FMI) that was used to describe the quality of different olive oils and potatoes in terms of compositional parameters and antioxidative properties of individual components. This study extends the development of the FMI concept to define an "optimum tea" based on reported relationships between the content of structurally different catechins of a large number of teas and their dual beneficial effects: antimicrobial activities against a foodborne pathogen and inhibition of human cancer cell lines. The described mathematical approach may be useful for predicting relative beneficial effects of new teas based on their catechin content.

KEYWORDS: Catechins; teas; composition; functional mathematical index; FMI; food quality; food safety

INTRODUCTION

Tea leaves produce secondary metabolites, organic compounds that are involved in the defense of the plants against invading pathogens including insects, bacteria, fungi, and viruses. These metabolites include the polyphenolic flavonoid compounds, catechins, present in green teas. Postharvest inactivation of phenol oxidases in green tea leaves prevents oxidation of the catechins to theaflavins and thearubigins, condensation products that impart the black color to black teas. Teas from different sources differ widely in their content of catechins. Interest in tea catechins arises from the fact that they are potent antioxidants and are reported to exhibit numerous health-related beneficial effects, including strong antibiotic, antitoxin, and anticarcinogenic activities. It has been shown that epigallocatechin-3-gallate (EGCG) and other polyphenols present in tea can block fatty acid synthase, suggesting their potential value in cancer therapy (*1*).

Tea catechins can exist as two geometrical isomers depending on the stereochemical configuration of the 3′,4′-dihydroxyphenyl and hydroxyl groups at the 2- and 3-positions of the C-ring: *trans*-catechins and *cis*-epicatechins (**Figure 1**). Each of the isomers, in turn, exists as two optical isomers: (+)-catechin and (−)-catechin and (+)-epicatechin and (−)-epicatechin, respectively. The gallocatechins contain an additional hydroxyl group on the ring. (−)-Catechin can be modified by esterification with gallic acid to form (−)-catechin-3-gallate (*1*−*4*).

In previous studies we (a) validated HPLC methods to measure catechins and theaflavins in a large number of commercial teas (*5*,*6*); (b) determined the activities of 13 tea compounds and 15 teas against breast, colon, liver, and prostate human cancer cells (*7*); (c) evaluated antibacterial effects of tea flavonoids and teas against the foodborne pathogen *Bacillus cereus* (*8*); and (d) found that tea catechins have a strong affinity for the lipid bilayer of cell membranes via hydrogen bonding to the bilayer surface, with some of the smaller catechins able to penetrate underneath the surface (*9*, *10*).

In a previous study, Finotti et al. (*11*) developed a mathematical formula named the functional mathematical index (FMI) that was used to describe the quality of olive oils in terms of different compositional parameters and antioxidative properties of individual oil components. It was suggested that relative FMI values could benefit both producers and consumers of olive oils, who may wish to select oils with optimal health benefits. In a related study, Finotti et al. (*12*) described the derivation and application of a new functional mathematical index that defines "potato nutritional quality" based on the content of potato components. It was suggested that the index can be used to predict changes in quality that may occur during the growth, production, distribution, and processing of potatoes and potato products.

The main objective of this study was to develop and apply FMIs that define an "optimum tea" based on our reported relationships between the content of structurally different catechins of a large number of teas.

DATA FOR MATHEMATICAL CALCULATIONS

Catechin content of teas was collected from a previous study (*5*). Briefly, commercial tea leaves were extracted with hot water, and the filtered extracts were then quantitated by HPLC. The activity of teas and tea catechins against cancer cells was determined with the aid of the tetrazolium microculture (MTT) assay (*7*). The composition and antimicrobial activities of teas against the foodborne pathogen *B. cereus* were determined as described by Friedman et al. (*8*). The composition data from these publications were used to calculate the FMIs outlined below.

MATHEMATICAL FORMULATION

Functional Mathematical Index for Tea Catechins and Teas. The following mathematical derivation extends the previously defined

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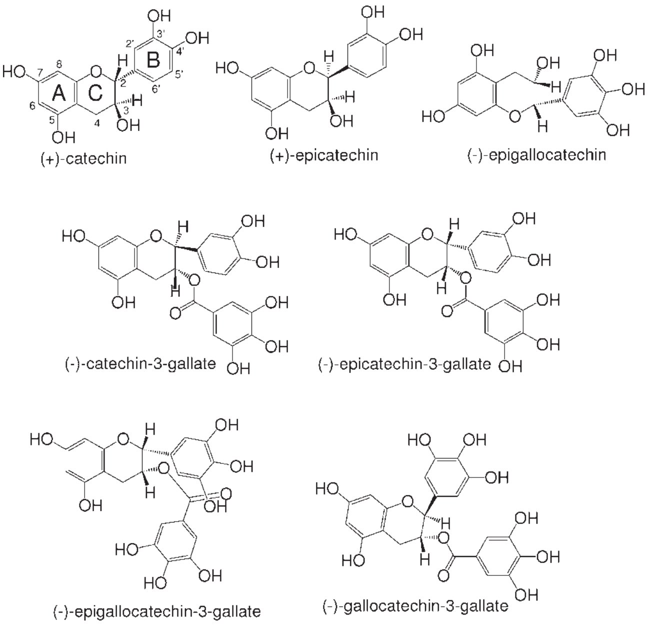

Figure 1. Structures of seven tea catechins evaluated in the present study.

FMIs. In this derivation, we use this "quality index", with equally weighted globally normalized parameters that we designate as the FMI for tea catechins and teas, defined as

$$\mathrm{FMI} = \sqrt{\sum_{i=1}^{N} X_i^4} \qquad (1)$$

,where X_i is a normalized (to unity) version of an experimental value (local index), usually the normalized distance of the experimental value from an optimal value

$$X_i = \frac{x_i - x_{\mathrm{optimal}}}{R} \qquad (2)$$

where R is a "quality range" for which X_i is 1 in the case of the minimal experimental quality value and 0 for an optimal value of the experimental parameter. The sum is extended to N different quality parameters. In this case, FMI is not globally normalized, with an upper limit of $(N)^{1/2}$. For example, in this study the calculated range of antibacterial FMI values is from 0 to 2.23, and the range of anticarcinogenic (antitumor) FMI values is from 0 to 2.64. By this definition, the value of $X_i = 1$ indicates the maximal distance from the optimal value, that is, the "worst" case. For the best case (the "optimal" product), FMI = 0 (any experimental index is equal to the optimal value).

In this paper, we propose a generalization of this formula. In fact, the above formulas are intended for products for which a single "quality" can be envisioned (for example, nutritional properties of an olive oil, potato, etc.). A food ingredient such as tea catechin can exhibit two or more beneficial qualities. Two such qualities, antibacterial and anticarcinogenic properties of teas and tea catechins, are the subject of the present study. To account for dual properties, we introduce the following new and unique FMI:

$$\mathrm{FMI} = \frac{\sqrt{\sum_{i=1}^{N_1} X_i^4}}{\sqrt{N_1}} + \frac{\sqrt{\sum_{j=1}^{N_2} Y_j^4}}{\sqrt{N_2}} \qquad (3)$$

The formulation is similar to the preceding FMI formulation, where X_i and Y_j refer to the (normalized) values of the local indices (see above); N_1 is the number of parameters of the first quality index group, and N_2 is the number of parameters of the second group. Obviously, the formula shown in eq 3 can, in principle, be extended to additional quality properties. In this case, the normalization is such that the maximum (worst) value is 2, each X_i and I value is equal to 1, and the single fractions in eq 3 are unitary. Because a chemical compound can have both properties (anticarcinogenic and antibacterial, in the present case), the same parameter can appear in both terms on the right-hand side of the last formula. This is a general property of such a formulation.

Computations of FMI Values. In the present formulation, seven parameters are involved in the FMI calculation: GC, EGCG, GCG, ECG, CG, C, and EC (parameters 1, 2, 3, 4, 5, 6, and 7, respectively). To illustrate how we obtained the three FMI values, anticarcinogenic, antibacterial, and total (unique), here we explicitly compute the FMIs for a randomly chosen sample (Sushi Bar mild tea; see **Table 2**). The values for the parameters used in the calculations are the measured catechin content of the tea in question.

Anticarcinogenic FMI Calculation. In the case of anticarcinogenic FMI, all seven parameters (catechins) are involved. Each partial index X_i (i = 1, ..., 7) is calculated by

$$X_i = \frac{x_{i,\max} - x_{i,\mathrm{exptl}}}{x_{i,\max} - x_{i,\min}}$$

where $x_{i,\mathrm{exptl}}$ is the experimental value of the ith parameter.

Thus, we have

$$\text{EGC (parameter 1): } X_1 = \frac{x_{1,\max} - x_{1,\mathrm{exptl}}}{x_{1,\max} - x_{1,\min}} = \frac{(14.2 - 13.8)}{(14.2 - 0.01)}$$
$$= 0.028 \quad X_1^4 = 0.0000$$

$$\text{EGCG (parameter 2): } X_2 = \frac{x_{2,\max} - x_{2,\mathrm{exptl}}}{x_{2,\max} - x_{2,\min}} = \frac{53.6 - 41.2}{53.6 - 0.2}$$
$$= 0.232 \quad X_2^4 = 0.0029$$

$$\text{GCG (parameter 3): } X_3 = \frac{x_{3,\max} - x_{3,\mathrm{exptl}}}{x_{3,\max} - x_{3,\min}} = \frac{6.7 - 5.1}{6.7 - 0.6}$$
$$= 0.262 \quad X_3^4 = 0.0047$$

$$\text{ECG (parameter 4): } X_4 = \frac{x_{4,\max} - x_{4,\mathrm{exptl}}}{x_{4,\max} - x_{4,\min}} = \frac{27.1 - 18.4}{27.1 - 0.4}$$
$$= 0.326 \quad X_4^4 = 0.0113$$

$$\text{CG (parameter 5): } X_5 = \frac{x_{5,\max} - x_{5,\mathrm{exptl}}}{x_{5,\max} - x_{5,\min}} = \frac{2.3 - 0.2}{2.3 - 0.01}$$
$$= 0.917 \quad X_5^4 = 0.7071$$

$$\text{C (parameter 6) : } X_6 = \frac{x_{6,\max} - x_{6,\mathrm{exptl}}}{x_{6,\max} - x_{6,\min}} = \frac{33.2 - 5.8}{33.2 - 0.5}$$
$$= 0.838 \quad X_6^4 = 0.4931$$

$$\text{EC (parameter 7): } X_7 = \frac{x_{7,\max} - x_{7,\mathrm{exptl}}}{x_{7,\max} - x_{7,\min}} = \frac{6.3 - 2.6}{6.3 - 0.2}$$
$$= 0.607 \quad X_7^4 = 0.1358$$

$$\mathrm{FMI} = \sqrt{X_1^4 + X_2^4 + X_3^4 + X_4^4 + X_5^4 + X_6^4 + X_7^4}$$
$$= \sqrt{0 + 0.0029 + 0.0047 + 0.0113 + 0.4931 + 0.1358}$$
$$= \sqrt{1.3549} = 1.164$$

which we designate AT-FMI.

Table 1. Upper and Lower Bounds (Concentrations) for Catechins and Antibacterial and Antitumor Data Used To Define FMI Values of Teas[a]

tea catechin	upper bound, highest concn (mg/g tea)	lower bound, lowest concn (mg/g tea)
(−)-epigallocatechin, EGC	14.2	0.01
(−)-epigallocatechin-3-gallate, EGCG	53.6	0.2
(−)-gallocatechin-3-gallate, GCG	6.7	0.6
(−)-epicatechin-3-gallate, ECG	27.1	0.4
(−)-catechin-3-gallate, CG	2.3	0.01
(+)-catechin, C	33.2	0.5
(−)-epicatechin, EC	6.3	0.2

[a] Data adapted from ref *5*.

The theoretical maximum for the AT-FMI is

$$\sqrt{1+1+1+1+1+1+1} = 2.64$$

To obtain the unique FMI, this value has to be normalized by dividing by the square root of the number of parameters, that is, $\sqrt{7} = 2.64575$:

$$\text{normalized FMI} = \frac{\sqrt{1.3549}}{\sqrt{7}} = \frac{1.164}{2.646} = 0.44$$

Antibacterial FMI Calculation. The antibacterial FMI is calculated with only five of the above seven parameters (catechins) because we have no data for (+)-catechin and epicatechin as they were found to be inactive in the antimicrobial assay. Because the local indices are based on the catechin concentrations in the teas, the X_i values for those five would be the same as above:

$$X_1^4 = 0.0000, X_2^4 = 0.0029, X_3^4 = 0.0047,$$
$$X_4^4 = 0.0113, \text{and } X_5^4 = 0.7071$$

Table 2. Concentrations (in Milligrams per Gram of Tea) of (−)-Epigallocatechin (EGC), (−)-Epigallocatechin-3-gallate (EGCG), (−)-Gallocatechin-3-gallate (GCG), (−)-Epicatechin-3-gallate (ECG), (−)-Catechin-3-gallate (CG), (+)-Catechin (C), and (−)-Epicatechin (EC) in the 40 Teas used for FMI Calculations[a]

tea	EGC	EGCG	GCG	ECG	CG	C	EC
Wild Raspberry herbal	0.01	0.2	0.6	0.4	0.2	1.4	0.2
Earl Grey	0.7	0.9	0.9	1.7	0.2	0.6	1.2
Orange Pekoe, pekoe and cut black	1	1.9	1.5	3.6	0.5	0.9	0.6
Tai Mahal Indian Assam	1.2	1.4	1.4	2.4	0.4	1.6	1.3
English Breakfast	3.4	6.6	2.4	10.1	0.7	3.5	2.3
Original India Spice chai	2	0.5	1.4	4.2	1.5	0.5	6.3
Exotica Osmanthus	2.2	9.9	3.7	7.8	0.6	3.7	0.9
English Breakfast black	3.4	6.6	2.4	10.1	0.7	3	2.3
Orange Spice black	1.9	6	1.5	10.8	1	3	1.7
Earl Grey black and green, organic	2.8	9	1.8	11	0.8	4.3	2.3
Earl Grey Black	6.4	5.2	2.3	10	0.7	5	2.1
Lemon Spice green (and black)	3.4	12.9	2.9	11.7	0.4	2.8	1.4
Nilgiri black	2.3	6.1	1.9	11.8	0.6	8.1	2.4
Exotica Assam Breakfast	2.3	9.5	1.6	16.1	0.5	7.1	2.6
Breakfast Blend, organic	2.5	12.7	2.1	14.5	0.6	7.4	2.5
Exotica Reserve blend	3	16.9	4.1	16.8	0.5	4.6	2.3
Darjeeling black	4.2	27	4.2	20.2	0.4	0.8	1.4
Exotica Ceylon Estate Earl Grey	10.3	23	1.1	20.6	0.5	2.7	4.3
Darjeeling spring	4.1	28	4.4	22.9	0.4	1.2	2
Exotica Golden Darjeeling	5.2	28	3.2	24.2	0.7	1.7	2.3
Kopili Assam black	2.3	13.3	6.7	24.4	1.3	6.7	4.2
Darjeeling summer	5.1	26.8	3	20.9	0.1	4.9	2.2
Darjeeling black, organic	3.1	23.5	6.1	26.8	0.6	5.3	4.1
Kukicha	1.1	7.4	6.3	5	0.1	3.5	0.5
premium green, decaffeinated	4.8	13.5	2.7	6	0.3	4.4	0.8
Moroccan Mint green	1	6.7	3.2	7.7	0.4	33.2	1.3
jasmine blossom green	6.4	29.4	5	15.9	0.3	6.2	0.9
Exotica Dragonwell green	0.7	43.6	1.7	19.2	0.2	7.9	1.1
premium green	13.6	38.4	5.1	15.9	0.1	2	0.9
Sencha Japanese green	14.2	35.7	5.4	14.3	0.2	4	2.4
green organic	13.9	41.8	2.4	18.6	0.1	1.7	1.7
Sushi Bar mild green	13.8	41.2	5.1	18.4	0.2	5.8	2.6
Darjeeling green, organic	8.1	53.6	3.9	27.1	0.3	5.1	1.9
pu-erh oolong	0.01	2.1	1.7	1.3	0.3	1.5	0.4
Fusion red and white	1.6	11.4	4.8	9.1	0.02	2.3	1.1
China oolong	5.7	23.2	3.5	2.2	2.3	5.7	2.5
Exotica China white	2.1	30.4	2.9	19.2	0.4	4.2	1.3
Exotica Champagne oolong	2.9	37.5	4.4	18.2	0.5	0.8	1.1
Fusion green and white	5.8	33.5	2.7	16.1	0.2	6.2	2.5
Exotica silver jasmine	6.1	36.3	2.7	26.9	0.3	7.9	2.9

[a] Data adapted from refs *5* and *6*.

Table 3. Calculated Antibacterial FMI Values for Individual Catechins and of 40 Teas (Range 0−2.23)[a]

tea	partial index (X_i^4) for individual catechins						
	EGC	EGCG	GCG	ECG	CG	sum	FMI
Wild Raspberry herbal	1.00	1.00	1.00	1.00	0.71	4.71	2.17
Earl Grey	0.82	0.95	0.82	0.82	0.71	4.11	2.03
pu-erh oolong	1.00	0.87	0.45	0.87	0.58	3.77	1.94
Tai Mahal Indian Assam	0.70	0.91	0.57	0.73	0.47	3.39	1.84
Orange Pekoe, pekoe and cut black tea	0.75	0.88	0.53	0.60	0.38	3.14	1.77
Original India Spice chai	0.55	0.98	0.57	0.54	0.01	2.65	1.63
Kukicha	0.73	0.56	0.00	0.47	0.85	2.61	1.61
Fusion red and white	0.62	0.39	0.01	0.21	0.98	2.21	1.49
Moroccan Mint green	0.75	0.60	0.11	0.28	0.47	2.20	1.48
Exotica Dragonwell green	0.82	0.00	0.45	0.01	0.71	1.99	1.41
Orange Spice black	0.56	0.63	0.53	0.14	0.10	1.97	1.40
Nilgiri black	0.49	0.63	0.38	0.11	0.30	1.92	1.38
Exotica Assam breakfast	0.49	0.47	0.49	0.03	0.38	1.86	1.36
premium green, decaffeinated	0.19	0.32	0.18	0.39	0.58	1.67	1.29
Earl Grey black and green, organic	0.42	0.49	0.42	0.13	0.18	1.64	1.28
English Breakfast tea	0.34	0.60	0.25	0.16	0.24	1.59	1.26
Exotica Osmanthus	0.51	0.45	0.06	0.27	0.30	1.60	1.26
English Breakfast black	0.34	0.60	0.25	0.16	0.24	1.59	1.26
breakfast blend, organic	0.46	0.34	0.32	0.05	0.30	1.48	1.22
Earl Grey black	0.09	0.67	0.27	0.17	0.24	1.44	1.20
Lemon Spice green (and black)	0.34	0.34	0.15	0.11	0.47	1.41	1.19
Darjeeling summer	0.17	0.06	0.14	0.00	0.85	1.22	1.11
Exotica Ceylon Estate Earl Grey	0.01	0.11	0.71	0.00	0.38	1.21	1.10
Exotica China white	0.53	0.04	0.15	0.01	0.47	1.20	1.09
green organic	0.00	0.00	0.25	0.01	0.85	1.11	1.05
China oolong	0.13	0.11	0.08	0.76	0.00	1.07	1.03
Fusion green and white	0.12	0.02	0.18	0.03	0.71	1.06	1.03
Exotica Reserve blend	0.39	0.22	0.03	0.02	0.38	1.05	1.02
premium green	0.00	0.01	0.00	0.03	0.85	0.89	0.95
Exotica silver jasmine	0.11	0.01	0.18	0.00	0.58	0.88	0.94
Kopili Assam black	0.49	0.32	0.00	0.00	0.04	0.86	0.92
Exotica Champagne oolong	0.40	0.01	0.02	0.01	0.38	0.82	0.91
Darjeeling black	0.25	0.06	0.03	0.00	0.47	0.81	0.90
Darjeeling spring	0.26	0.05	0.02	0.00	0.47	0.80	0.90
Darjeeling black, organic	0.37	0.10	0.00	0.00	0.30	0.78	0.88
Sencha Japanese green	0.00	0.01	0.00	0.05	0.71	0.77	0.88
jasmine blossom green	0.09	0.04	0.01	0.03	0.58	0.75	0.87
Sushi Bar mild green	0.00	0.00	0.00	0.01	0.71	0.73	0.85
Darjeeling green, organic	0.03	0.00	0.04	0.00	0.58	0.66	0.81
Exotica Golden Darjeeling	0.16	0.05	0.11	0.00	0.24	0.56	0.75

[a] Listed values are adimensional.

$$\text{non-normalized FMI} = \sqrt{X_1^4 + X_2^4 + X_3^4 + X_4^4 + X_5^4}$$

$$= \sqrt{0 + 0.0029 + 0.0047 + 0.0113 + 0.7071}$$

$$= \sqrt{0.7260} = 0.852$$

which we designate AB-FMI.

The theoretical maximum for the AB-FMI is

$$\sqrt{1+1+1+1+1} = 2.23$$

$$\text{normalized FMI} = \frac{\sqrt{0.7260}}{\sqrt{5}} = \frac{0.852}{2.236} = 0.381$$

Finally, the two normalized values must be added to obtain the total (unique) FMI:

$$\text{unique FMI} = (\text{AT-FMI normalized}) + (\text{AB-FMI normalized})$$

$$= 0.440 + 0.381 = 0.821$$

The theoretical maximum for the unique FMI is

$$\frac{\sqrt{N_1 \times 1}}{\sqrt{N_1}} + \frac{\sqrt{N_2 \times 1}}{\sqrt{N_2}} = i, \text{ in this case } = 2$$

Statistical Analysis. Excel (Microsoft, Redmond, WA) was used to compute the FMI values using the primary compositional data for tea catechins described in previous publications. The Pearson product moment correlation between catechin level and unique FMI, as well as between the two component FMIs (antimicrobial and antitumor) was calculated using SigmaPlot 11.0 (Systat Software, Inc., Chicago, IL).

RESULTS

Table 1 shows the upper and lower bound values of the parameters. These values represent the upper and lower concentrations of each catechin evaluated. The same values were used for computing both antibacterial and anticarcinogenic FMI values.

Table 2 shows the catechin values for each studied tea. These represent the experimental data we used for computing both antibacterial and anticarcinogenic FMI values

Table 4. Calculated Anticarcinogenic FMI Values for Individual Catechins and for 40 Teas (Range 0−2.64)[a]

	partial index (X_i^4) for individual catechins								
tea	EGC	EGCG	GCG	ECG	CG	C	EC	sum	FMI
Wild Raspberry herbal	1.00	1.00	1.00	1.00	0.71	0.89	1.00	6.60	2.57
Earl Grey	0.82	0.95	0.82	0.82	0.71	0.99	0.49	5.59	2.36
pu-erh oolong	1.00	0.87	0.45	0.87	0.58	0.88	0.88	5.53	2.35
Orange Pekoe, pekoe and cut black	0.75	0.88	0.53	0.60	0.38	0.95	0.76	4.85	2.20
Tai Mahal Indian Assam	0.70	0.91	0.57	0.73	0.47	0.87	0.45	4.72	2.17
Kukicha	0.73	0.56	0.00	0.47	0.85	0.68	0.82	4.11	2.03
Original India Spice chai	0.55	0.98	0.57	0.54	0.01	1.00	0.00	3.65	1.91
Fusion red and white	0.62	0.39	0.01	0.21	0.98	0.80	0.53	3.54	1.88
Orange Spice black	0.56	0.63	0.53	0.14	0.10	0.73	0.32	3.02	1.74
premium green, decaffeinated	0.19	0.32	0.18	0.39	0.58	0.60	0.66	2.93	1.71
Exotica Dragonwell green	0.82	0.00	0.45	0.01	0.71	0.36	0.53	2.87	1.70
Exotica Osmanthus	0.51	0.45	0.06	0.27	0.30	0.66	0.61	2.87	1.69
Moroccan Mint green	0.75	0.60	0.11	0.28	0.47	0.00	0.45	2.66	1.63
Lemon Spice green (and black)	0.34	0.34	0.15	0.11	0.47	0.75	0.42	2.57	1.60
English Breakfast black	0.34	0.60	0.25	0.16	0.24	0.73	0.18	2.50	1.58
English Breakfast	0.34	0.60	0.25	0.16	0.24	0.68	0.18	2.45	1.57
Earl Grey black and green, organic	0.42	0.49	0.42	0.13	0.18	0.61	0.18	2.43	1.56
Nilgiri black	0.49	0.63	0.38	0.11	0.30	0.35	0.17	2.43	1.56
Exotica Assam Breakfast	0.49	0.47	0.49	0.03	0.38	0.41	0.14	2.40	1.55
premium green	0.00	0.01	0.00	0.03	0.85	0.83	0.61	2.34	1.53
Exotica Champagne oolong	0.40	0.01	0.02	0.01	0.38	0.96	0.53	2.32	1.52
green organic	0.00	0.00	0.25	0.01	0.85	0.86	0.32	2.30	1.52
Exotica China white	0.53	0.04	0.15	0.01	0.47	0.62	0.45	2.27	1.51
Earl Grey black	0.09	0.67	0.27	0.17	0.24	0.55	0.22	2.22	1.49
Darjeeling black	0.25	0.06	0.03	0.00	0.47	0.96	0.42	2.19	1.48
Breakfast blend, organic	0.46	0.34	0.32	0.05	0.30	0.39	0.15	2.02	1.42
Darjeeling summer	0.17	0.06	0.14	0.00	0.85	0.56	0.20	1.99	1.41
Exotica Ceylon Estate Earl Grey	0.01	0.11	0.71	0.00	0.38	0.76	0.01	1.98	1.41
Darjeeling spring	0.26	0.05	0.02	0.00	0.47	0.92	0.25	1.97	1.40
jasmine blossom green	0.09	0.04	0.01	0.03	0.58	0.46	0.61	1.83	1.35
Exotica Reserve Blend	0.39	0.22	0.03	0.02	0.38	0.59	0.18	1.82	1.35
China oolong	0.13	0.11	0.08	0.76	0.00	0.50	0.15	1.72	1.31
Fusion green and white	0.12	0.02	0.18	0.03	0.71	0.46	0.15	1.68	1.30
Exotica Golden Darjeeling	0.16	0.05	0.11	0.00	0.24	0.86	0.18	1.61	1.27
Sencha Japanese green	0.00	0.01	0.00	0.05	0.71	0.64	0.17	1.58	1.26
Darjeeling green, organic	0.03	0.00	0.04	0.00	0.58	0.55	0.27	1.48	1.22
Sushi Bar mild green	0.00	0.00	0.00	0.01	0.71	0.49	0.14	1.35	1.16
Exotica silver jasmine	0.11	0.01	0.18	0.00	0.58	0.36	0.10	1.34	1.16
Darjeeling black, organic	0.37	0.10	0.00	0.00	0.30	0.53	0.02	1.33	1.15
Kopili Assam black	0.49	0.32	0.00	0.00	0.04	0.43	0.01	1.30	1.14

[a] Listed values are adimensional.

Table 3 shows the calculated antibacterial FMI scores. The results show that EGCG, GCG, and ECG are the major contributors to the FMI scores because all of the local FMIs are very low. Wild Raspberry herbal tea had the highest and Exotica Golden Darjeeling, the lowest, FMI values.

Table 4 shows the anticarcinogenic FMI values. The results indicate that the Kopili Assam Black tea had the best FMI score due to the low values of its parameters (local FMI value of individual catechins), in particular GCG and ECG. The Wild Raspberry tea had a very poor FMI because five of the local FMI values reached the value of 1.

Table 5 shows the calculated "unique" FMI values for the 40 teas. In general, the trends are the same in **Tables 4** and **5**, except the samples premium green, Kopili Assam black, Exotica silver jasmine, and Darjeeling black have assumed a different set position in this latter table.

DISCUSSION

The cited observations suggest that it should be possible to extend the mathematical concepts developed for olive oils and potatoes to other food categories. Because we previously reported that individual polyphenolic tea ingredients and freshly brewed teas exhibited anticarcinogenic and antimicrobial properties, the main objective of this study was to define mathematical indices for these two beneficial effects of teas in terms of their known catechin content.

In this study, the FMI has been shown to be useful for computing the quality score and classifying different tea samples with different potencies beneficial to human health. The classification of each FMI (see **Tables 3** and **4**) has been tweaked in the last table (**Table 5**), in which the best tea is Exotica Golden Darjeeling, which possesses the best antibacterial FMI. By contrast, Wild Raspberry herbal tea presents both low anticarcinogenic and antibacterial FMI values.

The FMI index provides useful indications about the global quality (combined effect against foodborne pathogens and human cancer cells) of a specific tea. It also makes it possible, depending on requirements, to obtain partial information for only one biological effect, in this case relative antibacterial or anticarcinogenic potency. The index can predict beneficial biological effects of teas in terms of content of structurally different catechins.

It is important to note that the FMI index is not an alternative computing analysis to classical statistical methods (multivariate analysis, cluster analysis, etc.). We suggest that the FMI index could complement such analyses.

Table 5. Unique FMI Values for Teas (Range 0−2)

tea	total FMI
Wild Raspberry herbal	1.94
Earl Grey	1.80
pu-erh oolong	1.76
Tai Mahal Indian Assam	1.64
Orange Pekoe, pekoe and cut black	1.62
Kukicha	1.49
Original India Spice (100% natural chai)	1.45
Fusion red and white	1.38
Orange Spice black	1.28
Moroccan Mint green	1.28
Exotica Dragonwell green	1.27
premium green, decaffeinated	1.22
Nilgiri black	1.21
Exotica Osmanthus	1.21
Exotica Assam Breakfast	1.20
Earl Grey black and green	1.16
English Breakfast black	1.16
English Breakfast	1.15
Lemon Spice green (and black)	1.14
Earl Grey black	1.10
Breakfast blend, organic	1.08
Exotica China white	1.06
green organic	1.04
Darjeeling summer	1.03
Exotica Ceylon Estate Earl Grey	1.02
premium green	1.00
Exotica Champagne oolong	0.98
Exotica Reserve blend	0.97
Darjeeling black	0.96
China oolong	0.96
Fusion green and white	0.95
Darjeeling spring	0.93
jasmine blossom green	0.90
Sencha Japanese green	0.87
Exotica silver jasmine	0.86
Kopili Assam black	0.84
Darjeeling black, organic	0.83
Darjeeling green, organic	0.82
Sushi Bar mild green	0.82
Exotica Golden Darjeeling	0.81

In conclusion, the described mathematical approach shows that it is possible to apply the FMI to food ingredients with dual biological activities. It would be of interest to extend the FMI concept to reported relative effects of processing (*13*) and storage (*14*) on catechin content of teas as well as antioxidative activities (*15*) of tea catechins.

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LITERATURE CITED

(1) Schwimmer, S. Desirable enzymatic browning. In *Handbook of Food Enzymology*; AVI: Westport, CT, 1981; pp 291−297.
(2) Shahidi, F.; Naczk, M. Phenolic compounds of beverages. In *Phenolics in Food and Neutraceuticals*; CRC Press: Boca Raton, FL, 2004; pp 241−248.
(3) Bonoli, M.; Colabufalo, P.; Pelillo, M.; Gallina Toschi, T.; Lercker, G. Fast determination of catechins and xanthines in tea beverages by micellar electrokinetic chromatography. *J. Agric. Food Chem.* **2003**, *51*, 1141−1147.
(4) Sang, S.; Lambert, J. D.; Tian, S.; Hong, J.; Hou, Z.; Ryu, J. H.; Stark, R. E.; Rosen, R. T.; Huang, M. T.; Yang, C. S.; Ho, C. T. Enzymatic synthesis of tea theaflavin derivatives and their anti-inflammatory and cytotoxic activities. *Bioorg. Med. Chem.* **2004**, *12*, 459−467.
(5) Friedman, M.; Kim, S.-Y.; Lee, S.-J.; Han, G.-P.; Han, J.-S.; Lee, R.-K.; Kozukue, N. Distribution of catechins, theaflavins, caffeine, and theobromine in 77 teas consumed in the United States. *J. Food Sci.* **2005**, *70*, C550−559.
(6) Friedman, M.; Levin, C. E.; Choi, S.-H.; Kozukue, E.; Kozukue, N. HPLC analysis of catechins, theaflavins, and alkaloids in commercial teas and green tea dietary supplements: comparison of water and 80% ethanol/water extracts. *J. Food Sci.* **2006**, *71*, C328−337.
(7) Friedman, M.; Mackey, B. E.; Kim, H. J.; Lee, I. S.; Lee, K. R.; Lee, S. U.; Kozukue, E.; Kozukue, N. Structure−activity relationships of tea compounds against human cancer cells. *J. Agric. Food Chem.* **2007**, *55*, 243−253.
(8) Friedman, M.; Henika, P. R.; Levin, C. E.; Mandrell, R. E.; Kozukue, N. Antimicrobial activities of tea catechins and theaflavins and tea extracts against *Bacillus cereus*. *J. Food Prot.* **2006**, *69*, 354−361.
(9) Sirk, T. W.; Brown, E. F.; Sum, A. K.; Friedman, M. Molecular dynamics study on the biophysical interactions of seven green tea catechins with lipid bilayers of cell membranes. *J. Agric. Food Chem.* **2008**, *56*, 7750−7758.
(10) Sirk, T. W.; Brown, E. F.; Friedman, M.; Sum, A. K. Molecular binding of catechins to biomembranes: relationship to biological activity. *J. Agric. Food Chem.* **2009**, *57*, 6720−6728.
(11) Finotti, E.; Bersani, A. M.; Bersani, E. Total quality indexes for extra-virgin olive oils. *J. Food Qual.* **2007**, *30*, 911−931.
(12) Finotti, E.; Bersani, E.; Vivanti, V.; Friedman, M. Application of a functional mathematical index to the evaluation of the nutritional quality of potatoes. *Food* **2009**, *3*, 30−36.
(13) Friedman, M.; Levin, C. E.; Choi, S.-H.; Lee, S.-U.; Kozukue, N. Changes in the composition of raw tea leaves from the Korean Yabukida plant during high-temperature processing to pan-fried Kamairi-cha green tea. *J. Food Sci.* **2009**, *74*, C406−C412.
(14) Friedman, M.; Levin, C. E.; Lee, S.-U.; Kozukue, N. Stability of green tea catechins in commercial tea leaves during storage for 6 months. *J. Food Sci.* **2009**, *74*, H47−H51.
(15) Chu, K. O. N.; Chan, K. P.; Wang, C. C.; Chu, C. Y.; Li, Y.; Choy, K. W.; Rogers, M. S.; Pang, C. P. Green tea catechins and their oxidative protection in the rat eye. *J. Agric. Food Chem.* **2010**, *58*, 1523−1534.

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