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APPLICATION OF A FUNCTIONAL MATHEMATICAL QUALITY INDEX TO ASPARAGINE, FREE SUGAR AND PHENOLIC ACID CONTENT OF 20 COMMERCIAL POTATO VARIETIES

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ABSTRACT

In this article, we apply a functional mathematical index (FMI), introduced in a previous publication, to 20 commercial potato varieties. The index allows evaluation of nutritional, safety and processing "quality parameters" of different potato cultivars. The main goal of the index is to link the quality of the chemical composition with factors that may affect the growth, production, distribution and processing of potatoes and potato products for commercial use. The index has been used to assess FMI values of 20 commercial potato cultivars in terms of their content of asparagine and reducing sugars, which form heat-induced potentially toxic acrylamide and of antioxidative phenolic compounds, which participate in nonenzymatic browning reactions and may exert beneficial effects after consumption.

PRACTICAL APPLICATIONS

The index could be useful to a wide set of users, including consumers of potatoes as well as to potato producers and breeders, because it makes it possible to relate the index to the potato price and operate a more accurate choice for selection of so-called "optimal potatoes." Potato producers may find the index useful because it can help them detect the critical points throughout the whole food production chain in order to facilitate selection of high-quality potatoes for sale to consumers. Potato breeders could apply the index to the development and selection of improved cultivars for commercial use.

INTRODUCTION

It is now generally recognized that the content of free asparagine and reducing sugars (glucose, fructose) is directly related to the formation of potentially toxic acrylamide in processed potato products such as chips and fries (Vivanti *et al.* 2006; Friedman and Levin 2008) and that antioxidative potato phenolic compounds, such as chlorogenic acid, are health-promoting (Prasad and Pushpa 2007; Singh and Rajini 2008; Stushnoff *et al.* 2008).

In previous studies, we introduced and applied a new quality numerical index, which we called functional mathematical index (FMI), to olive oil (Finotti *et al.* 2007) and potatoes (Finotti *et al.* 2006). The mathematical index is calculated in an *n*-dimensional parameter space as a Euclidean distance between the coordinates of an "optimal potato" and the experimental coordinates pertaining to the studied potato. The main goal of the index is to relate the chemical composition and the nutritional quality of potatoes. In particular, this numerical tool detects how the chosen parameters can influence the nutritional quality and suggest at which growth or process step(s) to intervene in order to increase the potato quality for animal and human diets.

The described results should facilitate selection of potato cultivars with optimum quality parameters to be used in the human diet and measuring changes in FMI values of newly developed potato cultivars: (1) during plant growing conditions and locations; (2) during large-scale plant breeding and molecular biology studies designed to develop improved potato varieties; (3) during harvesting, postharvest handling, storing and sampling of potatoes; and (4) in nutritional and toxicological assessment of dietary roles of potatoes following consumption by animals and humans.

In the present study, we have chosen 20 potato varieties from a widespread market such as the USA. Our main objective was to extend the mathematical quality index to the published data on the composition of these ingredients in 20 potato varieties sold in retail stores. Our specific focus was on the relation of asparagine content to acrylamide formation and on the experimentally observed trends in the content of reducing sugars and phenolic compounds.

MATERIALS AND METHODS

The compositional data of the potatoes evaluated in the present study were taken from our previous publications (Finotti *et al*. 2006; Im *et al*. 2008). For convenience, we will briefly describe the analytical methods that were used to obtain the following parameters.

The water content was determined according to Association of Official Agricultural Chemists method at 105C (Thiex and Van Erem 2002). The content of individual carbohydrates of the potatoes was determined by high performance liquid chromatography (HPLC) (Finotti *et al*. 2006; Varian Application note 186 2004). The asparagine content of the potatoes was determined by ion exchange chromatography (Mondino *et al*. 1972; Finotti *et al*. 2006). Chlorogenic acid and its isomers, caffeic acid and total phenolic compound content were determined by HPLC (Im *et al*. 2008).

Experimental Compositional Data Used for Mathematical Treatment

As mentioned earlier, the experimental compositional data used for the mathematical treatment were obtained from our previous publications on the water, asparagine, total free sugar (glucose, fructose, sucrose), chlorogenic acid, isomeric chlorogenic acid, caffeic acid and total phenolic content of the same 20 commercial varieties purchased in local stores evaluated in the present study (Vivanti *et al*. 2006; Im *et al*. 2008). For convenience, these are listed in Table 1.

Mathematical Treatment of Experimental Data

In a preceding article (Finotti *et al*. 2007), we introduced and applied the new mathematical index (FMI) to a set of compositional data of olives at a fixed time of harvesting. For the mathematical derivation of the index, we introduced a number of normalized (i.e., adimensional) parameters (in that case, 9, normalized to 1) related to the distance of chemical properties from the optimal conditions (see Table 1) as

TABLE 1. CONCENTRATIONS OF COMPONENTS OF 20 POTATO CULTIVARS USED TO CALCULATE FUNCTIONAL MATHEMATICAL INDEX VALUES*

Potato variety	Water %	Total free sugar mg/100 g	Asparagine mg/100 g	Chlorogenic acid mg/100 g	Isomer chlorogenic acid mg/100 g	Caffeic acid mg/100 g	Total phenols mg/100 g
Purple, Peruvian	77.27	745.29	49.63	637.00	90.50	29.30	171.00
Red medium organic	82.33	369.22	77.35	35.10	7.98	4.01	8.33
Yukon Gold grade B medium	75.49	824.35	80.92	19.00	6.01	5.04	7.36
Red grade A large	80.87	595.40	83.56	56.40	17.00	7.90	15.50
Ruby Red Crescent	78.89	599.31	85.67	49.50	16.40	6.47	15.30
Fingerling Ozette 1	79.97	199.26	89.76	105.00	49.70	13.80	33.60
Yukon Gold grade C small	82.31	451.21	92.93	26.70	7.47	7.86	7.45
Yukon Gold grade A large	76.89	374.02	106.26	14.30	4.69	4.55	5.45
White medium	79.36	376.67	107.98	34.10	12.80	6.05	10.90
Kennebec	75.02	95.47	115.63	3.28	0.34	0.47	1.03
Purple large	75.25	547.65	118.40	109.00	37.90	5.27	37.50
White large	79.93	121.10	140.84	21.60	6.71	2.83	6.27
Red grade C small	81.30	425.29	145.46	73.10	22.30	15.20	20.70
White Creamer small	83.41	318.60	150.48	41.90	10.40	9.83	10.30
Butterball Creamer organic German	80.47	310.41	258.72	36.00	13.40	7.14	11.00
Red Creamer, Marble	84.25	326.41	268.75	65.60	37.20	1.07	16.40
Fingerling French	79.27	636.08	274.16	203.00	69.70	7.83	58.10
Russet 1	79.49	298.40	334.62	18.20	1.020	1.82	4.31
Fingerling Ozette 2	78.51	86.24	378.84	113.00	41.90	12.70	36.10
Russet 2	80.18	374.33	760.98	25.90	10.90	2.53	7.98

* Adapted from Im *et al*. (2008) and Vivanti *et al*. (2006).

TABLE 2. PARAMETERS AND UPPER AND LOWER BOUNDS FOR POTATOES USED TO DEFINE FUNCTIONAL MATHEMATICAL INDEX

Potato class	Composition parameter	Upper bound in mg/100 g (%)	Lower bound in mg/100 g (%)
I	Water,	(84.25)	(75.02)
I	Total free sugars	824.35	86.24
I	Asparagine	760.98	49.63
II	Chlorogenic acid	637.00	3.28
II	Chlorogenic acid isomer	90.50	0.34
II	Caffeic acid	29.30	0.47
II	Total phenolic compounds	171.00	1.03

well as a global index (that we named global quality index, I_{GQ}) calculated as an Euclidean norm in an n-dimensional parameter space defined as:

$$I_{GQ} = \sqrt{\sum_{n=1}^{N} (X_n)^2}$$

where X_n is the normalized distance of the nth chemical parameter from its optimal nutritional/quality value. This is the classic formulation of the Euclidean norm. However, not all the indices used have the same weight (each index contributes in a different way, and it is very difficult to attribute to each of them the correct role played in this system). We are therefore introducing the following new weighted formula:

$$I_{GQ} = \sqrt{\sum_{n=1}^{N} w_n \cdot (X_n)^2}$$

where w_n are the weight and $\sum_{n=1}^{N} w_n = 1$

The new formulation shown in the next section minimizes (buffers) the effect of the different weights of each index using the fourth power of X_n of the second power as aforementioned, thus eliminating the weight problem.

$$FMI = \sqrt{\sum_{n=1}^{N} (X_n)^4}$$

We have also introduced a new set of parameters that are more suitable to describe the FMI used in this study. With this calculation, we obtain other useful information regarding each single index that represents a local FMI, defined as the quality evaluation for each single parameter:

$$LocalFMI := \max\{X_n^4\} \quad (n = 1, \ldots, n).$$

When the local FMI value is ≤1, the chemical parameter is within the good quality range. If it is >1, the value is outside the optimal range, suggesting the need for a suitable intervention.

The calculation of the index is therefore based on the parameters listed in Table 2. Since the nature of the single parameter is different (for example, the optimal value for some of parameters is between a minimal and a maximal value; for others, it is the maximal value), the mathematical formula for each of the X_n terms changes. To facilitate application of the revised index, we grouped the data into two parameter classes, class I and class II. These are listed in Table 2. For the class I parameters:

$$X_n = \frac{x_n}{x_{max}}$$

where x_n is the experimental value of the specific parameter, x_{max} is the maximum value shown in Table 2. For the class II parameters:

$$X_n = \frac{x_{max} - x_n}{x_{max} - x_{min}}$$

where x_n has the same meaning as aforementioned and x_{max} and x_{min} are, respectively, the maximum and minimum values of the allowed range.

With these definitions, a potato cultivar with a very low FMI value possesses very good nutritional/quality properties. In addition, as previously discussed (Finotti *et al.* 2007), we also propose a quality index for asparagine, free sugar and phenolic acid content in potatoes.

For this purpose, we used seven sets of experimental data to calculate the FMI values for 20 potato varieties.

Calculation of the Global FMI. As an example, we perform here a detailed calculation of the global FMI for one of the samples listed in Table 2. Because it has all nonzero parameter values (the most general situation), we selected the Butterball Creamer Organic German potato sample. Using the data from Tables 1 and 2, we can write the following:

(1) $X_1 = \frac{80.47}{84.25} = 0.955$ for water %

(2) $X_2 = \frac{310.41}{824.35} = 0.377$ for total free sugars;

(3) $X_3 = \frac{258.72}{760.98} = 0.340$ for asparagine;

(4) $X_4 = \frac{637.00 - 36.00}{637.00 - 3.28} = 0.948$ for chlorogenic acid;

(5) $X_5 = \frac{90.50 - 13.40}{90.50 - 0.34} = 0.855$ for chlorogenic acid isomer;

(6) $X_6 = \frac{29.30 - 7.14}{29.30 - 0.47} = 0.769$ for caffeic acid;

(7) and $X_7 = \frac{171.00 - 11.00}{171.00 - 1.03} = 0.941$ for total phenolic compounds.

For the FMI calculation, we calculate the fourth power of these normalized parameters: $X_1^4 = 0.832$, $X_2^4 = 0.020$, $X_3^4 = 0.013$, $X_4^4 = 0.809$, $X_5^4 = 0.535$, $X_6^4 = 0.349$ and $X_7^4 = 0.785$.

The FMI value is then the sum of these latter values:

$$FMI = \sqrt{X_1^4 + X_2^4 + X_3^4 + X_4^4 + X_5^4 + X_6^4 + X_7^4} = \sqrt{0.832 + 0.020 + 0.013 + 0.809 + 0.535 + 0.349 + 0.785} = 1.829$$

In this case, the local FMI corresponds to the water index (0.832).

RESULTS AND DISCUSSION

In Table 1, we list the values for water, total free sugar (glucose, fructose and glucose), asparagine, chlorogenic acid, chlorogenic acid isomer, caffeic acid and total phenolic acid content of the potato cultivars.

Table 2 lists the upper and lower bounds (concentrations) of water, total free sugar (glucose, fructose and glucose), asparagine, chlorogenic acid, chlorogenic acid isomer, caffeic acid and total phenolic acid content of the potato cultivars. The upper and lower bound (concentration) of each parameter have been established considering the maximum and minimum experimental values found only for each of the cultivars studied, respectively.

Table 3 shows the calculated local FMI, their sums and the FMI values. The FMI value for all cultivars evaluated was below the upper limit of 2.65. This means that they have a good phenolic acid pattern and low FMI values for asparagine and total free sugars. These findings suggest that with respect to these potato ingredients (compounds), all cultivars are of good quality. Table 3 also shows that the Local FMI values for the following three cultivars equal to one: Russet 2 (asparagine), Yukon Gold grade B medium (total free sugar) and Red Creamer Marble (water). The Local FMI values for the following two additional cultivars are close to one in more than one parameter: Kennebec (chlorogenic acid, chlorogenic acid isomer, caffeic acid and phenolic acids) and Russet 1 (chlorogenic acid isomer and phenolic acids). These values penalize the total score and the FMI. In fact, Russet 2 and, Yukon Gold grade B Medium Kennebec cultivars have the highest FMI values (2.22; 2.16 and 2.15, respectively). Because only the water value for the Red Creamer Marble cultivar is equal to one and because the values for the other parameters are very low and thus contribute to a decrease of its FMI score, the FMI for this cultivar is not penalized to the same extent.

Examination of the data in Table 3 indicates that a single parameter does not significantly influence the FMI score. In fact, the FMI values (in parenthesis) of the last four cultivars, Fingerling French (1.36), Fingerling Ozette 2 (1.36), Fingerling Ozette 1 (1.36) and Purple Peruvian (1.17), have the lowest FMI scores. These results are due to the very low values obtained with the other parameters. For example, five of the seven parameters for the Purple Peruvian potatoes equal to the "optimum value" of zero.

The data in Table 3 also suggest that the critical points are mainly due to the high water, asparagine and total free sugars values and that the chlorogenic acid and chlorogenic acid isomer values contribute to increases in the FMI value. These observations suggest that potato cultivars with high FMI values associated with these parameters and low FMI values for caffeic acid and total phenolic acids can contribute to improved potato quality.

CONCLUSIONS

The main goal of the described FMI is to detect the critical points during the entire production chain of factors that adversely or beneficially influence the quality of potatoes. The application of the index to the experimental data of the present and previous studies contributes to the evolution of quality indices during the different phases of growth, transport, storage and processing of potatoes. As is possible to observe in Table 3, the Russet 2 cultivar is defective in asparagine content, the Yukon Gold grade B medium is defective in sugar, the Kennebek is defective in chlorogenic acid, chlorogenic acid isomer, caffeic acid and total phenols contents, the Russet 1 is defective in chlorogenic acid isomer and the Red Creamed Marble presents high water content.

The low normalized distance of the values of these parameters substantially contributes to the low value of the FMI and globally, to the high quality because low FMI values mean good quality (a very short Euclidean distance from the "optimal potato"). Moreover, in order to obtain this result, the local FMI values have to be low. The index makes it possible to decide which parameter value(s) should be modified in order to enhance compositional, nutritional and safety aspects and to decrease the toxic potential of processed potato products and to optimize the technological processes for the benefit of potato growers, processors and consumers.

Further development of the FMI concept could be, e.g., divide the interval of all possible FMI values obtained from a large set of sample in "quality subintervals," arbitrarily chosen, in order to detect the corrections that could be performed to allow the passage of a specific cultivar to a "better quality" subinterval. This tool can help potato breeders, growers and processors detect the critical points along the whole food production chain and when appropriate, institute

TABLE 3. LOCAL FUNCTIONAL MATHEMATICAL INDEX (FMI), SUM AND FMI VALUES FOR 20 POTATO CULTIVARS

Potato cultivar	Water %	Total free sugars mg/100 g	Asparagine mg/100 g	Chlorogenic acid mg/100 g	Chlorogenic acid isomer mg/100 g	Caffeic acid mg/100 g	Total phenols mg/100 g	SUM	FMI
Russet 2	0.82	0.04	1.00*	0.85	0.60	0.70	0.83	4.83	2.20
Yukon Gold grade B medium	0.64	1.00*	0.00	0.89	0.76	0.47	0.84	4.60	2.14
Kennebec	0.63	0.00	0.00	0.98*	0.99*	0.94*	0.98*	4.51	2.12
Russet 1	0.79	0.02	0.04	0.89	0.96*	0.77	0.90*	4.37	2.09
White large	0.84	0.00	0.00	0.87	0.73	0.67	0.86	3.98	1.99
Yukon Gold grade A large	0.69	0.04	0.00	0.91	0.81	0.51	0.88	3.85	1.96
Red medium organic	0.91	0.04	0.00	0.80	0.69	0.56	0.82	3.81	1.95
Yukon Gold grade C small	0.91	0.09	0.00	0.84	0.71	0.29	0.84	3.68	1.92
White medium	0.79	0.04	0.00	0.80	0.54	0.40	0.77	3.34	1.83
Red Creamer, Marble	1.00*	0.02	0.02	0.65	0.12	0.86	0.67	3.34	1.83
White Creamer small	0.96	0.02	0.00	0.76	0.61	0.19	0.78	3.33	1.83
Ruby Red Crescent	0.80	0.28	0.00	0.72	0.45	0.37	0.69	3.31	1.82
Butterball Creamer organic German	0.83	0.02	0.01	0.79	0.53	0.33	0.77	3.28	1.81
Red grade A large	0.85	0.27	0.00	0.69	0.44	0.28	0.68	3.21	1.79
Red grade C small	0.87	0.07	0.00	0.61	0.32	0.05	0.60	2.53	1.59
Purple large	0.66	0.19	0.00	0.47	0.11	0.45	0.37	2.27	1.51
Fingerling French	0.78	0.35	0.02	0.22	0.00	0.29	0.19	1.85	1.36
Fingerling Ozette 2	0.75	0.00	0.06	0.46	0.08	0.10	0.39	1.85	1.36
Fingerling Ozette 1	0.81	0.00	0.00	0.49	0.04	0.08	0.42	1.84	1.36
Purple, Peruvian	0.71	0.67	0.00	0.00	0.00	0.00	0.00	1.38	1.17

* Local FMI.

needed corrections at different stages in order to obtain high-quality potatoes and potato products.

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