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Original Research Article

A functional mathematical index for predicting effects of food processing on eight sweet potato (*Ipomoea batatas*) cultivars

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ABSTRACT

In this paper we apply an improved functional mathematical index (FMI), modified from those presented in previous publications, to define the influence of different cooking processes of eight sweet potato (*Ipomoea batatas*) cultivars on composition of six bioactive phenolic compounds (flavonoids). The index allows the evaluation of nutritional, safety, and processing aspects of the following six phenolic compounds: neochlorogenic acid (3-CQA), cryptochlorogenic acid (4-CQA), chlorogenic acid (5-CQA), and three isochlorogenic acids, namely isochlorogenic acid A (3,5-diCQA), isochlorogenic acid B (3,4-diCQA), and isochlorogenic acid C (4,5-diCQA). These sweet potato components are considered to be the most representative phenolic compounds in this widely consumed food. The results of the mathematical analysis suggest that the derived total and individual FMI values provide a tool for predicting the relative adverse effects of food-processing effects (boiling, deep frying, microwaving, oven baking, sautéing, and steaming) on the evaluated phenolic compounds of eight sweet potato varieties. The use of the FMI makes it possible to predict the effects of processing conditions on the content of phenolic compounds of new sweet potato varieties, without the need to actually subject the sweet potatoes to the various cooking conditions.

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1. Introduction

Phenolic compounds play a fundamental role in the health of the sweet potato plant because they protect it against attacks by insects and phytopathogens (Friedman and Levin, 2009). It has also been reported that phenolic compounds inhibit the growth of human cancer cells (Kurata et al., 2007), possess antidiabetic properties (Ludvik et al., 2008), inhibit the growth of microbes and fungi (Lattanzio, 2003) and increase the health quality of the human diet (Teow et al., 2007). Sweet potatoes (*Ipomoea batatas*) contain high levels of chlorogenic acid derivatives, a family of esters formed from cinnamic and quinic acids (Clifford et al., 2003). The following phenolic compounds have been found in sweet potatoes: neochlorogenic acid (3-CQA), cryptochlorogenic acid (4-CQA), chlorogenic acid (5-CQA), and three isochlorogenic acid isomers–isochlorogenic acid A (3,5-diCQA), isochlorogenic acid B (3,4-diCQA) and isochlorogenic acid C (4,5-diCQA) (Jung et al., 2011; Ishiguro et al., 2007).

Antioxidative phenolic compounds are partly degraded during cooking processes, as described in detail in a previous publication (Jung et al., 2011). In previous studies (Finotti et al., 2007, 2009, 2011b; Friedman and Levin, 2009), we developed a mathematical formula called the functional mathematical index (FMI), which 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 the relative FMI value could benefit both producers and consumers of olive oils, who might wish to select oils that have optimal health benefits, as defined by the FMI concept. In related studies, we describe the derivation and application of new functional mathematical indices that define "potato nutritional quality" on the basis of the content and composition of potato components such as glycoalkaloids (Finotti et al., 2009). The concept was also applied to bioactive tea catechins found in black and green teas (Finotti et al., 2011a). We 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 and of tea leaves.

The main objectives of this study were to further refine the mathematical aspects of the FMI concept and to apply the derived relationships to the reported wide-ranging composition of

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phenolic compounds (flavonoids) of eight sweet potato cultivars (Jung et al., 2011). The described approach makes it possible to optimize and predict the beneficial effects of different components in different food categories.

2. Materials and methods

FMI is a mathematical index aimed at measuring quality that we first introduced to define the quality of olive oils. The mathematical derivations and applications of FMI were then extended to other foods. To apply it to sweet potatoes, the index is defined by the following mathematical equation:

$$\mathrm{FMI} = \sqrt{\frac{\sum_{i=1}^{n} loc_i^4}{n}} \quad (1)$$

where loc_i is a normalized parameter related to quality, defined experimentally below by physical and chemical parameters, and n is the number of parameters involved. This definition is related to the well-known (normalized to 1) Euclidean distance, but with a more general exponent than the usual second power. FMI is the square root of a finite sum of quantities; each one is a function of a specific measured quality parameter of the system. The number and types of parameters of the index can vary and depend on the specific application. In the present study, we consider three different types of parameters. In future, however, other types can be considered in order to improve the modeling of the systems. Every acceptable local parameter must have values in the range $[-1, +1]$. The fourth power named local FMI, can have values in the range [0,1]. Because the sum of n parameters can have a maximum value of 1, it must be divided by n, the number of parameters being evaluated. The minimum value that FMI can have is 0 (the best quality), and the maximum value is 1 (the worst quality). Because FMI measures the distance from an "optimal" sweet potato, the more a parameter differs from 0, the worse is the sample quality. We will now define the types of parameter used in the development and application of the FMI concept to sweet potatoes.

2.1. Parameters

In the present study, there are three types of parameter, which we indicate as:

- centered
- more
- less

All parameters x_n have two extreme acceptable values: maximum (x_n^M) and minimum (x_n^m). Some parameters are chosen on the basis of international law or recommendations, others are chosen on the basis of literature data or by some constraints. In other cases, they are simply maximum and minimum values of all studied samples. They are all fixed a priori.

The *centered* parameters represent those observable properties of which the optimum is the average of the two extreme values. The *more* parameters represent those observable properties of which the optimum is the maximum value. The *less* parameters represent those observable properties of which the optimum is the minimum value.

2.2. Centered parameter

The normalization function of a centered parameter x_n assigns the value 0 to the best possible value, the average, 1 or -1 to the boundaries.

Defining the range (r) semi-dispersion as follows:

$$r_n = \frac{x_n^M - x_n^m}{2}$$

and the range average as:

$$\overline{x_n} = \frac{x_n^M + x_n^m}{2}$$

the normalized function becomes:

$$loc_n = \frac{x_n - \overline{x_n}}{r_n}$$

2.3. More parameter

The normalization function of a more parameter x_n has 0 as the best possible value, or the minimum accepted value, and 1 as the worst acceptable value, or the minimum value of the acceptable range. For these parameters, the definition of the normalization function is:

$$loc_n = \frac{x_n^M - x_n}{x_n^M - x_n^m}$$

2.4. Less parameter

The normalization function of a less parameter x_n has the minimum accepted value as the best value (i.e. 0), and the maximum value as the worst one. In this case, the normalization function is defined as:

$$loc_n = \frac{x_n - x_n^m}{x_n^M - x_n^m}$$

Note that if the experimental value of the parameter exceeds the extremes of the acceptable range of values, the sign of the normalized loc is negative. Indeed, the absolute value of the defined loc should be considered. In any case, we use the fourth power and the sign of the loc is not important.

2.5. Nested FMI

Here we improve a previous attempt to generalize the definition of FMI for its application to different features of foods (not only the quality). If the product has different (independent) features – for instance, antibacterial and antitumor properties in the case of tea-independent definitions for each partial FMI (named subFMI) can be defined using specific local parameters.

From a mathematical point of view, it is possible to nest an FMI inside another (a more general or "global") FMI. Indeed, it is possible to consider a set of subFMIs and embed them into a single parameter raised to the second power. The previous FMIs then become new local FMIs (the above subFMI) of an extended FMI considering all the product features. For this application, we obtain the following general definition:

$$\mathrm{FMI} = \sqrt{\frac{\sum_{i=1}^{n_1} loc_i^4 + \sum_{j=1}^{n_2} \mathrm{subFMI}_j^2}{n_1 + n_2}}$$

In this definition, two different types of local parameters have been considered; the first sum refers to parameters that cannot be included in any subFMI, the second sum is extended to all subFMIs.

Because they are divided by the normalized sum of the global FMI, using this approach, we have implicitly assigned more weight to the local parameters of the FMI than to those of the subFMI. As the FMI definition is recursive, a subFMI is always defined as a nested FMI.

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