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Original Research Article

Application of a functional mathematical index (FMI) for predicting effects of the composition of jujube fruit on nutritional quality and health

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ABSTRACT

In the present study, we extend the concept of a functional mathematical index (FMI), introduced in previous publications, for the assessment and prediction of food quality and safety of jujube fruit, a medicinal food widely consumed in Asian countries. In this study the index has been applied to one field-grown jujube fruit harvested at eight stages of maturity and three commercial Korean jujube cultivars. The index allows quantitative evaluation of nutritional, health-promoting, and safety aspects based on reported essential amino acid and phenolic content and antioxidative and cancer-cell-inhibiting activities of the test substances. For example, the FMI values for the antioxidative capacities ranged from 0.36 to 0.87 and for the inhibition normal and cancer cells from 0.35 to 0.86, suggesting that consumers have a choice of selecting growth (maturity) stages of jujube fruit with optimum beneficial properties. The use of specific performance FMI values seems to be a better tool for predicting relative beneficial and adverse effects than prediction on the basis of concentrations of the nutritional and bioactive compounds. The FMI approach, that numerically scores compositional, nutritional, and health-related aspects of food, complements but does not replace standard statistical analysis of the original compositional analytical data from which this value is derived. The method can be used to detect critical points during growth and processing of food that make it possible to optimize nutritional and health benefits.

1. Introduction

Jujube fruits are widely consumed in Asian countries as a health-promoting functional food (Choi et al., 2011, 2012; Gao et al., 2012; Huang et al., 2007; Pahuja et al., 2011; Plastina et al., 2012; Yeung et al., 2012; Yu et al., 2012). In previous studies, Finotti and colleagues (Finotti et al., 2007) 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 value could benefit both producers and consumers of olive oils, who may wish to select oils with optimal health benefits. In related studies, we describe the derivation and application of a new functional mathematical index that defines the nutritional and health-promoting quality of several foods, including, potatoes (Finotti et al., 2009, 2010, 2011b), teas (Finotti et al., 2011a), and sweet potatoes (Finotti et al., 2012). 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, to define and predict relationships between anticarcinogenic and antimicrobial effects of tea catechins, and to select sweet potato cultivars that resist damage resulting from home-cooking processes.

The main objectives of this study were: (a) to apply the derived mathematical relationships to the reported wide-ranging content of amino acids and secondary metabolites in relation to antioxidative and cancer-cell inhibiting effects of extracts of

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jujube fruit cultivar harvested at different stages of growth; and (b) to compare the FMI values of three commercial cultivars. The described approach makes it possible to optimize beneficial effects of the different jujube categories.

2. Mathematical methods

FMI is a Mathematical Functional Index, the aim of which is to measure quality. We previously introduced the index in order to study the quality of olive oil (Finotti et al., 2007) and we extended it to other foods (Finotti et al., 2009, 2010, 2011a,b, 2012). The index is defined by the following *mathematical expression*:

$$\mathrm{FMI} = \sqrt{\frac{\sum_{n}^{i=1} loc_i^4}{n}}, \tag{1}$$

where loc_i is a normalized and adimensional local parameter related to quality experimental (i.e. chemical, physical and biological) parameters (see below) and n is the number of parameters involved; the "i" index in the sum covers the number n of the different parameters. This definition recalls 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 application. In the present study we consider three different types of loc_i parameters (see below for the mathematical definition (Eqs. (4)–(6)). However, in future other types can be considered in order to adapt the model to suit other systems. Every acceptable local parameter must have values in the range [−1, +1]. The fourth power of each *loc* (indexed with "i"), named local FMI (indexed with "i") (i.e. local $\mathrm{FMI}_i = loc_i^4$ 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 minimum value that FMI can have is 0 (the best quality), and the maximum value is 1 (the worst quality). The more a parameter differs from 0, worse is the sample quality, because the FMI measures the distance from the "optimal" sample. We will now define the types of the parameters. Note that for the sake of simplicity, we can omit the subscript "i".

2.1. Parameters

In the present study there are three types of parameters which we define as: *centered*, more, and less. All parameters have two extreme acceptable values: maximum (X_M) and minimum (X_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. Anyway, they are fixed a priori. The *centered* parameters represent those observable properties whose optimum is the average of the two extreme values. The *more* parameters represent those observable properties whose optimum is the maximum value. The *less* parameters represent those observable properties whose optimum is the minimum value.

2.2. Centered parameter

The normalization function of a centered parameter assigns the value 0 to the best possible value, which is the average, and 1 or −1 to the boundary acceptable one.

Defining the range semi-dispersion as follows:

$$r = \frac{X_M - X_m}{2} \tag{2}$$

and the range average:

$$\bar{X} = \frac{X_M + X_m}{2} \tag{3}$$

the normalized function is:

$$loc = \frac{x - \bar{X}}{r}, \tag{4}$$

where x is the experimental value and r is $r = (X_M - X_m)/2$, X_M is the maximum values and X_m is the minimum value.

2.3. More parameter

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

$$loc = \frac{X_M - x}{X_M - X_m} \tag{5}$$

2.4. Less parameter

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

$$loc = \frac{x - X_M}{X_M - X_m} \tag{6}$$

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. In fact, 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 improved a previous attempt to generalize the FMI definition to the case of different features of foods (no only the quality) (Finotti et al., 2011a). If the product has different (independent) features – for instance, anti-bacterial and anti-tumor in the case of tea – independent definitions for each partial FMI (named subFMI) can be stated, 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. In fact, it is possible to consider a set of subFMIs and embed them in a single parameter raised to the second power. The previous FMIs become new local FMIs (the above subFMI) of an extended FMI considering all the product features. In general, we obtain the following definition:

$$\text{Global FMI} = \sqrt{\frac{\sum_{n_1}^{i=1} loc_i^4 + \sum_{n_2}^{j=1} \mathrm{subFMI}_j^2}{n_1 + n_2}} \tag{7}$$

In this definition, two different kinds 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 subFMI values.

Using this approach, we have implicitly assigned more weight to the local parameters of the FMI than to those of the subFMI because they are divided even by the normalization sum of the global FMIs. As the FMI definition is recursive, a subFMI must be defined as a nested FMI.

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