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Application of a Functional Mathematical Index to the Evaluation of the Nutritional Quality of Potatoes

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ABSTRACT

This paper describes the derivation and application of a new functional mathematical index that was used to evaluate the nutritional, safety, and processing quality aspects of potatoes. The index introduces the concept of an "optimal potato", using appropriate distance and N-dimensional parameter space models. Although the index may not be a unique answer to the need for defining a "quality potato index", the results of the present study show that it presents an approach that can be used to establish whether a specific potato variety or processed potato product can be considered of high, medium, or low nutritional quality. The main goal of the index is to link composition and chemical quality to factors that govern growth, production, distribution, and processing of potatoes and potato products for commercial use. In addition, it is expected that the index will be a useful parameter that can detect critical points (harvest time, storage conditions, treatment processes) as affected by variety and composition during the entire growth, production, and distribution cycle of potatoes, and thus suggests new ways to increase the value of potatoes for the human diet. The index is intended to complement and extend methods for nutritional quality and safety of potato proteins.

Keywords: acrylamide, functional mathematical quality, glycoalkaloids, nutritional quality, potato composition, potato, safety

INTRODUCTION

Interest in human nutrition and the food demand for high quality food has increased in recent years in the European Union (FAO 2000; Rickertsen 2003), the United States (Chern 2003) and in developing countries including China and India (White Paper 2007). Consumers are now much more aware of the importance of the relationship between diet and health. Producers and retailers are taking into account this awareness in deciding on the composition, labelling, and marketing of foods. In recent studies, researchers have reported on the rapid growth in the market for nutritionally improved foods (Olsen *et al.* 2008) and on the perception of effective 'food risk management' from various points of view ranging from the producer to the consumer, and how that effects food quality across the whole food chain (Houghton *et al.* 2008).

There is also interest in finding tools to assess food quality. McCarty (2004) suggested the use of a 'phytochemical index' (PI) as the percent of dietary calories derived from foods rich in phytochemicals. A checklist of indicators has been developed to assess food and nutrition services in older adult assisted-living facilities intended to correlate with the 'quality of life' and 'health outcomes' of the residents (Chao *et al*. 2007) developed a checklist of indicators to assess food and nutrition services in older adult assisted-living facilities intended to correlate with the 'quality of life' and 'health outcomes' of the residents (Chao *et al.* 2007). Other studies have focused their interests on estimating the costs associated with obtaining a specific quality level in processed foods (Zugarramurdi *et al.* 2007). To identify functions that contribute to realisation of food quality, some studies have developed techno-managerial models (Luning and Marcelis 2007).

Consumer acceptance is another important factor. For example, ethnicity factors have been analysed in the United States. Research showed, that despite limited food resources and low incomes, Hispanic American mothers consumed adequate fruits and vegetables (Hoerr *et al.* 2008).

A widely accepted definition of "food quality" refers to the sum of internal (chemical, physical microbial and other safety aspects) as well as external factors (size shape, colour, gloss, consistence, texture and flavour) of food.

Because foods are susceptible to contamination during processing, food manufacturing requires high quality control standards. Many consumers read labels in order to know the ingredients present that impact dietary (kosher, halal, vegetarian), nutritional, or medical requirements including cancer, diabetes, and allergies.

In addition to the quality of ingredients the issue of safety is also important. Manufacturing processes have to produce the safest possible food for consumers. Other important quality features are traceability and packaging as well as ingredient and nutritional information (Potter and Hotchkiss 1995). The above mentioned definition for 'food quality' is quite general. External factors are too subjective and are difficult to assess. If safety requirements are to be mandated by law, there is a need to define both external and internal quality factors in order to obtain the 'total quality'.

In a previous paper we proposed a rapid and flexible Functional Mathematical Index (FMI) to describe the total quality of olive oil (Finotti *et al.* 2007). In another study, we surveyed nine Italian potato cultivars for nutritional quality and suitability for different technological processes (Finotti *et al.* 2006).

In this paper we have applied the quality FMI we developed for olive oil (Finotti *et al.* 2007) to the potato parameters we described in the aforementioned potato survey paper (Finotti *et al.* 2006). We chose to apply the quality FMI to potatoes because all the parameters are comparable, and because potatoes have played an important role in the human diet. For background and for general interest

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in potato nutrition, we will first briefly review previous studies designed to define the protein nutritional quality of potatoes. The derived quality FMI values are intended to extend and complement the definition of potato quality.

Protein nutritional quality of potatoes

Potatoes, members of the Solanaceae plant family, serve as major, inexpensive low-fat food sources providing energy (starch), high-quality protein, fiber, and vitamins. Potatoes also produce biologically active secondary metabolites, which may have both adverse and beneficial effects in the diet. These include glycoalkaloids, calystegine alkaloids, protease inhibitors, lectins, phenolic compounds, anthocyanins, and chlorophyll.

Protein nutritional quality is governed by amino acid composition, ratios of essential amino acids, susceptibility to hydrolysis during digestion, and the effects of processing. To optimize the biological utilization of proteins, a better understanding is needed of the various interrelated parameters that influence their nutritive value. Although potatoes are commonly perceived as a carbohydrate source, they are also a good source of high-quality protein. Although potatoes contain only about 2% protein on a fresh weight basis, the value increases to about 10% when examined on a dry weight basis, equal to that of most cereals such as rice or wheat (McCay *et al.* 1987). A summary of the nutritive value of potato protein by Markakis (1975) and Lisinska and Leszczynski (1989) shows the following: (a) About 50% of the total nitrogen of potatoes is derived from proteins; the remaining nitrogen consists of free amino acids (15%), amide nitrogen, associated with asparagine and glutamine (23%), and non-protein nitrogen associated with the glycoalkaloids solanine and chaconine and secondary metabolites such as acetylcholine, adenine, cadaverine, guanine, hypoxanthine, narcotine, trigonelline, and xanthine (12%). (b) Based on amino acid composition, the calculated protein quality is about 70% that of whole egg protein. (c) Potatoes provide an excellent source of lysine, but low contents of sulfur amino acids, cystine and methionine, limit their nutritive value. (d) Human feeding trials suggest that potato proteins are of a very high quality, possibly higher than indicated by the amino acid composition. This may be because protein utilization is enhanced by the high content of free amino acids and other nitrogen-containing compounds.

A good source of potato protein is as a waste product of potato starch production. Recovery of this high quality protein could solve factory problems with disposal polluting effluents (Ralet and Guéguen 2000; Ralet and Guéguen 2001).

Potato hybrids and concentrates

The protein efficiency ratio (PER) values for proteins from intraspecific potato hybrids calculated from amino acid analyses data of 2.64 to 2.79 were higher than corresponding values obtained from rat feeding studies (Kapoor *et al.* 1975; Boody and Desborough 1984). The latter ranged from 2.16 to 2.77. Nestares *et al*. (1993) found that the potato concentrate's nutritional quality was excellent when measured in terms of protein efficiency ratio (PER, 2.90), biological value (BV), net protein utilization (NPU), and nitrogen retention. Kies and Fox (1972) fed human volunteers potato protein (derived from dehydrated flakes) with and without supplementation. They reported that (a) the mean crude protein digestibility of the potato protein was 78% and (b) the mean nitrogen balance of the human subjects increased when the potato protein was fortified with 0.3% methionine, but not with leucine or phenylalanine. These results suggest that complementary diets consisting of both potatoes, which are high in lysine but low in sulfur amino acids, and cereals, which are low in lysine but high in sulfur amino acids, should provide a well-balanced protein source. They also imply that a need exists to develop new potato cultivars high in both protein and sulfur amino acids (see below).

Eppendorfer and Eggum (1994) found that a large amount of nitrogen fertilizer increased the quantity and reduced the quality of potato protein. Tubers from potato plants grown in rotation with other crops such as alfalfa contained over 50 kg of additional protein available for harvest per hectare compared to potato-potato rotation (Honeycutt 1998). By contrast, treatment of field grown potato plants with the insecticide deltamethrin resulted in a 17% decrease in protein and in a 46% increase in free amino acid content of the tubers compared to untreated controls (Fidalgo *et al.* 2000).

Low-glycoalkaloid potato protein

Many attempts to isolate potato protein from potatoes resulted in co-isolation of glycoalkaloids which may adversely affect nutritional quality. For example, our studies (unpublished results) revealed that a commercial potato protein concentrate contains significant amounts of glycoalkaloids (~200 mg/100 g). If potato protein isolates are to assume a greater role in animal and human nutrition, a need exists to reduce their glycoalkaloid content.

Several studies have shown a negative correlation between glycoalkaloid content and nutritional value of proteins. Kerr *et al*. (1998) observed lowered food intake, growth, and differences in performance of pigs fed a high-glycoalkaloid potato protein (303.0 mg/100 g). By contrast, a low-glycoalkaloid (15.6 mg/100 g) potato protein diet was equivalent in quality to fish protein. Feeding dietary high-glycoalkaloid potato protein to salmon resulted in severe weight loss, whereas a low-glycoalkaloid potato protein was highly nutritious without apparent adverse effects (Refstie and Tiekstra 2003). These observations are similar to our own studies on feeding of mice (Friedman 1996).

Potato fruit juice prepared from potato berries contains about 20 g of protein per liter. To minimize the presence of glycoalkaloids that may be co-extracted into the juice, Backleh *et al.* (2004) devised an Adsorptive Bubble Separation Method which can remove nearly all of the glycoalkaloids from the juice. Alt *et al.* (2005) devised an improved HPLC method with an overall detection limit of 20 ppm for α-chaconine and α-solanine in the potato protein powder derived from the juice. Low-glycoalkaloid, inexpensive potato protein could serve as a major food source in the human nutrition.

Transgenic potatoes

The creation of new transgenic potato cultivars with improved resistance against phytopathogens and improved composition is currently a very active area of worldwide research. Nutritional value may not be significantly affected by genetic manipulations as indicated by the following observations. Total protein content of tubers from insect- and virus-resistant potato plants did not differ from corresponding amounts that were present in tubers from conventional varieties (Rogan *et al.* 2000). Similar results were observed by El-Sanhoty *et al.* (2004) and Sadowska *et al.* (2008) for transgenic cultivars.

A rat feeding study revealed a slight difference in final body weights between the control and experimental transgenic groups, but no other differences in biochemical parameters and organ weights (El Sanhoty *et al.* 2004). Molecular biology methods were successfully used to increase the biosynthesis of cystine and methionine content of potato proteins (Zeh *et al.* 2001; Nikiforova *et al.* 2002). Such high-quality proteins merit further study for their value in animal and human nutrition.

Potato protease inhibitors of digestive enzymes

Dehydrated White Rose potatoes contained the following amounts of inhibitors (in units/g): trypsin, 1020; chymotrypsin, 370; carboxypeptidase, A 112. Dehydrated potatoes contain ~25% and fresh potatoes ~6% of the amount of

inhibitors in soybeans (Dao and Friedman 1994). Potato protease inhibitors in potato protein suppressed proteolytic activity in feces from patients suffering from protease-related peri-anal dermatitis (Ruseler-van Embden *et al.* 2004). The authors suggest that topical application of the inhibitors may prevent this disease. It is not known whether potato protease inhibitors can act as a cancer preventative as do soybean inhibitors (Friedman and Brandon 2001).

Antimicrobial potato protein

Feeding of potato protein isolated from red skin variety "Gogu valley" reduced coliform pathogenic bacteria in the digestive tract and in the feces of weanling pigs. The potato protein also improved performance of weanling pigs (Jin *et al.* 2008). This important study suggests that inexpensive potato protein has the potential to replace antibiotics in animal feed.

In conclusion the described results show that potato protein merits inclusion in various food formulations as a source of high-quality protein.

With the above described background, we will now proceed to define and apply another approach to the determination of potato quality.

Functional mathematical index for potato quality

It should be emphasized that the index does not pretend to be the unique answer to the need of a "quality index". The main feature of our index is its flexibility. It can be adapted to different quality parameters selected for evaluation.

To evaluate the nutritional quality of different potato varieties, we have chosen eight chemical parameters divided into the following nutritional and anti-nutritional parameters:

- *nutritional parameters* - starch, malic acid, citric acid, ascorbic acid and chlorogenic acid.
- *anti-nutritional parameters* - total free sugars, asparagines and the sum of glycoalkaloids α-solanine plus α-chaconine.

We consider total free sugars as an anti-nutrient, because they are involved in the Maillard browning reaction and in acrylamide formation. Moreover, asparagine is an important precursor of acrylamide and is therefore also considered to be an anti-nutrient (Friedman *et al.* 2003). The glycoalkaloids α-solanine and α-chaconine – the two major glycoalkaloids present in potatoes – are also defined as anti-nutrients. The toxicity of these compounds may be due to adverse effects on the central nervous system, disruption of the cell membranes, and impairment of the digestive system and general body metabolism (Friedman 2006). For these reasons, there are informal guidelines limiting the total glycoalkaloid concentration in potato to 200 mg/kg fresh weight of potatoes (Souci *et al.* 2000).

MATERIALS AND METHODS

Potatoes

The potatoes samples were provided by Quality Seed s.r.l. (Minervio, Bologna, Italy). All cultivars were harvested during the same period and then stored at 4°C. Some were lyophilized and stored at room temperature under vacuum dryer. The determinations of water, ascorbic acid, malic acid and citric acid content were performed on fresh samples. The concentrations of starch, free carbohydrates, chlorogenic acid, asparagine, α-solanine, and α-chaconine were determined with lyophilized samples.

Water

The water content was determined according to AOAC methods at 105°C (Thiex and Van Erem 2002).

Starch

Total starch content was determined using 100 mg dry samples with the Diffchamb EnzyPLUS™ Starch Kit (Diffchamb AB, Sweden).

Carbohydrates

The fresh potato sample (1 g) was extracted with 10 ml of acetonitrile/water (80:20 v/v), stirred, and then centrifuged at 3000 rpm for 10 min. The supernatant was then filtered through a 0.45 μm Millex filter (Millipore) before to HPLC analysis.

A Beckman 342 HPLC model (Palo Alto, Ca USA) equipped with R.I. detector, and an INERTSIL NH_2 4 × 250 mm (GL Sciences, Japan) column was used for HPLC. An isocratic mode elution with a mobile phase acetonitrile/water (80:20 v/v) at a flow rate of 0.5 ml/min was used to separate the potato carbohydrates. Filtered solutions (50 μl) were injected into the column as previously described (Finotti *et al.* 2006, Application Note 186).

Asparagine

A lyophilized sample (100 mg) was deproteinized by 50 ml of a 0.3 M sulphosalicilic acid solution. The sample was then stirred and centrifuged at 10,000 rpm for 5 min. The supernatant (250 μl) was injected into an Beckman 118 BL amino acid analyzer (Mondino *et al.* 1972; Finotti *et al.* 2006).

Chlorogenic acid

A fresh sample (1-3 g) was extracted by a methanol:water (50:50 v/v) solution, stirred, and then heated to 100°C for 30 min. The sample was cooled and filtered through a 0.45 um Millex filter (Millipore) and injected into HPLC (Beckman 342 HPLC model Palo Alto, CA, USA) equipped with an UV-Vis detector and a Supelcosil C18 4.6 × 250 mm column (Supelco Bellefonte Ca, USA). The analysis was performed by isocratic mode using mobile phase: buffer citric acid 6.1 mM and dihydrogen sodium phosphate 8.8 mM (pH 4.2) wavelength, 310 nm; flow rate at 1.2 ml/min. (Stevens and Davelaar 1996).

α-Solanine and α-chaconine

The glycoalkaloids were extracted according to the procedure described by Friedman *et al*. (2003) and analyzed by HPLC (Beckman 342 model, Palo Alto CA, USA) equipped with a UV-Visible detector using an Inertsil NH_2 column 5 μM, 4.0 × 250 mm (GL Science, Japan). As the mobile phase, a solution of acetonitrile/20 mM KH_2PO_4 (80:20 v/v) was used in isocratic mode at 208 nm with a flow rate of 1.0 ml/min. The sample solution (20 μl) was injected into the HPLC column. The glycoalkaloids, α-solanine and α-chaconine, were quantified by comparison to a standard chromatogram.

Statistical analysis

ANOVA was used to determine the statistical differences at $P \leq 0.05$. Data presented in tables show the calculated means and standard deviations. Different letters indicate significant differences at $P \leq 0.05$ (Duncan's multiple range test).

Table 1 Parameters and related bounds potatoes used to define total quality FMI of potatoes.

		Upper bound	Lower bound
1	Total free sugars g/100 g fresh product	2.1	0
2	Asparagine mg/100 g fresh product	761.62	0
3	α-Chaconine +α-Solanine mg/100 g fresh product	200	0
4	Starch g/100 g fresh product	18.76	12.7
5	Malic acid mg/100 g fresh product	163.65	96.81
6	Ascorbic acid mg/100 g fresh product	24.65	3.59
7	Citric acid mg/100 g fresh product	657.5	252.2
8	Chlorogenic acid mg/100 g fresh product	12.2	1.25

The mathematical formulation

In **Table 1** we have divided the set of parameters into two groups:
1) Parameter of the first kind (anti-nutrients): the smaller the value, the better the quality (indexes 1 to 3, **Table 1**);
2) Parameter of the second kind or "saturating parameters" (nutrients): the higher the value, the better the quality; (indexes 4 to 8, see **Table 1**).

The parameters must be normalized to obtain for every index values varying in the interval [-1, 1].

For the first group (indexes 1 to 3, see **Table 1**) let us consider $X_n = \frac{x_n}{x_n^{MAX}}$;

for the second group (indexes 4 to 8, see **Table 1**) we define

$$X_n = H(x_n - x_n^{MAX}) + sign(x_n - x_n^{MAX}) \cdot \frac{x_n - x_n^{MAX}}{x_n^{MAX} - x_n^{MIN}} = \begin{cases} \frac{x_n^{MAX} - x_n}{x_n^{MAX} - x_n^{MIN}} & if \quad x_n \le x_n^{MAX} \\ \frac{x_n - x_n^{MAX}}{x_n^{MAX} - x_n^{MIN}} + 1 = \frac{x_n - x_n^{MIN}}{x_n^{MAX} - x_n^{MIN}} & if \quad x_n > x_n^{MAX} \end{cases} \quad (1)$$

where $sign(t) = \begin{cases} 1 & if \quad t > 0 \\ 0 & if \quad t = 0 \\ -1 & if \quad t > 0 \end{cases}$

and $H(t) = \begin{cases} 1 & if \quad t > 0 \\ 0 & if \quad t \le 0 \end{cases}$

is obtained from the so-called Heaviside step function (Jordan and Smith 1994), which allows the index to jump discontinuously from 0 to 1, when the parameter exceeds its maximum allowable value. Deviating from the Heaviside function, we put H(0) = 0, to guarantee that, when $x_n = x_n^{MAX}$, the corresponding index becomes 0.

In **Fig. 1** we have plotted the qualitative behaviour of the two parameter groups. The indexes related to the second group can assume values not belonging to the interval [0,1]. Let us introduce the Euclidean space R^N (where N is the number of parameters studied), endowed with the usual Euclidean metric or norm for every vector $X = (X_1, X_2, ..., X_N) \in \Re^N$ (Horn and Johnson 1990).

The Euclidean norm of the vector X, whose components are the indexes X_n, will represent our "Global Quality" index (or Global quality FMI) I_{GQ}:

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

With this choice, the "optimal potato" corresponds to the vector X = (0,0,...,0), that is the origin. Potato quality is indirectly a function of the I_{GQ} value obtained by equation (2). In fact, every component of the vector represents the normalized distance of the parameter from the optimal value. Thus, a good product has a small value of I_{GQ}; a poor product has a high value of I_{GQ}.

A parameter whose value belongs to the allowed quality range corresponds to an index such that $|X_n| \le 1$. Consequently, a product with only good values of the quality parameters corresponds to a vector, in the N-dimensional space, whose norm is less or equal to $\sqrt{N}$. If a product has a high global quality, its quality vector must belong to the N-dimensional hypersphere S_N, centred in the origin and with radius of length $\sqrt{N}$. The farther from the origin of the vector, the worse its "global quality" the nearer the origin to the vector, the better its "global quality".

The index I_{GQ} can be interpreted as a "global" index, because its value is obtained by the sum of N contributions by every single component. However, belonging to the N-dimensional hypersphere S_N does not guarantee a high quality "potato". In fact, if it is true that for every product whose parameters belong to the intervals shown in **Table 1**, then the corresponding index vector X belongs to the hypersphere S_N. In general, the reverse implication is no longer true, except for the indexes 1 to 3 (see the above discussion). Therefore, belonging to the N-dimensional hypersphere S_N is only a necessary condition for a high quality potato.

To consider (and correct) this situation, we introduce a second

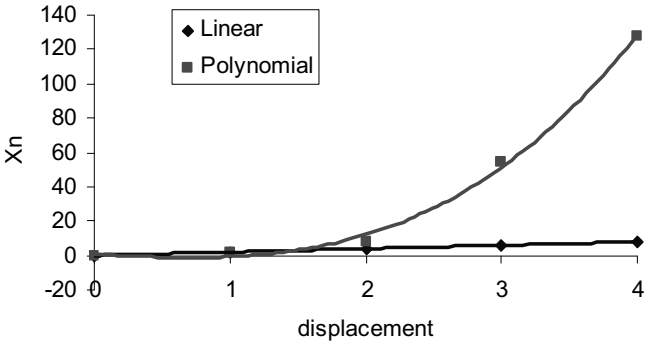

Fig. 1 Penalization Award Comparison between linear *versus* polynomial indexes. Note: The abscissa shows the value of the normalized displacement of the experimental value from the "optimal values". The ordinate shows the N^{th} power (N = 1 for linear and N integer > 1 for polynomial) of the displacement.

index that represents the "Local Quality" index (or Local quality FMI) I_{LQ}:

$$I_{LQ} := \max|X_n| \qquad (n = 1, \ldots, N) \quad (3).$$

The condition $I_{LQ} \le 1$ excludes product with even only one index greater than 1. This is a sufficient condition for a high quality potato, because it guarantees that all the parameters belong to the intervals shown in **Table 1**. The I_{LQ} is a first checkpoint for testing the quality potato. If a specific potato cultivar does not fulfil this condition (i.e. has one $I_{LQ} > 1$), it is not considered further in the mathematical analysis.

We adopted two quality indexes because $I_{LQ} \le 1$ guarantees that no parameters of a product exceed the values shown in **Table 1** (without considering the global contribution of the parameters). I_{GQ} (representing the distance from the optimal point, i.e., the origin) describes a global property of the potato.

The second index can be considered a "local" index, because it gives only the information about the maximal value of the components. Consequently, the vectors X_1 = (1, 1, ... , 1, 1) and X_2 = (1, 0, 0, ..., 0, 0) have the same I_{LQ}. Thus we cannot neglect the global index, which tells us that for every vector whose I_{LQ} is less than 1, and how much it is close to the origin, i.e., how good it is.

The quality FMIs are flexible and can be adapted to new local or international regulations, new literature data, etc. On the other hand, the previous formulas for the indexes X_n can be easily adapted to several different requirements. If, for example, we decide that a product exceeding the threshold for one or more parameters must be considered a "poor quality potato", then we can decide to modify the corresponding indexes in such a way that they strongly impact the quality FMI value.

One of the simplest ways to yield this result is to modify the indexes by defining $X_n = M$ if x_n does not belong to the allowed range, where M is an arbitrary value, which can be established depending on the penalization level chosen. As observed above, the indexes of the first group cannot exceed the value of 1.

If we want to include products that slightly exceed the threshold and simultaneously heavily penalize those whose excess is high, we can modify the formulas as follows by introducing a "penalization – awarding" coefficient. If x_n does not belong to the allowed range, instead of $X_n = M$, use the relation $X_n = f(x_n)$, where $f(x_n)$ is a function with values close to 1, when x_n slightly exceeds the allowed bounds and grows fast when x_n moves far apart from the bounds. A polynomial $P_N(x_n) = \sum_{k=0}^{N} a_k x^k$ of degree N or an exponential function would perfectly match these requirements.

Moreover, we can reproduce the realistic situation of products assuming parameter values sufficiently close to the optimal ones to be considered of the highest quality. We cannot expect that a parameter score, of the second kind equal to zero (i.e. the experimental data correspond to the maximum allowed value). A very good result is obtained for a nearly zero value of the parameter. We can take into account these requirements using polynomials of degree N greater than 1, for $x_n^{MIN} \le x_n \le x_n^{MAX}$. In this case, we build the following indexes:

for the first group (indexes 1 to 3):

$$X_n = \left(\frac{x_n}{x_n^{MAX}} \right)^N ;$$

for the second group (indexes 4 to 8):

$$X_n = \left(\frac{x_n^{MAX} - x_n}{x_n^{MAX} - x_n^{MIN}} \right)^N .$$

As already remarked, if a parameter value belongs to the allowed range shown in **Table 1**, the value of the corresponding component X_n lies in the interval [-1,1].

Since we consider 8 parameters, when all the parameter values belong to the ranges listed in **Table 1**, the Global quality FMI ranges from 0 to $\sqrt{8} = 2.83$. Let us recall that $I_{GQ} \leq 2.83$ is only a necessary condition for a high quality potato.

The lower bound of the Global quality FMI, which obviously is equal to 0, is called a standard reference "potato", and represents the optimal (i.e., "ideal") value for a "perfect potato". Finally, in order to test our Global and Local quality FMIs, we have chosen a second degree (i.e., quadratic) polynomial for the indexes shown in **Fig. 1**.

RESULTS AND DISCUSSION

Table 2 shows the literature values of water, glucose, fructose, sucrose and starch (Souci *et al.* 2000). 'Sponta' has the lowest values for water, glucose, and fructose; 'Jelli' and 'Agria' have low values for all free carbohydrates; and 'Primura' has a low concentration for sucrose. Total free sugars is an important parameter because they are involved in the Maillard reaction and acrylamide formation (Friedman and Levin 2008). The cultivars with low sugar concentrations are more suitable than others to be employed in high-temperature food processes. 'Marabel' had the highest value for sucrose and starch, probably due to a better storage process (Amrein *et al.* 2003).

Table 3 shows the values of organic acids. All samples provide a good nutritional value for malic, citric, and ascorbic acids. The malic acid value is highest in 'Primura'.

'Merit' has a high content of ascorbic acid. 'Sponta' and 'Agria' have the highest concentration of citric acid; the latter cultivar has a very low concentration for ascorbic acid. Compared to the literature (Souci *et al.* 2000), only 'Merit', 'Primura' and 'Agria' are good sources of chlorogenic acid.

Table 4 lists the values for asparagine, α-solanine and α-chaconine. 'Agata' and 'Arinda' have the lowest asparagine content. Since asparagine is an important precursor of acrylamide formation, these two cultivars are perhaps more suitable for use in high-temperature food processes than the others. Other cultivars contain different amounts of asparagine, with highest values in 'Frinka', 'Sponta' and 'Primura'. **Table 4** also lists the concentrations of α-solanine and α-chaconine. In all the cultivars studied, the sum of both glycoalkaloids are low enough to be acceptable for human consumption (Morgan and Coxon 1987).

Table 5 shows the quality FMI values for each cultivar evaluated in the present study. All the cultivars are of high quality. From the described mathematical analysis, such low scores can be obtained only if each single parameter is very close to zero. This is an excellent result from a nutritional standpoint because all the nutritional parameters are well

Table 2 Water and sugar content of potatoes (g/100 g of fresh product) used to define total quality FMI.

Cultivars	Water	±	Glucose	±	Fructose	±	Sucrose	±	Starch	±
Agata	81.00 cd	1.10	0.23 c	0.01	0.17 e	0.01	0.53 cd	0.01	12.22 a	0.07
Primura	80.86 cd	1.12	0.21 de	0.02	0.13 d	0.01	0.35 a	0.01	12.44 b	0.15
Arinda	81.83 d	1.00	0.34 f	0.03	0.08 c	0.01	0.57 d	0.05	12.54 b	0.02
Merit	79.03 bc	1.00	0.18 d	0.01	0.13 d	0.01	0.78 e	0.03	13.34 c	0.14
Marabel	81.70 d	1.60	0.12 c	0.01	0.11 d	0.01	1.39 f	0.14	18.63 g	0.18
Jelli	77.70 b	1.50	0.02 a	0.01	0.05 b	0.01	0.33 a	0.02	14.30 d	0.16
Frinka	79.40 bcd	0.50	0.22 e	0.01	0.18 e	0.01	0.46 c	0.04	15.09 e	0.02
Sponta	75.23 a	1.12	0.03 a	0.01	0.00 a	0.01	0.45 bc	0.02	17.06 f	0.07
Agria	80.13 cd	2.06	0.07 b	0.03	0.05 b	0.02	0.36 ab	0.02	15.15 e	0.12
F ANOVA	8.15 ***		108.43 ***		80.43 ***		116.02 ***		1053.30 ***	

Each value is the mean of three determinations; different letters indicate significant differences at $P \leq 0.05$ Duncan's multiple range test.

Table 3 Malic, ascorbic, citric, and chlorogenic acid content of potatoes (mg/100g of fresh product) used to define total quality FMI.

Cultivars	Malic acid	±	Ascorbic acid	±	Citric acid	±	Chlorogenic acid
Agata	124.67 d	1.50	19.19 f	0.64	425.36 e	1.10	4.75 c
Primura	139.52 e	1.67	9.98 c	0.08	388.60 d	40.53	10.09 e
Arinda	122.65 cd	6.56	8.06 b	0.10	255.72 a	4.98	3.45 b
Merit	97.57 °	1.01	24.23 g	0.63	478.60 f	7.21	12.11 f
Marabel	161.40 f	3.42	17.50 e	0.54	286.13 b	5.14	6.42 d
Jelli	100.26 °	1.62	13.27 d	0.60	423.82 e	4.81	1.40 a
Frinka	126.64 d	1.07	8.51 b	0.19	320.13 e	1.81	7.07 d
Sponta	105.60 b	1.01	18.53 f	0.21	655.70 h	1.67	4.26 c
Agria	118.38 c	0.90	3.68 a	0.08	624.72 g	0.17	10.51 e
F ANOVA	164.77 ***		760.88 ***		296.63 ***		222.11 ***

Each value is the mean of three determinations; different letters indicate significant differences at $P \leq 0.05$ Duncan's multiple range test.

Table 4 α-Chaconine, α-solanine and asparagine (mg/100 g of fresh product) content of potatoes used to define total quality FMI.

Cultivars	Asparagine	±	α-Chaconine	±	α-Solanine	±	α-Chaconine + α-solanine	±
Agata	15.61 a	0.90	0.89 a	0.005	0.15 a	0.005	1.04 a	0.001
Primura	392.05 f	17.00	1.51 b	0.01	0.33 c	0.001	1.84 b	0.01
Arinda	50.40 b	2.40	1.71 c	0.04	0.29 b	0.005	2.00 c	0.05
Merit	154.34 c	6.20	2.16 d	0.16	0.74 f	0.01	2.90 d	0.15
Marabel	183.03 d	9.30	3.54 g	0.01	0.68 e	0.005	4.22 h	0.02
Jelli	238.18 e	10.90	2.95 e	0.15	0.59 d	0.01	3.54 e	0.14
Frinka	458.42 g	14.70	3.26 f	0.06	0.56 d	0.01	3.81 f	0.05
Sponta	458.40 g	20.50	4.09 h	0.03	1.01 g	0.027	5.10 i	0.01
Agria	146.71 c	6.40	3.39 fg	0.11	0.67 e	0.03	4.07 g	0.09
F ANOVA	620.50***		470.16 ***		825.26 ***		817.51 ***	

Each value is the mean of three determinations; different letters indicate significant differences at $P \leq 0.05$ Duncan's test.

Table 5 Calculated total quality FMI values for potato cultivars.

Cultivars	FMI	
	Mean	± SD
Arinda	0.89	0.03
Jelli	0.85	0.03
Marabel	0.73	0.10
Agria	0.73	0.01
Frinka	0.67	0.01
Sponta	0.58	0.02
Primura	0.50	0.01
Agata	0.46	0.04
Merit	0.32	0.04

Each value is the mean of three determinations.

Table 6 Potato cultivars divided into groups for different processing purposes.

Group	Cultivar	Suitability for processing
A	Agata, Arinda	High temperature food processes
B	Sponta, Marabel	Low temperature processes
C	Primura, Merit, Jelli, Finka, Agria	Domestic purpose and home cooking

Table 7 Potato cultivars classified into groups and suitability for different uses.

Group	Cultivar	Suitability for processing
A	1st Agata	High temperature food processes
	2nd Arinda	
B	1st Sponta	Low temperature processes
	2nd Marabel	
C	1st Merit	Domestic purpose and home cooking
	2nd Primura	
	3rd Finka	
	4th Agria	
	5th Jelli	

expressed.

The anti-nutritional parameters all have very low values. Based on the quality FMI analysis, 'Merit' has the highest nutritional value and 'Arinda' the lowest. However, there is a very narrow range of 0.6 units for both cultivars. Previously, we found a wider spread in the values for olive oils (Finotti *et al.* 2007).

In a previous publication (Finotti *et al.* 2006) we divided the potato cultivars studied into three groups, each being suitable for different technological processes (**Table 6**):

(a) group: 'Agata' and 'Arinda'. Suitable for high-temperature food processes prone to browning reactions and acrylamide formation (i.e. chips, snacks, French fries, fried food), because they have a very low asparagine content.

(b) group: 'Sponta' and 'Marabel'. Suitable for use in low temperature processes such as minimally processed foods and stir fry foods because they have a good quality nutritional value (good starch and organic acids concentration) but have high amount of asparagine and high concentration of α-solanine and α-chaconine.

(c) group: 'Primura', 'Merit', 'Jelli', 'Frinka' and 'Agria'. Suitable for use in home cooking (low temperature) and with peeling, because they have high concentration for α-solanine and α-chaconine.

To extend the results of the previous study together with the information given by quality FMI, a more refined discrimination within each group can be done using the FMI approach.

With this new approach, we can classify the cultivars for each group. For example, for the (a) group we can state that 'Agata' is better than 'Arinda' because it contains low amounts of the anti-nutrient asparagine. For the (b) group, we can select 'Sponta' as the best, because it has a higher calculated nutritional value compared to 'Marabel'. For the (c) group, we can select 'Merit' because it contains a higher nutritional value and a lower concentration of glycoalkaloids compared to the other cultivars (**Table 7**).

In conclusion, the described functional mathematical index for potato quality is a valuable tool that can be used to discriminate among otherwise similar cultivars. Further studies are needed to find out whether the calculated parameters based on the composition of different cultivars correlate with animal and human feeding studies similar to those described above for protein nutritional values.

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