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Fibre concentrates from apple pomace and citrus peel as potential fibre sources for food enrichment

Fernando Figuerola [a,*], María Luz Hurtado [b], Ana María Estévez [b], Italo Chiffelle [b], Fernando Asenjo [a]

[a] Facultad de Ciencias Agrarias, Instituto de Ciencia y Tecnología de Alimentos, Universidad Austral de Chile, Chile
[b] Departamento de Agroindustria y Enología, Facultad de Ciencias Agronómicas, Universidad de Chile, Chile

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Abstract

Research to evaluate some functional properties of fibre concentrates from apple and citrus fruit residues, in order to use them as potential fibre sources in the enrichment of foods, was carried out. Fiber concentrates were analysed for their proximate content (moisture, lipids, protein and ash); caloric value; dietary fibre composition and functional properties (water retention capacity – WRC, swelling capacity – SW, fat adsorption capacity – FAC and texture). All the fibre concentrates had a high content of dietary fibre (between 44.2 and 89.2 g/100 g DM), with a high proportion of IDF. Protein and lipid contents ranged between 3.12 and 8.42 and between 0.89 and 4.46 g/100 g DM, respectively. The caloric values of concentrates were low (50.8–175 kcal/100 g or 213–901 kJ/100 g). Grapefruits had the highest WRC (2.09–2.26 g water/g DM) high SW and FAC. Texture was strongly dependent on the particle size and it was increased by the heat treatment. Every concentrate studied had interesting characteristics, suggesting possible uses in the development of fibre enriched foods.

Keywords: Functional properties; Water retention capacity; Dietary fibre; Hydration properties

1. Introduction

Dietary fibre consists of a variety of non starch polysaccharides which include cellulose, hemicellulose, pectin, β-glucans, gums, and lignin (Gallaher & Schneeman, 2001; Lamghari et al., 2000). Dietary fibre is composed mainly by remnants of edible plant cells; parenchymatous tissues are known to be the most important source of vegetable fibre (De Vries & Faubion, 1999; Eastwood, 1992). Cell walls of fruits, vegetables, pulses and cereals make up most of the dietary fibre intake (Jiménez et al., 2000).

Dietary fibre plays an important role in human health (Anderson, Smith, & Guftanson, 1994). High dietary fibre diets are associated with the prevention, reduction and treatment of some diseases, such as diverticular and coronary heart diseases, (Anderson et al., 1994; Gorinstein et al., 2001; Villanueva-Suarez, Redondo-Cuenca, Rodríguez-Sevilla, & de las Heras, 2003). The physiological effects are related to the physicochemical and functional properties of dietary fibre. It is widely known that dietary fibres obtained by different methods and from different sources, behave differently during their transit through the gastrointestinal tract, depending on their chemical composition and physicochemical characteristics and on the processing that food undergo (Chau & Huang, 2003 ; Herbafood, 2002; Jiménez et al., 2000).

Fiber is often classified as soluble dietary fibre (SDF) and insoluble dietary fibre (IDF) (Gorinstein et al., 2001). Because solubility refers simply to fibres that are dispersible in water, the term is somewhat inaccurate. Originally it was thought that this categorization might provide a simple way to predict physiological function, but this has not always been the case (Gallaher & Schneeman, 2001). However, the SDF/IDF ratio is important for both, dietary and functional properties. It

* Corresponding author.
E-mail address: ffignero@uach.cl (F. Figuerola).

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is generally accepted that those fibre sources suitable for use as food ingredient should have an SDF/IDF ratio close to 1:2 (Jaime et al., 2002; Schneeman, 1987). Fibre derived from fruits and vegetables have a considerably higher proportion of soluble dietary fibre, whereas cereal fibres contain more insoluble cellulose and hemicellulose (Herbafood, 2002). Plant fibres show some functional properties, such us water-holding capacity (WHC), swelling capacity (SWC), viscosity or gel formation, bile acid binding capacity, and cation-exchange capacity which have been more useful for understanding the physiological effect of dietary fibre, than the chemical composition alone (Femenia, Lefebvre, Thebaudin, Robertson, & Bourgeois, 1997; Gallaher & Schneeman, 2001). These properties are related to the porous matrix structure formed by polysaccharide chains which can hold large amounts of water through hydrogen bonds (Dawkins et al., 2001; Kethireddipalli, Hung, Phillips, & Mc Watters, 2002). Functional properties of plant fibre depend on the IDF/SDF ratio, particle size, extraction condition and, vegetable source (Cadden, 1987; Drehen, 1987; Jaime et al., 2002). According to Kethireddipalli et al. (2002), grinding the dry fibrous material to fine powder may adversely affect both its WHC and SWC; the effect is attributed not only to particle size reduction, but also to the altering the fibre matrix structure. The literature concerned with the effects of treatments for fibre extraction on its physicochemical properties is scarce and sometimes contradictory, since different materials, different methodologies for measurements of dietary fibre, and different process conditions have been used (Larrauri, 1999).

Currently, there is a great variety of raw materials, mainly processing by-products, from which dietary fibre powders are obtained (Femenia et al., 1997). The main characteristics of the commercialized fibre product are: total dietary fibre content above 50%, moisture lower than 9%, low content of lipids, a low caloric value and neutral flavour and taste (Larrauri, 1999). In order to take advantage of the dietary and functional properties of fibre, some high dietary fibre formulated foods are currently being developed (Grigelmo-Miguel & Martín-Belloso, 1999; Herbafood, 2002; Tudorica, Kuri, & Breenan, 2002). To be acceptable, a dietary fibre added to a food product must perform in a satisfactory manner as a food ingredient (Jaime et al., 2002). According to Larrauri (1999), the "ideal dietary fibre" should meet, among others, the following requirements; have no nutritionally objectionable components, be as concentrated as possible, be bland in taste, colour and odour; have a balanced composition and adequate amount of associated bioactive compounds; have a good shelf life; be compatible with food processing; have the expected physiological effects. It must be kept in mind that fibre-enrichment not only influences the overall quality of food by changing its physiological properties, but also significantly affects the sensorial properties of a product. When plant fibres are added to a food product, they contribute to water holding properties and viscosity of the product (Kethireddipalli et al., 2002). The viscosity of the soluble dietary fibre fraction is more important than the amount of soluble fibre in a food. Soluble dietary fibre becomes viscous when mixed with water (Gorinstein et al., 2001).

Dietary fibres from cereals are more frequently used than those from fruits; however, fruit fibre have better quality due to higher total and soluble fibre content, water and oil holding capacity and colonic fermentability, as well as lower phytic acid content and caloric value. Therefore, it becomes necessary to develop processes for the preparation of fruit fibres that minimize the losses of associated bioactive compounds which may exert higher health-promoting effects than dietary fibre itself (Larrauri, 1999). Dietary fibre concentrates can be used in various application in the food industry with excellent results. Fibers with 15% of SDF are able to bind and retain several times their weight of water (Herbafood, 2002).

Apples are good sources of fibre with a well balanced proportion between soluble and insoluble fraction (Gorinstein et al., 2001). Residues from orange juice extraction are potentially an excellent source of DF because this material is rich in pectin and may be available in large quantities (Grigelmo-Miguel & Martín-Belloso, 1998). Citrus and apple fibres have better quality than other dietary fibres due to the presence of associated bioactive compounds, such as flavonoids, polyphenols and carotenes (Fernández-Ginés, Fernádez-López, Sayas-Barberá, & Pérez-Alvarez, 2003; Wolfe & Liu, 2003).

An increase in the level of dietary fibre in the daily diet has been recommended (25–30 g/day). Because of this, it is interesting to increase the consumption of all foods that can supply fibre to daily food intake. Fiber incorporation, in frequently consumed food, could help to overcome the fibre deficit (Fernández-Ginés et al., 2003).

Dietary fibres are not only desirable for their nutritional properties, but also for their functional and technological properties and because of those they can also be used to upgrade agricultural products and by-products for use as food ingredients (Schieber, Stintzing, & Carle, 2001; Thebaudin, Lefebvre, Harrington, & Bourgeois, 1997). So, the functional properties of DF from different sources should be studied in order to obtain the individual characteristics of each one (López et al., 1996). The industry of fruit juice produces significant amounts of by-products which could cause problems in their disposal. Usually, these products are used in animal feeding. However, their high amount of dietary fibre could permit the use of them in developing new natural ingredients for the food industry.

According to Sloan (2001), the demand for a unique fibre ingredient will continue. With a well established market for dietary fibre it is quite clear that a new ingredient, particularly one that could be linked to the possibility of obtaining nutritional requirements through normal dietary practices, would be very well received.

The purpose of this study was to evaluate some functional properties of fibre concentrates obtained from apple and citrus fruit residues, in order to use them as a potential fibre source in the enrichment of foods.

2. Material and methods

2.1. Materials

Residues from juice extraction of grapefruit (Ruby and Marsh cultivars), lemon (Eureka and Fino 49 cultivars), orange (Valencia cultivar) and apple Royal Gala (Granny Smith and Liberty cultivars) were used as fibre source.

2.2. Obtaining fibre concentrates

- Apple fibres were obtained by washing, coring, chopping, and separation of juice from pomace by pressing. Apple pomace was washed twice with warm water (30 °C); then it was dried at 60 °C during 30 min in an air tunnel drier and ground to a particle size of 500–600 μm.
- Grapefruit, lemon and orange fibres were obtained by cutting, extraction of juice, peel residue chopping, washing with warm water, drying under the same conditions as apple fibres, and grinding to a particle size of 500–600 μm.

The material was washed under mild conditions to avoid or minimize losses of some soluble fibre components (such as pectins and pentosans) as well as bioactive components (such as flavonoids, polyphenols and carotenes). Washing allows reduction of free sugar and ash contents (Larrauri, 1999).

Drying at temperatures below 65 °C avoids changes in the functional properties and in the content of polyphenols, tannins, anthocyanidins and proteins (Larrauri, 1999).

Grinding to a relative large particle size, was done to not affect the hydration characteristics on the textures of the fibre concentrates (Kethireddipalli et al., 2002).

2.3. Analysis of fibre concentrates

2.3.1. Dietary fibre composition

This was determined by the enzymatic-gravimetric method of Lee, Prosky, and De Vries (1992).

2.3.2. Proximate composition

Moisture, lipids, protein (Nx 6.25) and ash were determined according to AOAC (1996). Caloric carbohydrates were determined by difference from the total dietary fibre, lipids, protein and ash contents (Chau & Huang, 2003). Caloric values were computed using the Attwater coefficients (Schmidt-Hebbel, Pennacchiotti, Masson, & Mella, 1992).

2.3.3. Functional properties

Water retention capacity (WRC), swelling capacity (SWC), and fat adsorption capacity (FAC) were measured according the methods reported by Femenia et al. (1997). Texture, expressed as the maximum compression force, was determined in a 20% concentrate suspension in phosphate buffer (pH 6.3) at room temperature and after heating at 80 °C during 2 h. Measurements were done in an INSTRON Universal Testing Machine with a compression rate of 10 mm/min with a 34-mm cylinder, recording the force profile at 1 cm of probe penetration (Femenia et al., 1997).

Three replications were carried out in every fibre source and standard deviation (SD) was calculated.

3. Results and discussion

3.1. General

Fibre concentrates were powdered materials, of particle size ranging between 460 and 600 μm, which permit, according to Tamayo and Bermúdez (1998), a high water retention and fat adsorption capacity. The concentrates had different colours, light yellow in Marsh grapefruit, in Eureka and Fino 49 lemons and Granny Smith apples, light orange in Liberty apples and Valencia oranges, light pink in Ruby grapefruit and light red in Royal Gala apples.

3.2. Dietary fibre composition

Table 1 shows total dietary fibre (TDF) and insoluble dietary fibre (IDF), soluble dietary fibre (SDF) content of the fibre concentrates and the ratio between IDF and SDF. The concentrates had more than 60% of TDF (dry matter basis), except for Marsh grapefruit; according to Femenia et al. (1997) and Larrauri (1999) these products could be considered as rich source of dietary fibre.

Between grapefruit varieties, Ruby had more TDF, with a higher IDF/SDF ratio (92.7% of its TDF corresponds to insoluble fibre). In the case of lemon varieties, Fino 49 had the highest amount of total dietary fibre, and 90.8% of it is represented by insoluble fibre. Valencia orange had a fibre composition similar to Eureka lemon and in agreement to the values reported by Chau and Huang (2003) for *Citrus sinensis*. The

Table 1
Dietary fibre composition (g/100 g DM) and IDF/SDF ratio of different fibre sources

Fiber concentrate	IDF	SDF	TDF	IDF/SDF
Ruby G.	56.0 ± 0.17[a]	4.57 ± 0.35[a]	62.6 ± 0.30[a]	12.7: 1
Marsh G.	37.8 ± 0.21	6.43 ± 0.45	44.2 ± 0.35	5.9: 1
Eureka L.	50.9 ± 0.20	9.20 ± 0.23	60.1 ± 0.22	5.5: 1
Fino 49 L.	62.0 ± 0.16	6.25 ± 0.16	68.3 ± 0.16	9.9: 1
Valencia O.	54.0 ± 0.23	10.28 ± 0.30	64.3 ± 0.30	5.3: 1
Royal Gala A.	63.9 ± 0.16	14.33 ± 0.61	78.2 ± 0.60	4.5: 1
Granny Smith A.	56.5 ± 0.20	4.14 ± 0.21	60.7 ± 0.23	12.9: 1
Liberty A.	81.6 ± 0.23	8.20 ± 0.15	89.8 ± 0.24	9.9: 1

G, grapefruit; L, lemon; O, orange; A, apple.
[a] Mean ± SD.

results of total dietary fibre obtained in this research in citrus fruits residues are very similar to those reported by Herbafood (2002). The total dietary fibre obtained in Valencia orange agrees with Larrauri, Rupérez, Bravo, and Saura-Calixto (1996) (61–69%); it is lower than the values presented by Fernández and Rodríguez (2001) (76.0–78 g/100 g DM), but higher than the values reported by Grigelmo-Miguel and Martín-Belloso (1998). The differences could be attributed to different cultivars studied and different fruit growing conditions.

Total dietary fibre of apple cultivars was higher than the values found by Suny, Hyman, Erickson, Björk, and Björk (2000) in whole fruits (31 g/100 g); Granny Smith apples had a TDF content similar to the results of Waszczynskyj, Witte, Protzek, Sossela, and Teixeira (2001) (60.3 g/100 g DM) and the Herbafood (2002) product (60%). On the other hand, Royal Gala and Liberty apple concentrates had much higher contents of TDF.

There were found different IDF/SDF ratios in the products studied, ranging between 13.7:1 in Granny Smith apple and 4.5:1 in Royal Gala apple; these values are in agreement with Jaime et al. (2002) who found ratios of 1:1 to 13:1 in onion. Among citrus fruits, Valencia orange, Eureka lemon and Marsh grapefruit had the lowest IDF/SDF ratios and the highest SDF contents. Among apple varieties, the lowest ratio was shown by the Royal Gala concentrate, which also had a high soluble fibre content (14.3%).

The relative amounts of insoluble dietary fibre of the concentrates from fruit obtained in this research are similar to the proportions reported by Zambrano, Meléndez, and Gallardo (2001) in vegetables such as carrot (91.8%) and beet (82.1%). Ruby grapefruit, Fino 49 lemon, Liberty apple and, Granny Smith apple had relative amounts of insoluble dietary fibre above 90%; Marsh pomegranate, Eureka lemon, Valencia orange and Royal Gala apple had values between 81.7% and 85.5%, similar to the values reported by Waszczynskyj et al. (2001) in apples (80.3%).

3.3. Proximate content and caloric value of fibre concentrates

Protein content ranged between 3.12 and 8.42 g/100 g DM in Royal gala apple and Ruby grapefruit, respectively (Table 2). The mild treatment during washing of the raw materials (fruit pomace/peels) maintained protein content. Citrus fruits concentrates had higher protein content than apples, with similar values to those reported by Grigelmo-Miguel and Martín-Belloso (1998) (8.1–10.1 g/100 g).

Lipid content if the fibre concentrates was low, between 0.89 g/100 g (DM) in Valencia orange and 4.46 g/100 g (DM) in Granny Smith apple. These values are in agreement with Grigelmo-Miguel and Martín-Belloso (1998) in their study of oranges (1.5–3.0 g/100 g DM). Among the concentrates obtained from fruit byprod-

Table 2
Proximate composition of fibre concentrates (g/100 g DM)

Fiber concentrate	Protein	Lipid	Ash	Caloric carbohydrates
Ruby G.	8.42 ± 0.12[a]	3.24 ± 0.05[a]	3.22 ± 0.01[a]	18.3
Marsh G.	4.46 ± 0.04	1.04 ± 0.01	3.27 ± 0.05	45.0
Eureka L.	6.79 ± 0.15	1.89 ± 0.02	3.47 ± 0.05	25.9
Fino 49 L.	7.92 ± 0.08	1.88 ± 0.03	3.91 ± 0.06	14.6
Valencia O.	6.70 ± 0.05	0.89 ± 0.04	2.71 ± 0.09	17.9
Royal Gala A.	3.12 ± 0.07	1.57 ± 0.08	1.88 ± 0.11	13.3
Granny Smith A.	3.68 ± 0.08	4.46 ± 0.10	1.24 ± 0.03	28.9
Liberty A.	3.64 ± 0.07	2.44 ± 0.12	0.56 ± 0.10	1.27

G, grapefruit; L, lemon; O, orange; A, apple.
[a] Mean ± SD.

Table 3
Moisture content (%) and caloric value (kcal/100 g DM) of fibre concentrates

Fiber concentrate	Moisture	Caloric value
Ruby P.	6.43 ± 0.05[a]	153
Marsh P.	4.34 ± 0.12	215
Eureka L.	2.94 ± 0.10	155
Fino 49 L.	4.75 ± 0.09	121
Valencia O.	10.5 ± 0.19	137
Royal Gala A.	2.46 ± 0.08	87.5
Granny Smith A.	2.00 ± 0.09	175
Liberty A.	2.50 ± 0.14	50.8

P, pomegranate; L, lemon; O, orange; A, apple.
[a] Mean ± SD.

Table 4
Hydration properties and oil adsorption capacities of fibre concentrates

Fiber concentrate	WRC (g water/g DM)	SWC (ml water/g DM)	FAC (g oil/g DM)
Ruby G.	2.09 ± 0.28[a]	8.02 ± 0.05[a]	1.52 ± 0.04[a]
Marsh G.	2.26 ± 0.21	6.69 ± 0.06	1.20 ± 0.05
Eureka L.	1.85 ± 0.04	7.32 ± 0.05	1.30 ± 0.03
Fino 49 L.	1.74 ± 0.08	9.19 ± 0.06	1.48 ± 0.04
Valencia O.	1.65 ± 0.20	6.11 ± 0.05	1.81 ± 0.05
Royal Gala A.	1.62 ± 0.10	6.59 ± 0.05	0.95 ± 0.05
Granny Smith A.	1.78 ± 0.13	6.89 ± 0.06	1.45 ± 0.05
Liberty A.	1,87 ± 0.10	8.27 ± 0.06	0.60 ± 0.04

G, grapefruit; L, lemon; O, orange; A, apple.
[a] Mean ± SD.

ucts, Granny Smith apple and Ruby grapefruit showed the highest lipid contents.

Ash content ranged between 0.56 g/100 g (DM) in Liberty apples and 3.91 g/100 g (DM) in Fino 49 lemon. Fiber concentrates from citrus fruits showed higher ash contents (about twice than the ones obtained from apples). Grigelmo-Miguel and Martín-Belloso (1998) reported an ash content of 2.6–3.1 g/100 g (DM) in oranges, and Fernández and Rodríguez (2001), values of 3.7 g/100 g (DM) in citrus fruit peels.

The products obtained had low contents of moisture except for Valencia orange. Their moisture contents were below 9.0%, pointed out by Larrauri (1999) as the upper limit for their handling and conservation (Table 3).

Caloric values of fibre concentrates varied widely, between 50.8 kcal/100 g (213 kJ/100 g) (in Liberty apples) and 215 kcal/100 g (901 kJ/100 g) (in Marsh grapefruit). Among apple varieties, concentrates from Granny Smith cultivar had the highest caloric value, due mainly to their high content of lipids and caloric carbohydrates. Marsh grapefruit had the highest value among the citrus fruit concentrates, caused by its high protein and caloric carbohydrate content. Grigelmo-Miguel and Martín-Belloso (1998) reported caloric values ranging between 351 and 373 kcal/100 g (1469 and 1561 kJ/100 g) (DM) in residues from orange juice extraction. According to Larrauri (1999), an adequate fibre concentrate should have a caloric value below than 200 kcal/100 g (837 kJ/100 g) limit which is met by almost every one of the fibre concentrates studied.

3.4. Functional properties

Hydration properties of dietary fibre refers to its ability to retain water within its matrix. Fiber with strong hydration properties could increase stool weight and potentially slow the rate of nutrient absorption from the intestine (Gallaher & Schneeman, 2001). Also, they can enhance viscosity of the added food.

As shown in Table 4, water retention capacity (WRC) of the concentrates ranged between 1.62 and 2.26 g/g (DM); the highest values were found in Ruby grapefruit and Liberty apple residues, which could be associated with their high amounts of insoluble dietary fibre (Femenia et al., 1997). The values of water retention capacity obtained in this research were lower than those reported by some authors in fruit and vegetable fibre concentrates (Femenia et al., 1997; López et al., 1996), and similar to those found in pineapple (2.1 g/g DM) by Larrauri, Borroto, Perdomo, and Tabarés (1995). The lower values of water retention capacity found in some of the concentrates studied could be attributed to the higher ionic strength of the phophate buffer solution in comparison with distilled or tap water (Barroto, Larrauri, & Cribeiro, 1995).

Swelling capacity (SWC) of concentrates was between 6.11 ml/g (DM) in Valencia orange, and 9.19 ml/g (DM) in Fino 49 lemon. The values obtained could also be related to the amount of insoluble dietary fibre found in the concentrates. López et al. (1996) reported values of 10.9 g/g in artichokes, similar to the values presented by the concentrate from Fino 49 lemon. It is known that the structural characteristics and the chemical composition of the fibre (water affinity of its components) play important roles in the kinetics of water uptake. According to López et al. (1996), water could be held in capillary structures of the fibre as a result of surface tension strength, and also water could interact with molecular components of fibre through hydrogen bonding or dipole forms. Femenia et al. (1997) reported higher values of swelling capacity (16.9–17.5 ml/g (DM)) for cauliflowers.

According to Femenia et al. (1997) and López et al. (1996), fat adsorption capacity (FAC) depends on surface properties, overall charge density, thickness, and hydrophobic nature of the fibre particle. The values showed by the concentrates were between 0.60 g/g (DM) in Liberty apples, and 1.81 g/g (DM) in Valencia oranges as expected for fruit residues. López et al. (1996) reported FAC values of 1.26–5.81 g/g in artichokes (see Table 5).

The values of maximum compression force varied widely among concentrates and particle size. When

Table 5
Texture (N) of fibre concentrates at two particle size (20 °C and after heating)

Fiber concentrate	500 μm		200 μm	
	20 °C	After heating	20 °C	After heating
Ruby G.	44.71	>49.98	10.89	12.63
Marsh G.	48.64	49.91	14.72	6.88
Eureka L.	4.51	>49.98	2.43	49.8
Fino 49 L.	6.28	>49.98	3.05	49.27
Valencia O.	47.85	>49.98	13.31	>49.8
Royal Gala A.	26.62	48.83	0.31	4.91
Granny Smith A.	23.83	>49.98	0.64	8.77
Liberty A.	48.19	>49.98	5.42	21.50

G, grapefruit; L, lemon; O, orange; A, apple.

measured at room temperature (20 °C), values ranged between 4.51 N in Eureka lemon to 48.64 N in Marsh grapefruit, which were higher than those reported by Femenia et al. (1997). When concentrate dispersions were heated, all of them increased the compression force. Only the texture of the Marsh grapefruit concentrate did not change upon heating. The increase in texture observed after heating, could be caused by the formation of a solid matrix (Femenia et al., 1997). This property could be very useful in enrichment of some foods where viscosity and mouth feel are desired. Texture decreases with particle size reduction, because of disruption of the fibre structure (Kethireddipalli et al., 2002).

The results obtained suggest that the way (particle size, temperature, ionic strength) of adding a fibre concentrate to a food would affect the effectiveness of it incorporation. The characteristics found in the concentrates suggest many potential applications (volume replacement, thickening or texturizing) in the development of foods reduced in calories and rich in dietary fibre. Every concentrate studied had some unique characteristics that could be useful in different types of food enrichment. The criterion for incorporation should be related to the desired physical, chemical or sensory characteristics of the particular food.

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