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Sensory profiling and hedonic judgement of probiotic ice cream as a function of hydrocolloids, yogurt and milk fat content

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ABSTRACT

Probiotic ice cream is a functional frozen dairy dessert with peculiar sensory characteristics combining the flavor and taste of fermented milks with the texture of ice cream. In this study, the effects of compositional parameters (hydrocolloids type and percentage, yogurt and milk fat content) on its texture and flavor were evaluated. The use of xanthan gum or hydroxypropylmethylcellulose at a level of 0.3 g/100 g in full fat (4 g/100 g milk fat) and low acidified (25 g/100 g yogurt addition) formulations is recommended to achieve improved creamy sensation, high textural quality and enhanced flavor. Based on hedonic and descriptive judgements, consumers' acceptability is mainly affected by ten sensory drivers including "sweet", "sour", "astringent", "vanilla flavor", "gummy", "coarse", "watery", "creamy", and "foamy". Partial least squares (PLS) regression was applied to model samples overall acceptability using the descriptive analysis data. One generic and six related to each compositional parameter (hydrocolloids type, yogurt and milk fat content) PLS models were successfully constructed. The generic PLS model can be used for the quantification of the consumers' acceptability of probiotic ice creams and related fermented products whereas the compositionally restricted PLS models could be a useful tool for the purposes of R&D in the food industry to design and develop novel products.

1. Introduction

Frozen dairy desserts are complex colloidal systems that consist of air cells, ice crystals and partially destabilized fat globules dispersed in a continuous aqueous phase within polysaccharides, lactose, sugars and mineral salts are dissolved (Goff, 1997). The awareness of consumers for healthier and functional food has led to the introduction in ice cream manufacture of certain materials with documented nutritional and physiological properties such as probiotics (Akin, Akin, & Kirmaci, 2007; Alamprese, Foschino, Rossi, Pompei, & Savani, 2002), lactic acid bacteria (Hong & Marshall, 2001), dietary fibers (Soukoulis, Lebesi, & Tzia, 2009), alternative sweeteners (Soukoulis & Tzia, 2010), natural antioxidants (Hwang, Shyu, & Hsu, 2009) and low glycemic index sweeteners (Whelan, Vega, Kerry, & Goff, 2008).

Probiotic ice cream is a partially acidified frozen dairy dessert structurally similar to ice cream. The acidification of the ice cream mix can be carried out either by the direct inoculation of the mix with the probiotic culture (*bifidobacteria*, *Lactobacillus acidophilus*, *Lactobacillus johnsonii*, *Lactococcus lactis*, *Lactococcus cremoris*) or by blending the ice cream mix with acidified milk or probiotic yogurt (Alamprese et al., 2002; Christiansen, Edelsten, Kristiansen, & Nielsen, 1996). Viability of probiotic bacteria in aerated frozen dairy desserts is limited due to intrinsic environmental parameters – high redox value, oxygen toxicity, rupture of bacteria cellular membranes during whipping-freezing step, vulnerability of the bacteria at acidic conditions (Cruz, Antunes, Sousa, Faria, & Saad, 2009).

Hydrocolloids are components of major importance for the thermodynamic stability of ice cream as their primary aim is the control of recrystallization phenomena, occurring due to temperature fluctuations which finally impair storage quality. The specified mechanisms depicting their particular action have been extensively studied (Goff, Ferninando, & Schorsch, 1999; Regand & Goff, 2003). Hydrocolloids also influence the textural quality, control the flavor intensity and its temporal release, improve the perceived creaminess, and affect the melting quality characteristics of frozen dairy desserts (Soukoulis, Chandrinos, & Tzia, 2008). However, their physicochemical action in fermented milks is strongly dependent on several intrinsic factors such as pH, ionic equilibrium, the protein–polysaccharides interactions, etc.

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Partial least squares regression (PLSR) is used for the investigation of the interrelationship between two data sets by predicting one data set (X) from the other set (Y). Usually, the one data set is referred to sensory data (quantitative descriptive analysis or hedonic evaluation data) and the other set to instrumental data. There are many reports on the application of PLSR for the correlation of consumers' acceptability with instrumental data (Tenehaus, Pages, Ambroisine, & Guinot, 2005) or sensory descriptive attributes (Heenan, Dufour, Hamid, Harvey, & Delahunty, 2008) as well as descriptive analysis data with instrumental and chemical properties (Bom Frøst, Heymann, Bredie, Dijksterhuis, & Martens, 2005).

The effects of supplemented ingredients on the probiotic bacteria viability, primary textural and physical properties of ice cream have been well established by many researchers (Akin et al., 2007; Alamprese et al., 2002). However, there is little information on mapping the specific sensory attributes of fermented frozen dairy desserts, probiotic ice cream included, as well as on interpreting the relationships between the descriptive attributes and hedonic judgements. Aims of this study were to: 1) map the specific sensory attributes describing the probiotic ice cream formulations, 2) investigate the effects of specific compositional parameters including milk fat percentage, yogurt base percentage and hydrocolloids type and percentage on the sensory characteristics of probiotic ice cream, and 3) reveal the particular interrelationships between descriptive attributes and hedonic judgements applying PLSR methodology.

2. Materials and methods

2.1. Ice cream samples preparation

The ice cream formulations had the following composition: 2 or 4% milk fat (provided as fresh cream 35% fat, 5.6% milk solids non fat (MSNF), Fage S.A., Athens, Greece), 11% MSNF (skim milk powder, Epiim S.A., Tallinn, Latvia), 16% sugar solids provided as sucrose (Hellenic Sugar Industry, Larissa, Greece) and partially as corn syrup solids 36DE (Roclys A3839S, Roquette S.p.a. Italia) 0.2% emulsifier (mono-diglycerides of fatty acids, 60% monoester content, Rikemal P-150S, Rikevita, Malaysia), and 0.2, 0.3 or 0.4% stabilizer. Five hydrocolloids were used including: xanthan gum (Luxara 7571/200, Branwell Ltd., Essex, UK), carboxymethylcellulose (Cekol 4000P, Noviant, Sweden), sodium alginate (Protanal, FMC Biopolymer, Drammen, Norway), guar gum (Grindsted, Danisco, Denmark) and hydroxypropylmethylcellulose (Methocel, F50FG, Dow Chemicals, Germany). The dry materials were dispersed under agitation (at 1000 rpm) into the liquid materials at 50 °C using a mechanical stirrer (Ika-Werke GmbH, Staufen, Germany). The mix was then batch pasteurized at 76 °C for 20 min using a water bath (GFL 1083, GFL GmbH, Burgwedel, Germany) and consequently two-stage (200 bar and 30 bar respectively) homogenized using a laboratory single piston homogenizer (APV Gaulin, Albertslund, Denmark). Then, the ice cream mixes were rapidly cooled to 4 °C and remained at constant temperature for 24 h to be aged. The aged mixes were whipped at 0 °C, gently blended with commercial probiotic yogurt (Bifidus stirred yogurt, 8.40 ± 0.18 log cfu/g for *Bifidobacterium bifidum*, 7.22 ± 0.31 log cfu/g for *Lactobacillus bulgaricus*, 8.89 ± 0.43 log cfu/g for *Streptococcus thermophilus*, Fage S.A., Athens, Greece) at the levels of 25 and 50% of the total ice cream mix (counts of viable cells for *B. bifidum* 6.89 ± 0.32 and 7.14 ± 0.23 cfu/g respectively), and then the acidified mixes were frozen using a batch freezer (Philips, HR2305, Guilford, UK) at a set draw temperature of -5.5 ± 0.3 °C, packaged into 300 mL HDPE containers (Mornos S.A., Thiva, Greece), hardened and stored in a deep freezer (Whirlpool, UK) under quiescent freezing conditions at −25 °C. The overall experimental procedure was duplicated giving a total of 120 formulations. In Table 1 are given some physicochemical data of the ice creams prepared.

2.2. Quantitative descriptive analysis

Nine panelists (five male and four female) working in the laboratory were chosen for the sensory assessment of ice cream samples. Three 2 h sessions were conducted for the panelists to be trained in order to use the sensory attributes correctly. The assessors had previous experience with sensory analysis of dairy products and were selected according to their taste sensitivity and their capacity to detect differences in the intensities of the below cited attributes (ISO, 1993). The reference samples preparation and the establishment of the sensory attributes were based on literature data (Bodyfelt, Tobias, & Trout, 1988; Ogden, 1993, chap. 3; Soukoulis et al., 2008). In order to achieve homogeneous conditions during all sensory analysis sessions, samples were tempered at -15 ± 1 °C overnight before their sensory assessment. Each sample was coded using a three digit random number and served successively to the panelists in individually partitioned booths. Samples were portioned and placed into white styrofoam plates with cup receptors each containing two scoops; every scoop was about 15 g adequate to evaluate the flavor, texture and appearance attributes.

Flavor/taste was evaluated by six main attributes including sweet taste, bitter aftertaste and sour, astringent, milk and vanilla flavor descriptors. Texture was evaluated both during scooping and mastication in mouth. Texture at scooping was assessed by introducing four sensory descriptors including: hard, coarse, gummy and brittle. Texture in the mouth was assessed by six attributes: hard, coarse, gummy, creamy, watery and greasy. Appearance was exclusively referred to the color intensity of the samples due to the absence of appearance defects. Samples color hue ranged from whitish to yellowish. Rating of sensory attributes was carried out using a ten point scale where 0 = nonexistent - imperceptible characteristic, 10 = too intense. Panelists were motivated to express any criticisms on the scoresheets used for the sensory evaluation. In Table 2 are displayed the sensory attributes used in sensory evaluation as well as their definitions and standards used for panelists training.

2.3. Hedonic evaluation

The consumer panel ($n = 51$) was composed by students and laboratory staff. The selection criterion was that subjects had to be regular consumers of typical dairy ice cream as well as their similar behavior between sensory evaluation sessions. The age composition of the panelists was 79% (22–35) and 21% (36–55)

Table 1
Some physicochemical characteristics of probiotic ice creams as affected by milk fat and yogurt concentration as well as hydrocolloids type (ANOVA mean values ± standard error).

Sample	pH[a]	Overrun[b] (%)	Viscosity[a] at 30 s^{-1} (mPa s)	Lactic acid[a] (g/100 g)
Low fat	5.41 ± 0.07	43.3 ± 3.8	2.83 ± 0.67	0.82 ± 0.04
High fat	5.51 ± 0.08	51.2 ± 3.5	2.96 ± 0.38	0.71 ± 0.03
Low yogurt	5.77 ± 0.03	52.7 ± 3.9	2.28 ± 0.39	0.66 ± 0.02
High yogurt	5.16 ± 0.09	38.4 ± 3.5	3.51 ± 0.61	0.93 ± 0.03
Guar gum	5.41 ± 0.09	53.2 ± 6.4	2.05 ± 0.43	0.84 ± 0.04
Sodium alginate	5.54 ± 0.14	41.3 ± 6.8	4.33 ± 0.23	0.62 ± 0.03
CMC	5.49 ± 0.11	54.6 ± 5.2	1.93 ± 0.60	0.77 ± 0.05
HPMC	5.65 ± 0.13	62.1 ± 5.1	1.46 ± 0.37	0.55 ± 0.04
Xanthan gum	5.22 ± 0.09	63.2 ± 4.1	4.71 ± 0.49	0.89 ± 0.05

[a] After Soukoulis et al. (2007).
[b] After Soukoulis et al. (2008).

Table 2
List of the 21 descriptive terms related to (a) flavor/taste, (b) texture perception during scooping, (c) mouthfeel, and (d) melting quality for probiotic ice creams, as well as the standards used for the training of the panelists.

Sensory attribute	Definition	Standards
Sweet	Evaluation of the sweet intensity. The product lacks bland or flat taste.	2% Sucrose solution
Sour	Defines a refreshing, fruity and sour flavor	A commercial sorbet ice cream (Unilever S.A., Marousi, Greece)
Bitter aftertaste	Detection of caffeine bitterness when sample is moved to the back center of the tongue	0.05 g/100 g Caffeine solution
Astringent	Sensation causing the drying of the tongue and puckering of the cheeks. Must be evaluated after swallowing	0.10 g/100 g Alum solution (150 mm)
Vanilla flavor	Evaluation of the intensity of vanilla flavor as it is released during consumption	A commercial frozen yogurt (Dodoni S.A.)
Milky	A flavor similar to that of fresh dairy milk	A commercial fresh full fat milk (Vivartia S.A., Agios Stefanos, Greece)
Hard in scoop	Represents the resistance against scooping a small proportion of ice cream (30 g)	A commercial ice cream (Aloma®, Nestlè, Tavros, Greece) stored and assessed at −28 °C
Coarse in scoop	The sample contains a significant number of detectable ice crystals which are acoustically and texturally perceived during scooping.	A commercial ice cream (Aloma®, Nestlè, Tavros, Greece) subjected to successive temperature cycles from −22 °C to −12 °C
Brittle in scoop	A crumble ice cream which falls apart during scooping and it is considerably dry	An ice cream mix is 1:4 diluted with milk prior to freezing
Gummy in scoop	The ice cream is hold together, resembles taffy and forms curls during scooping	Addition of 5 g/100 g extra corn syrup 42DE solids in ice cream mix prior to freezing
Icy	It is referred to the freezing effect of the product which may be accompanied by tongue numbing	An ice cream mix is diluted by 50% with milk prior to freezing
Hard mouthfeel	The samples is characterized by a very stiff structure which is gradually diminished as the product melts	A commercial ice cream (Aloma®, Nestlè, Tavros, Greece) stored and assessed at −28 °C
Coarse mouthfeel	The defect is evident during biting down the ice cream sample. The ice crystals hold slightly apart the incisors leading to a crunchy and rough sensation which is disappears as the ice crystals melt.	A commercial ice cream (Aloma®, Nestlè, Tavros, Greece) subjected to successive temperature cycles from −22 °C to −12 °C
Gummy	Food is pulled apart by downward movement of the tongue and the resulting threats are sensed as sticky by tongue, palate, and throat making swallowing difficult.	Addition of 0.3 g/100 g extra stabilizer in ice cream mix prior to freezing
Watery	The sample melts unusually quickly to an uncharacteristically thin water like fluid	An ice cream mix without added hydrocolloids
Creamy	The sample is orally perceived by a smooth texture, without any defects, melts uniformly to thick and homogenous fluid	A commercial vanilla ice cream (Aloma®, Nestlè, Tavros, Greece)
Fusible	The sample melts quickly and characterized by low resistance to shape retention and slumping	An ice cream prepared without emulsifiers addition
Wheyoff	The ice cream develops a ring of clear greenish or bluish fluid collecting around the edges of the scoop of ice cream early in the meltdown test.	A unstabilized frozen yogurt
Thin	The ice cream melts generating a watery low viscosity fluid	An ice cream without emulsifiers and stabilizers
Foamy	A great mass of fine stable air cells is noticed when ice cream sample is completely melted	A commercial vanilla ice cream (Aloma®, Nestlè, Tavros, Greece)
Bulky	Ice cream is characterized by a curdy meltdown separating into small distinct pieces rather than a smooth uniform liquid	A highly acidified (pH < 4.5) ice cream

whereas the gender composition was 39% male and 61% female. During the ten sessions, samples were presented in the same location as that used for the sensory panel and in a similar manner regarding to lighting, containers, rinsing water, samples codification and presentation order. 15 g portions of ice cream samples were served for sensory assessment and consumers were asked to evaluate the sample without any break. Consumers examined the samples for the Degree Of Liking (DOL) using a ten point scale with the following definition: 0 = unacceptable, not like at all, 5 = acceptable, like moderately, 10 = excellent, like extremely.

2.4. Statistical analysis

Analysis of variance (ANOVA) was applied for the determination of the main effects of the investigated independent factors (milk fat and yogurt percentage, hydrocolloid type and percentage) and their interactions on the sensory attributes as they were rated during the QDA procedure. Duncan's multiple range test was used to separate means of sensory attributes data when significant differences ($p < 0.05$) were observed. The sensory attributes that did not significantly discriminated between the independent factors were excluded from further statistical analyses.

Linear correlation (Pearson's correlation coefficients) was applied on the hedonic and descriptive measurements data to reveal their particular interrelationships. Stepwise selection with discriminant analysis of the mean data was used to determine the particular communalities between samples with different compositional profile (hydrocolloids type, milk fat and yogurt content). All statistical treatments were carried out using STATISTICA® software (Statistica release 7, Statsoft Inc., Tulsa, OK, USA).

Overall acceptability (DOL) of probiotic ice cream samples was mapped using partial least squares regression (PLS1) to investigate its potential interrelationships with the selected sensory attributes. PLS1 was carried out using Unscrambler version 9.7 (CAMO®, AS, Trondheim, Norway). PLSR is a multivariate method that establishes the linear relationships between a set of predictors (X-block) and one response (Y-block). Different PLSR models were constructed using the entire data set (generic PLS model) and specific data sub-sets created by the similarities of the samples according to discriminant analysis results (six PLS models based on the hydrocolloids type, milk fat and yogurt percentage). Due to the limited number of the data, all created PLS models were full cross-validated (leave-one-out) to estimate how well the response Y were predicted by X data. Jack-knifing was implemented to eliminate the useless X variables, to simplify and to improve the predictability of the models. Variables that contributed little or displayed high levels of uncertainty estimates were removed. The final PLS models were selected based on the root mean squares error of prediction (RMSEP). The RMSEP was also used to determine the optimum number of PC's to be used.

3. Results and discussion

3.1. Effects of probiotic yogurt percentage

In Tables 3 and 4 the main effects of the investigated compositional factors on sensory attributes are displayed. Flavor profile perception in probiotic yogurt systems is generally similar to that of standard yogurt (Hekmat & Reid, 2006). Vanilla flavor was partially masked by the addition of yogurt suggesting that its release was strongly inhibited by the contemporaneous release of yogurt volatile aroma compounds such as acetaldehyde, acetoin, diacetyl, lactic and acetic acid. Indeed, the samples with 50% probiotic yogurt were highly rated as sour and astringent leading to the depression of the interrelated sweet and vanilla flavor attributes. Guner, Ardic, Keles, and Dogruer (2007) have reported the inverse correlation of sweet and sour–astringent attributes whereas Hekmat and McMahon (1992) observed that development of probiotic off-flavor is related to pH changes. In our study, there was not introduced a probiotic flavor attribute as it can be adequately described by the combination of sour–astringent attributes.

The increase of yogurt to ice cream mix ratio imparted coarseness and wateriness, increased hardness and decreased gumminess and creamy perception of samples. Creaminess is directly related to the overall acceptability of semi-solid dairy desserts including ice cream (de Wijk, Terpstra, Janssen, & Prinz, 2006). Particularly in ice cream, it is influenced by the compositional parameters (e.g. hydrocolloids, fat and sugars), structural elements, as well as manufacturing and storage conditions e.g. freezing conditions–temperature fluctuations during storage. The development of coarse and watery texture is indicative of recrystallization phenomena occurrence (Marshall, Goff, & Hartel, 2003). The observed texture deterioration in samples with 50% probiotic yogurt can be attributed to several factors including increased instability of hydrocolloids (Tamime & Robinson, 1999) lactose hydrolysis leading to freezing point depression (Baer & Keating, 1987), as well as microstructural changes of the mixes resulted by the yogurt addition e.g. changes in the viscoelasticity, increase of the water molecules retention in the casein-whey proteins network of yogurt (Goh, Nair, & Matia-Merino, 2008)

The increase of yogurt percentage was also accompanied by increased bulky and wheying off defects and decreased of foamy and thin attributes. The curdy appearance of ice cream melts is particularly associated with protein destabilization and salts imbalance due to acidity increase, parameters which also explain the syneresis defect (Tamime & Robinson, 1999). The colloidal protein and exopolysaccharides entanglements in probiotic yogurt may explain the poor foamy structure of ice cream melts containing 50% yogurt as well as their increased viscosities.

Table 3
ANOVA main effects of milk fat, yogurt percentage, and hydrocolloids percentage on the sensory attributes.

Attribute	Effects of milk fat	Effects of yogurt percentage	Effects of hydrocolloids type	Effects of hydrocolloids percentage
Color	−−−	NS	+++/−−−	NS
Sweet	+++	NS	+++/−−−	−−−
Bitter	−−	+++	+++/−−−	++/−−
Astringent	−−−	+++	+++/−−−	NS
Sour	−	+++	+++/−−−	+++
Vanilla flavor	+++	−−−	+++/−−−	−−−
Milky	+++	NS	+++/−−−	+++
Hard (S)	−−−	+++	+++/−−−	+++
Coarse (S)	−−−	NS	+++/−−−	+++
Brittle	−	+++	+++/−−−	−−−
Gummy (S)	+++	NS	+++/−−−	+++
Hard (M)	−−−	+++	+++/−−−	−−−
Coarse (M)	−−−	+	+++/−−−	−
Gummy (M)	+++	−−−	+++/−−−	NS
Watery	−−−	+++	+++/−−−	NS
Creamy	+++	−	+++/−−−	−−−
Greasy	+++	−−−	+++/−−−	++
Fusible	−−−	+	+++/−−−	++
Wheyoff	−−−	+++	+/−	NS
Thin	NS	−	+++/−−−	++
Foamy	+++	−−−	++/−−	NS
Bulky	−−−	+++	+/−	NS

+/−: $p < 0.05$, ++/−−: $p < 0.01$, +++/−−−: $p < 0.001$, NS: not significant.

3.2. Effects of milk fat

Milk fat has been recognized as a critical parameter for the formation and support of structural characteristics of ice cream as well as for the perceived textural quality e.g. lubrication of tongue, increase of mouthcoating effect, enhancement of creaminess, thickness and flavor perception (de Wijk et al., 2006; Dresselhuis, de Hoog, Cohen Stuart, Vingerhoeds, & van Aken, 2008; Granger, Leger, Barey, Langendorff, & Cansell, 2005; Hyvönen, Linna, Tuorila, & Dijksterhuis, 2003; Turgut & Cakmacki, 2009). By increasing the milk fat content, vanilla, sweet and milky attributes were enhanced whereas sour, bitter and astringent attributes were depressed. The ability of milk fat to mask to the polar flavor compounds existing in fermented milks (acetaldehyde, acetoin, diacetyl, acetic acid etc.) is the most prominent factor that led to the intensity reduction of perceived sourness and astringency and enhancement of sweet taste. The inverse correlation of fatty and sour–astringent attributes fermented milks has been reported (Muir, Hunter, & Delaudier, 1997; Turgut & Cakmacki, 2009). Moreover, the dissolution of lipophilic vanillin in the apolar fat substrate favored the temporary control of vanilla flavor release, an action that has been also demonstrated in other studies (Hyvönen et al., 2003; King, 1994).

Concerning the texture attributes, the milk fat content elevation was accompanied by significant increase of creamy and greasy and decrease of hard, coarse, watery and brittle attributes. The former is interconnected with milk fat functionality including fat destabilization, favoring of air incorporation and air cells stabilization, lubrication of oral tissue and improvement of mouth sensation due to the covering of tongue mucosa (de Wijk et al., 2006; Dresselhuis et al., 2008; Marshall et al., 2003). The partial destabilization of milk fat during the whipping step leads to the formation of fat networks that stabilize the air cells. Thus, high fat ice creams are well known for their foamy and smooth texture (Goff, 1997). Moreover, the increase of milk fat in dairy desserts contributes to the reduction of friction, through a partial coalescence mechanism facilitating the better perception of creamy, greasy and gummy (sticky) attributes (Dresselhuis et al., 2008).

The effects of milk fat on the melting behavior of ice cream samples revealed that the increase of milk fat improved the quality characteristics of the melted product (increased viscosity, foamy like appearance, prevention of wheying off and melting resistance). The contribution of fat to the structural characteristics of ice cream as well as its reduced heat conductivity can explain the former effects.

3.3. Effects of hydrocolloids

Hydrocolloids affect ice cream texture and flavor perception throughout different mechanisms including: control of recrystallization phenomena, viscosity increase and water retention, stabilization, emulsification and volatile aroma compounds entrapment (Cook, 2006; Huang, Kakuda, & Cui, 2001; Regand & Goff, 2003). The addition of xanthan gum improved sweet and vanilla flavor perception and moreover, inhibited significantly the sour and

Table 4
ANOVA mean values of the sensory attributes categorized in terms of the compositional profile of probiotic ice cream samples.

Attribute	Effects of milk fat (g/100 g)		Effects of yogurt percentage (g/100 g)		Effects of hydrocolloids type					Effects of hydrocolloids percentage (g/100 g)		
	2	4	25	50	Guar	Alginate	CMC	HPMC	Xanthan	0.2	0.3	0.4
Color	5.60^{A}	6.65^{B}	6.08^{A}	6.07^{A}	5.46^{A}	5.88^{AB}	5.99^{BC}	6.50^{C}	6.81^{C}	5.40^{A}	5.72^{A}	5.74^{A}
Sweet	4.98^{A}	6.26^{B}	5.60^{A}	5.64^{A}	5.56^{BC}	5.18^{AB}	5.82^{BC}	5.39^{B}	6.13^{C}	5.42^{B}	5.05^{AB}	4.89^{A}
Bitter	3.96^{B}	3.01^{A}	3.05^{A}	3.87^{B}	3.51^{BC}	3.99^{C}	3.78^{C}	3.33^{B}	3.03^{A}	3.53^{B}	3.84^{B}	3.05^{A}
Astringent	3.76^{B}	2.87^{A}	2.66^{A}	3.29^{B}	2.42^{A}	3.04^{B}	3.88^{C}	2.34^{A}	2.25^{A}	2.63^{A}	2.74^{A}	2.81^{A}
Sour	3.71^{B}	2.99^{A}	3.17^{A}	4.05^{B}	2.47^{A}	4.32^{C}	3.56^{B}	3.72^{B}	2.41^{A}	3.01^{A}	3.60^{B}	3.43^{B}
Vanilla flavor	4.63^{A}	6.04^{B}	5.96^{B}	5.42^{A}	6.19^{BC}	5.22^{A}	5.73^{B}	5.51^{AB}	6.02^{C}	5.68^{B}	5.27^{A}	5.11^{A}
Milky	3.19^{A}	3.95^{B}	3.63^{A}	3.51^{A}	3.43^{A}	3.39^{A}	3.89^{B}	3.98^{B}	3.55^{AB}	3.71^{A}	4.39^{B}	4.17^{B}
Hard (S)	4.37^{A}	5.90^{B}	4.89^{A}	5.65^{B}	5.98^{C}	5.33^{B}	5.21^{B}	5.17^{B}	3.92^{A}	4.86^{A}	5.07^{AB}	5.35^{B}
Coarse (S)	3.98^{A}	3.09^{B}	3.57^{A}	3.71^{A}	3.83^{C}	4.66^{D}	3.60^{BC}	3.35^{B}	2.36^{A}	3.11^{A}	2.78^{A}	3.87^{B}
Brittle	4.46^{A}	4.89^{B}	4.41^{A}	5.03^{B}	4.59^{B}	5.57^{C}	4.08^{A}	4.92^{B}	3.61^{A}	5.07^{B}	4.41^{A}	4.28^{A}
Gummy (S)	3.34^{B}	2.77^{A}	2.98^{A}	2.84^{A}	3.14^{B}	2.21^{A}	2.97^{B}	3.18^{B}	3.23^{B}	2.61^{A}	2.98^{AB}	3.43^{B}
Hard (M)	3.93^{A}	4.66^{B}	3.89^{A}	4.48^{B}	4.54^{BC}	4.74^{C}	4.33^{BC}	4.26^{AB}	3.71^{A}	4.67^{B}	4.23^{A}	4.14^{A}
Coarse (M)	3.87^{A}	3.12^{B}	3.21^{A}	3.91^{B}	4.18^{C}	4.81^{D}	3.36^{B}	3.26^{B}	2.61^{A}	3.73^{A}	3.35^{AB}	3.02^{B}
Gummy (M)	2.71^{B}	2.34^{A}	2.73^{B}	2.30^{A}	2.87^{B}	2.13^{A}	2.41^{A}	2.46^{AB}	2.92^{B}	2.48^{A}	2.54^{A}	2.81^{A}
Watery	4.12^{B}	3.61^{A}	4.19^{B}	3.51^{A}	4.31^{C}	5.97^{A}	4.90^{B}	4.81^{B}	4.15^{C}	5.82^{B}	4.91^{A}	4.88^{A}
Creamy	5.38^{A}	6.39^{B}	6.02^{B}	5.14^{A}	6.17^{B}	4.81^{A}	6.21^{B}	6.34^{B}	7.21^{C}	6.58^{A}	6.93^{A}	6.01^{B}
Greasy	3.55^{B}	2.73^{A}	3.34^{B}	2.88^{A}	3.04^{A}	2.77^{A}	3.26^{A}	2.99^{A}	3.58^{B}	2.88^{A}	3.02^{A}	3.51^{B}
Fusible	4.15^{A}	3.63^{B}	3.73^{A}	4.02^{B}	3.30^{A}	3.09^{A}	4.65^{B}	4.89^{B}	3.80^{B}	3.73^{A}	3.88^{A}	4.20^{B}
Wheyoff	2.62^{B}	1.84^{A}	1.88^{A}	2.58^{B}	2.17^{A}	2.29^{AB}	2.57^{B}	2.67^{B}	2.05^{A}	2.17^{A}	2.18^{A}	2.47^{B}
Thin	3.52^{A}	3.59^{A}	3.89^{B}	3.26^{A}	2.47^{A}	4.44^{C}	4.11^{B}	3.83^{BC}	2.90^{A}	2.98^{A}	3.37^{A}	4.31^{B}
Foamy	2.19^{A}	4.21^{B}	3.98^{A}	3.04^{B}	3.76^{B}	3.87^{B}	2.63^{A}	3.45^{B}	2.70^{A}	2.99^{A}	3.07^{A}	3.54^{A}
Bulky	4.54^{B}	3.52^{A}	3.47^{A}	4.78^{B}	4.78^{B}	3.67^{A}	3.95^{A}	3.98^{A}	3.58^{A}	3.77^{A}	3.96^{A}	4.07^{A}

$^{A-D}$Different letter between columns indicates significant difference according to Duncan's post hoc comparison test.

astringent attributes. On the contrary, sodium alginate failed to enhance the samples flavor quality. Considering the impact of hydrocolloids content on flavor, the lowest percentage led to the greatest vanilla and sweet enhancement and astringency constraint and thus to depression of yogurt volatile compounds release. Sourness was reduced at the intermediate milk fat content.

The vulnerability of stabilizers against acidic conditions is of particular importance for their action and thus, stabilizing systems that are stable in fermented milks and have an established cryoprotective, thickening and stabilizing effect in ice cream must be used in the case of partially or fully acidified frozen dairy desserts (Regand & Goff, 2003; Soukoulis, Panagiotidis, Koureli, & Tzia, 2007). Xanthan gum significantly reduced the perceived coarse, hard, watery and brittle attributes whilst it increased the gumminess and creaminess. Guar gum, CMC and HPMC had a noticeable effect on textural quality of ice creams though less efficient than xanthan gum. Guar gum constrained wateriness, and increased gummy and greasy perception of ice creams. On the other hand, the use of sodium alginate failed to improve the samples textural quality as almost all the evaluated sensory characteristics were negatively influenced by its presence. Similar results according the functionality of hydrocolloids have also reported in the case of frozen yogurt (Soukoulis & Tzia, 2008).

The use of 0.3–0.4% hydrocolloid in probiotic ice cream has been proved adequate to prevent coarseness and decrease hardness. Creaminess was better perceived in samples with intermediate percentages of added hydrocolloids than the expectedly highest ones. Creaminess is a sensory attribute that is perceived through a complex pattern including perception of thickness, wateriness, friction, coarseness, mouthcoating, oral tissue lubrication, etc. (de Wijk et al., 2006). Thus, the addition of high amounts of hydrocolloids (overstabilization) led to the development of extremely thick and sticky samples and thus, to loss of the creamy sensation. The occurring overstabilization at samples containing 0.4% of stabilizer resulted in the depression of vanilla flavor release.

The addition of xanthan gum led to the improvement of samples melting quality and increased their melting resistance as well. Guar gum though enhanced the viscosity of ice creams it also imparted a curdy and foamy like texture. Although CMC and HPMC significantly increased the melting resistance of probiotic ice creams they were not able to control wheying off defect. The syneresis occurring during melting of ice creams containing is related with phase separation induced by the incompatibility of cellulosics with whey proteins (Murrey, 2000, chap. 12).

3.4. *Investigation of sensory properties interrelationships and samples classification*

According to the results of linear correlation (Table 5), the quality of probiotic ice cream is evaluated by the consumers through a complex perceiving pattern including flavor, texture, oral processing and melting behavior characteristics. Creaminess, coarseness, orally assessed viscosity (wateriness), vanilla flavor and sweetness have the most pronounced impact on consumers' acceptance scores. Moreover, the masking of sour and astringent flavor is another critical parameter for enhancing consumers' acceptability of frozen fermented dairy desserts. With respect to the particular interrelationships between descriptive attributes, we highlight the positive correlation of creaminess with sweetness, vanilla flavor, and greasiness and its negative correlation with sourness and astringency. The phenomena occurred during oral processing of ice cream e.g. deformation of structural elements (air cells and ice crystals), melting of ice crystals, dilution with saliva, release of flavor compounds, fat coalescence, fat coating of tongue mucosa, and friction contribute significantly to the perception of creaminess (de Wijk et al., 2006; de Wijk et al., 2003; Dresselhuis et al., 2008; Soukoulis et al., 2008).

In order to reveal the commonalities among samples quality characteristics we performed stepwise discriminant analysis introducing only the sensory attributes which were highly correlated with DOL (Figs. 1 and 2). From the 17 sensory attributes, discriminant analysis returned 12 including: creamy, vanilla flavor, gummy (S), greasy, sweet, astringent, sour, coarse (S), hard (S), watery, hard (M), and coarse (M). In the case of samples differing on the hydrocolloid type, the percentage of correct classification was 83.33% with samples containing xanthan (91.33%), sodium alginate

Table 5
Correlation coefficients between consumers' acceptability (DOL) and descriptive sensory attributes.

	DOL	Color	Sweet	Bitter	Astringent	Sour	Vanilla	Milky	Hard (S)	Coarse (S)	Brittle (S)	Gummy (S)	Hard (M)	Coarse (M)	Gummy (M)	Watery	Creamy	Greasy	Fusible	Whey off	Thin	Foamy	Bulky
DOL	1.00	***0.64***	***0.87***	***−0.47***	***−0.74***	***−0.82***	***0.89***	0.14	***−0.68***	***−0.94***	***−0.54***	***0.61***	***−0.73***	***−0.89***	***0.38***	***−0.87***	***0.99***	***0.66***	***0.40***	0.11	−0.19	***0.47***	0.23
Color		1.00	0.62	−0.11	***−0.46***	***−0.47***	***0.62***	0.12	***−0.49***	***−0.54***	−0.13	−0.06	***−0.45***	***−0.42***	0.08	***−0.50***	***0.58***	***0.43***	0.17	0.25	−0.10	***0.46***	0.04
Sweet			1.00	−0.20	***−0.60***	***−0.62***	***0.71***	0.12	***−0.55***	***−0.67***	***−0.38***	***0.45***	***−0.52***	***−0.51***	0.20	***−0.53***	***0.74***	***0.62***	0.09	0.26	0.04	***0.39***	0.18
Bitter				1.00	***0.40***	***0.41***	−0.20	0.20	0.19	0.18	0.15	0.14	***0.41***	0.11	0.05	0.03	−0.17	0.07	−0.05	−0.04	0.19	−0.08	−0.08
Astringent					1.00	***0.71***	***−0.53***	−0.17	***0.49***	***0.59***	0.15	−0.26	***0.59***	***0.61***	−0.16	***0.56***	***−0.67***	−0.21	−0.19	−0.16	−0.05	−0.22	−0.07
Sour						1.00	***−0.52***	0.07	***0.49***	***0.67***	***0.45***	***−0.40***	***0.50***	***0.68***	−0.14	***0.60***	***−0.74***	***−0.46***	−0.04	−0.16	0.06	−0.04	0.03
Vanilla							1.00	0.19	***−0.64***	***−0.61***	***−0.44***	0.28	***−0.53***	***−0.46***	−0.04	***−0.50***	***0.70***	0.26	0.24	0.04	0.17	***0.48***	0.08
Milky								1.00	−0.17	−0.08	−0.01	0.19	−0.09	−0.03	0.17	0.00	0.01	−0.04	0.13	0.18	−0.21	0.27	0.05
Hard (S)									1.00	***0.64***	−0.07	0.03	***0.89***	***0.57***	0.01	***0.55***	***−0.71***	***−0.42***	***−0.41***	−0.17	0.04	−0.13	−0.12
Coarse (S)										1.00	***0.66***	***−0.50***	***0.62***	***0.87***	−0.24	***0.73***	***−0.85***	***−0.63***	***−0.50***	−0.13	0.20	***−0.38***	−0.25
Brittle (S)											1.00	***−0.52***	−0.04	***0.50***	−0.26	0.14	***−0.41***	***−0.41***	−0.23	−0.06	0.14	−0.14	−0.18
Gummy (S)												1.00	−0.12	***−0.55***	0.19	***−0.47***	***0.58***	0.25	0.10	−0.16	−0.16	0.09	0.11
Hard (M)													1.00	***0.57***	−0.05	***0.63***	***−0.70***	−0.29	***−0.43***	−0.04	0.05	−0.09	−0.18
Coarse (M)														1.00	−0.26	***0.77***	***−0.83***	***−0.53***	***−0.45***	−0.02	0.16	−0.22	−0.03
Gummy (M)															1.00	−0.23	0.18	***0.40***	0.00	0.22	***−0.45***	0.18	0.22
Watery																1.00	***−0.94***	***−0.49***	***−0.42***	0.03	***0.77***	−0.21	−0.18
Creamy																	1.00	***0.64***	***0.51***	0.10	−0.19	0.27	0.28
Greasy																		1.00	0.15	0.22	−0.11	0.27	0.23
Fusible																			1.00	0.12	−0.14	0.15	0.27
Wheyoff																				1.00	−0.02	***0.47***	0.17
Thin																					1.00	0.11	***−0.51***
Foamy																						1.00	0.26
Bulky																							1.00

Coefficients marked by bold and italics are significant at $p < 0.05$.

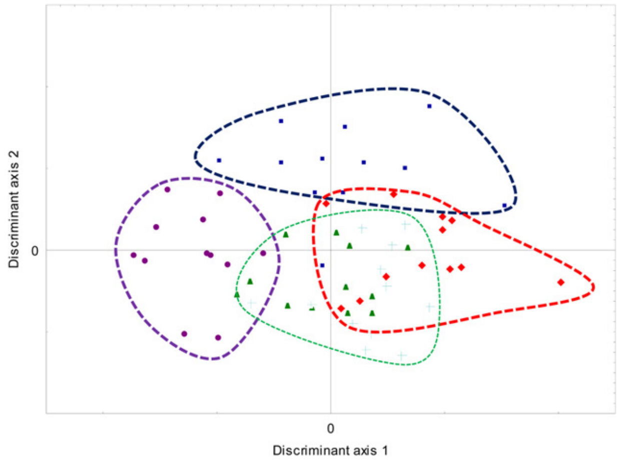

Fig. 1. Discriminant analysis performed for the investigation of the communalities among probiotic ice cream samples differing on the type of the stabilizing system. ■ = guar gum, ◆ = sodium alginate, ▲ = CMC, + = HPMC, ● = xanthan gum.

(91.33%) and guar gum (85%) to be well discriminated. The Mahalanobis distances between samples with xanthan, guar gum and sodium alginate were significantly different ($p < 0.01$) whereas in the case of CMC and HPMC it was not observed significant difference among their Mahalanobis distances suggesting the similar functionality. According to Fig. 2, the correct classification percentage was 90% with the 100% of samples containing 25 and 50% probiotic yogurt to be discriminated. However, in the case of samples with different percentages of milk fat the classification rate was substantially lower as the samples with 50% yogurt could not be adequately discriminated by means of milk fat content.

3.5. Modeling of consumers' acceptability by descriptive sensory drivers using PLS1

In order to understand the way that descriptive sensory drivers could be used for the interpretation of frozen fermented dairy desserts consumers' acceptability, the descriptive sensory and hedonic judgements data were subjected to PLS1 analysis (Table 6). The entire sample data set was used for the construction of a generic linear model able to illustrate the pattern in which

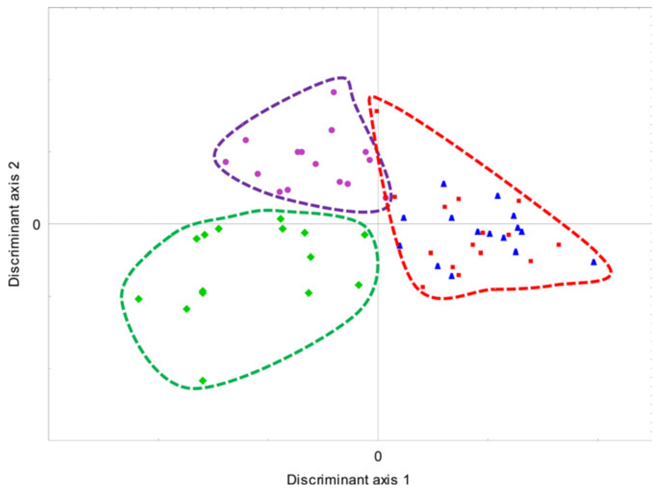

Fig. 2. Discriminant analysis performed for the investigation of the communalities among probiotic ice cream samples differing on their milk fat and yogurt concentration. ● = 4 g/100 g milk fat – 25 g/100 g yogurt addition, ■ = 4 g/100 g milk fat – 50 g/100 g yogurt addition, ◆ = 2 g/100 g milk fat – 25 g/100 g yogurt addition, ▲ = 2 g/100 g milk fat – 25 g/100 g yogurt addition.

Table 6
Prediction capabilities of the PLS1 models constructed for the determination of consumers' acceptability of probiotic ice cream samples.

Data set	Correlations		Calibration		Validation	
	Positive	Negative	RMSEC	R^2	RMSEP	R^2
Generic	Sweet, vanilla, gummy, creamy, greasy, foamy	Astringent, sour, coarse, watery	0.267	0.956	0.328	0.951
Xanthan gum	Sweet, vanilla, gummy, creamy, greasy, foamy	Astringent, sour, coarse, watery	0.203	0.982	0.243	0.972
Sodium alginate	Sweet, gummy, creamy, foamy	Astringent, coarse, watery	0.189	0.985	0.291	0.959
CMC–HPMC	Sweet, gummy, creamy, foamy	Astringent, coarse, watery,	0.205	0.972	0.277	0.956
Guar gum	Sweet, vanilla, gummy, creamy	Sour, coarse, watery	0.177	0.978	0.354	0.908
High fat	Sweet, vanilla, creamy	Astringent, sour, coarse, watery	0.262	0.972	0.340	0.954
Low fat	Sweet, vanilla, gummy, creamy, greasy	Sour, coarse, watery	0.276	0.962	0.369	0.927
High yogurt	Sweet, vanilla, creamy	Astringent, sour, coarse, watery	0.261	0.952	0.324	0.927
Low yogurt	Sweet, vanilla, gummy, creamy, greasy	Astringent, sour, coarse, watery	0.292	0.972	0.321	0.961

consumers' perceive quality of probiotic ice cream. Moreover, considering the specific communalities among samples as DA revealed, different sensory–hedonic data sub-sets were used for the construction of compositionally driven PLS models (based on the hydrocolloids type, yogurt and milk fat percentage). The latter models could be a useful tool for R&D purposes so to understand, quantify and enhance consumers' acceptability of probiotic ice cream and related products.

For the constructed generic model, the results displayed that ten sensory attributes represented an explained variance of 46% that described 96% of the DOL data, on the first two PC's. In Fig. 3 are shown the validation coefficients and the predicted DOL data obtained by the PLS model against actual DOL data. The RMSEP of the constructed model was 0.328 (on the 0–10 scale) signifying its good predictability. Considering the participation of the sensory drivers on the DOL of probiotic ice creams, it is well illustrated that the attributes indicating the occurrence of recrystallization phenomena, or increasing friction (sour, astringent, watery, coarse) have a negative impact on DOL whereas the attributes that favor mouthcoating, tongue lubrication, and enhanced flavor are positive contributors to DOL scores.

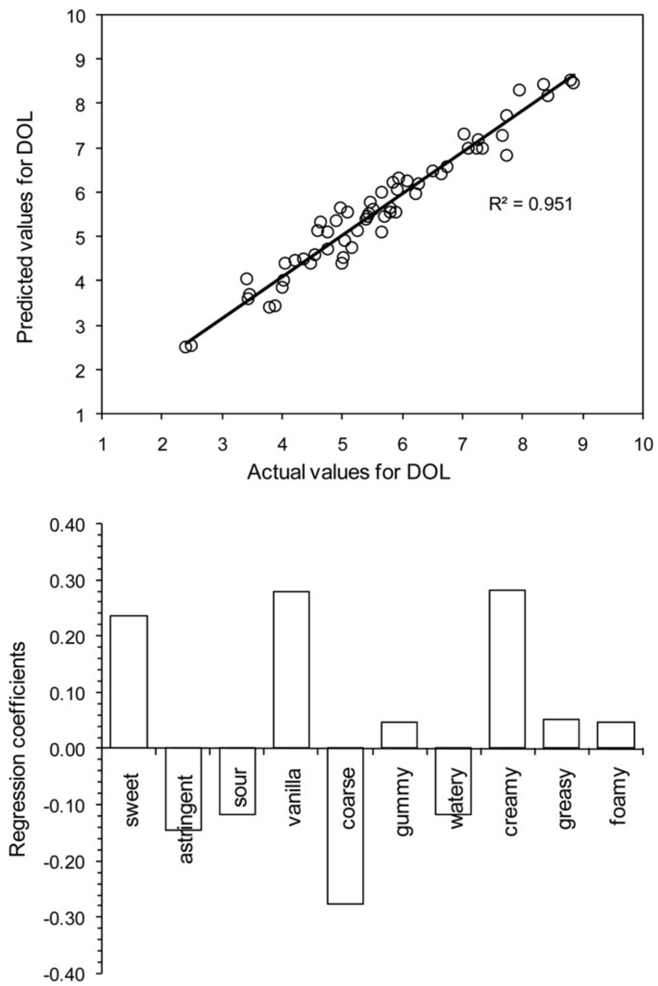

Fig. 3. Cross-validated estimation of consumers' acceptability of probiotic ice cream based on specific selected descriptive sensory attributes.

In Table 6 are displayed the results of PLS regression for the models constructed by the different calibration sub-sets according to the particular communalities of the hydrocolloids. Thus, four linear models were developed for guar gum, sodium alginate, CMC/HPMC, and xanthan gum, comprised of seven to ten sensory attributes which represented an explained variance ranging from 53 to 71% that accounted for the 91–99% of the DOL data in the first two PC's. The RMSEP of the models ranging from 0.243 to 0.354 signified the good predictability of the models. It is interesting the fact that only four attributes (sweet, coarse, watery and creamy) that participated in the generic PLS model were also contributors to the models created according to hydrocolloids type. This could be of particular importance in the case of developing new products or testing the functionality and efficiency of ingredients with communalities on their functional properties.

Two PLS models were constructed by the two calibration data sub-sets created based on samples milk fat concentration (Table 6). The two models were comprised of 8 (for the low fat) and 7 (for the high fat) sensory characteristics that represented an explained variance of 59 and 56% that accounted for the 95% and 96% of the DOL data respectively. The RMSEP of the models were 0.34 and 0.369 showing a slightly higher variability considering the generic PLS model. This may be caused due to the greater similarities among samples differing on their milk fat content. Considering the contribution of the specific sensory drivers to DOL scores, the increase of milk fat is accompanied with increased greasiness, gumminess and vanilla flavor intensity, and masking of sour flavor.

Similarly, two models were constructed using the two calibration sub-sets of the data differing on the yogurt percentage (Table 6). Seven sensory attributes were loaded for the construction of the models that represented an explained variance of 55 and 66% that described the 96 and 97% of the DOL values respectively. The RMSEP of the models were 0.321 and 0.324 for the low and high yogurt formulations respectively. The increase of yogurt changed the structure of the PLS models by increasing the participation of the flavor attributes and coarse texture.

4. Conclusions

The complex matrix and the rich flavor profile of probiotic ice cream critically affect the perceived quality to the consumers. Compositional parameters such as milk fat and yogurt concentration and hydrocolloids type influenced significantly the sensorial quality of probiotic ice creams. High fat (4% milk fat solids)–low acidified (25% yogurt base addition) probiotic ice creams containing 0.3% xanthan gum or HPMC were characterized by enhanced creaminess and mouthfeel, increased mouth-perceived viscosity, enhanced vanilla flavor release and acceptable melting quality characteristics. Consumer acceptability of probiotic ice cream was found to be interrelated with specific flavor and texture attributes including sourness, astringency, sweetness, vanilla flavor, gumminess, coarseness, wateriness, creaminess, greasiness and foaminess. These parameters were used for the construction of simplified linear PLS models that can quantify and predict consumers acceptability. Modified linear models based on the former attributes were also constructed in order to have a more targeted (based on compositional parameters) determination of probiotic ice cream acceptability. The last is of paramount importance for the R&D purposes in the food industry as these models can be used for the design and development of new products.

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