Functional properties of food starches in a food model emulsion

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ABSTRACT

Four food starches were modified using five types of chemical modification. Effects on functional properties were investigated using a starch-based dressing model. The model products were characterised by descriptive sensory analysis and by a range of instrumental rheological analyses. Data were analysed using a chemometric approach.

A clear tendency towards sample grouping based on starch origin was seen. Effects of starch modification were seen within these groups.

The results from sensory analysis and rheological analysis showed similar sample groupings. Strong correlations between sensory attributes and instrumental parameters were found. Sensory attributes related to firm and gelled textures could be predicted from instrumental data with prediction coefficients as high as 0.97.

INTRODUCTION

Texture is of major importance for the consumers' acceptability of food products. Because of its textural properties, starch is extensively used as a thickener or as a gelling agent in food products[1]. The functional properties of starch largely depend on its molecular structure[2]. Changing the molecular structure by chemical modification can alter the properties of food starches[3]. Crosslinking is used to improve the processing stability e.g. heat-, shear- and low pH stability, while substitution is used to improve the storage stability by reducing retrogradation and syneresis[4]. In order to evaluate the effect of new starch ingredients in food applications a model product test system is a valuable tool[5]. In earlier work[6] we studied the functional properties of genetically modified starches in a starch-based dairy model and found that differences in starch chain length distribution were reflected in the sensory and rheological properties of the starches when tested in a model product.

In this study four native starches (potato, maize, waxy maize and tapioca) were chemically modified using five types of modification, totally 24 starches with different molecular structures. The functional properties of the starches were tested in a dressing model. The texture properties of the food models were characterised by sensory and rheological analyses.

MATERIALS AND METHODS

Materials

Native starches from potato, tapioca, maize and waxy maize were obtained from KMC, Brande, Denmark. Chemically modified starches were produced by KMC (acetylation, crosslinking using phosphorous acid) and by ISI, Aarhus, Denmark (hydroxypropylation). Combining these modifications gave a total of 24 starches (Table 1).

Table 1. Overview of chemically modified starches and sample codes.

Chemical modifications	Cross linked distarch phosphate	Not cross linked
Acetylated	P_ADP, T_ADP, M_ADP, W_ADP	P_A, T_A, M_A, W_A
Hydroxypropylated	P_HDP, T_HDP, M_HDP, W_HDP	P_H, T_H, M_H, W_H
Not acetylated nor hydroxypropylated	P_DP, T_DP, M_DP, W_DP	Native starches: P_N, T_N, M_N, W_N

P=potato, T=tapioca, M=maize, W=waxy maize. Suffices refer to the type of chemical modification.

Rapeseed oil was from Århus United, Århus, Denmark. Whole egg powder was obtained from Sanovo Foods A/S, Odense, Denmark. Sugar was from Danisco Sugar, Copenhagen, Denmark. Sodium chloride, citric acid and sodium sorbate were obtained from Merck, Darmstadt, Germany.

Production of dressing

Dressing was prepared using a two-step procedure; gelatinisation followed by emulsification. A semi-industrial Stephan mixer with a jacket (Stephan UMC5 electronic, Hameln, Germany) connected to both a heating bath (Haake B7N6 circulation glycerol at 120°C) and a cooling bath (HETOFrig CB7 circulating water of 0°C) was used for the gelatinisation procedure. Emulsification was performed using a Silverson L4R laboratory mixer, Silverson Machines LTD, Waterside, England.

Dressings were manufactured in 2000 g batches using 3.0% test starch, 50% rapeseed oil, 42,3% water, 1.9% sugar, 1.6% whole egg powder, 0.8% sodium chloride, 0.3% citric acid and 0.1% sodium sorbate.

Starch and half of the water were heated for 10 min to reach 95°C and subsequently cooled for 5 min to 45°C during continuous stirring at 500 rpm using the Stefan mixer. The dry ingredients were suspended in the rest of the water and mixed into the gelatinised mixture for 3 min using the Silverson mixer. Rapeseed oil was added over a 2 min. period while mixing at maximum speed, and mixing was continued for another 2 min. Batches were kept in plastic beakers (40 mL) at 5°C for further analysis. All batches were produced in two replicates.

Sensory evaluation

A panel of eight trained and experienced assessors evaluated the texture characteristics of the model dressings. Two days were used to develop a consensus set of descriptors (table 2). The set of descriptors was based on the perceived attributes when assessors were presented for dressings prepared from selected test starches. The scale of intensity of each descriptor is based on variation in the tested dressings.

Samples were unimodally presented at 10°C in 40 mL beakers according to a complete randomised design. Panellists were provided with a cup of water and unsalted saltine crackers and instructed to cleanse their palates after the evaluation of each sample. The evaluation was conducted in individual booths. All dressing batches were evaluated in two replicates.

Rheological testing

Rheological analyses were performed on a Bohlin CS rheometer (Bohlin Instruments, Ltd, Cirencester, UK) equipped with a plate-plate 40 mm geometry. Frequency sweeps were carried out within the linear viscoelastic region in the range 0.1 to 10 Hz.

Table 2. Texture attributes for sensory evaluation of dressing.

Descriptor	Definition
Firm-ts	The resistance of the product towards a horizontal movement of the spoon
Pourable-ts	The degree to which the product is easily poured from the spoon or beaker
Cohesive-ts	The degree to which a spoonful resists / must be cut to be removed (ant: short)
Gelled-ts	The degree of shape retention of the hole in the product when a spoonful is removed
Spoonable-ts	The degree of shape retention when a spoonful of the product is replaced in the beaker
Sticky-ts	The degree to which the product sticks to the spoon
Thick-tm	The force required to move the sample around in the oral cavity
Oily-tm	The degree to which a fatty/oily layer is perceived in the mouth after swallowing
Sticky-tm	The degree to which the product adheres or sticks to the tongue, palate, mouth or teeth
Lumpy-tv	The degree to which the product appears lumpy

Suffix –ts: texture perceived by a spoon; -tm: texture perceived in the mouth; tv texture perceived visually

From frequency sweeps the storage modulus and the phase angle at 1 Hz were read. Shear viscometry was run over a shear rate range of 1 - 300 s^{-1}. Flow curves were fitted to the power law equation: $\eta = K \cdot \dot{\gamma}^{(n-1)}$. The consistency index, K and the power law index, n were calculated.

Spreadability analyses were performed using a concentric cylinder (d=30 mm and h=20 mm). 16 ml of sample was poured into the cylinder. The cylinder was moved and the diameter of the sample was read after 2 min. Texture analyses were performed on a TaXT2 (StableMicroSystems, Surrey, UK) using *backward extrusion* where a 25 mm plunger penetrated 85% into the 40 ml beakers in a down and upward stroke at a speed of 3 mm/s. From texture curves maximum force and extrusion work were read.

All rheological analyses were carried out at 10°C and performed in triplicates.

Data treatment

Multivariate data analysis was used to get an overview of the data set and to explore relations between sensory and instrumental variables. PCA (principal component analysis) and PLS (partial least square analysis) were applied using the software Unscrambler v8.0 (Camo A/S, Oslo, Norway).

RESULTS AND DISCUSSION

Sensory evaluation

Texture attributes from sensory evaluations of the model products are outlined in Table 2. In order to get an overview of all results from sensory analyses principal component analysis (PCA) was performed.

Using PCA the first two principal components could describe 94% of the variation in the sensory data. In the PCA scores plot (Fig. 1) sample grouping can be studied. Interestingly there is a clear tendency towards sample grouping based on starch origin rather than type of modification. In the plot all maize starches are placed far to the right along PC1 separated from all other starches. Dressings prepared from waxy maize starches are placed far left along PC1 in the scores plot, while tapioca and potato starches overlap towards the middle of PC1. Within groups there is a tendency towards grouping based on modification. Native starches (suffix N) are all placed at the bottom of the plot, while modifications involving hydroxypropylation (suffix H, HDP) are placed towards the top.

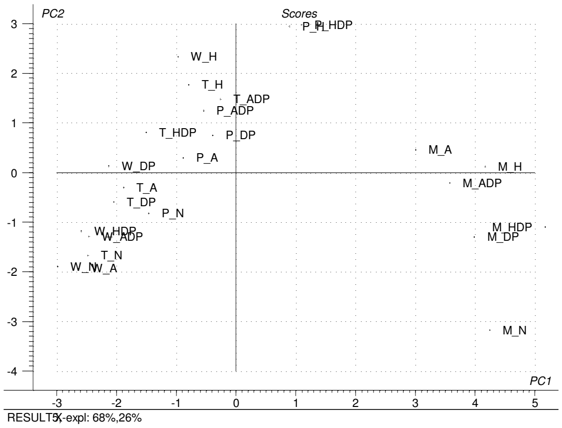

Figure 1. PCA scores plot of all starches based on sensory analyses of dressings.

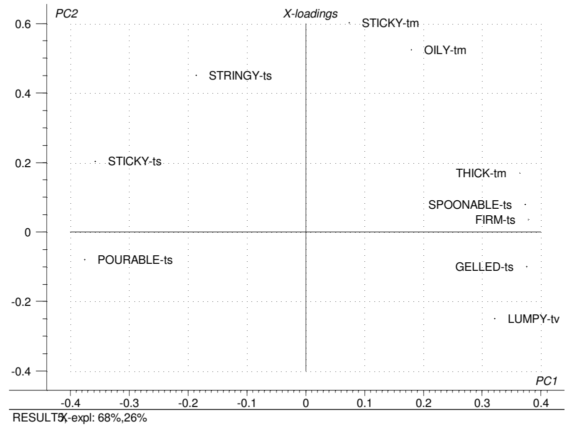

Figure 2. PCA loading plot of texture attributes from sensory analysis of dressing.

From the PCA loading plot (Fig. 2) it is seen that samples placed to the far right along PC1 are characterised by thick and gelled textures. Thus maize starches regardless of modification produced dressings with thick and gelled textures as compared to the other starches. It is well known that native maize starches set to firm and cuttable gels during cooling due to intensive retrogradation caused by their high amylose content[4]. However, this should be reduced by hydroxypropylation or acetylation where intermolecular interactions are weakened due to introduction of bulky side groups on the starch molecule[4]. When comparing the localisation of native maize starch (M_N) to acetylated maize starch (M_A) and hydroxypropylated maize starch (M_P) in Fig. 1 and comparing the loadings in Fig. 2 it is seen that M_N is characterised by a very gelled and lumpy texture, while M_A and M_H are thick and spoonable. Thus the bulky groups have weakened the gel.

From Fig. 1 and Fig. 2 it appears that dressings prepared from waxy maize starches are characterised by pourable, non-gelled textures. This is expected, since waxy maize starches due to their extremely low amylose content have inherent resistance to retrogradation. Notice that all waxy maize starches except from W_H are placed in the bottom left corner of the scores plot (Fig. 1). This indicates that chemical modification of waxy maize starch does not affect the functional properties as effectively as compared to potato, tapioca and maize starches possibly due to the low amylose content.

No unambiguous conclusion on the effect of the different types of modifications can be drawn. However, all native starches are placed at the bottom of PC2 and modifications move the texture characteristics from thin and pourable in the direction of firmer more stringy and sticky textures for waxy maize, tapioca and potato starches, while maize starches become less gelled upon modification. There is a tendency that modifications involving hydroxypropylation have the highest impact on texture characteristics.

Subjective evaluation of the dressings rated P_H, P_HDP, M_A and M_H highest in stability and appealing texture. These four starches are all located in the upper right corner of the scores plot. Maize starches are often preferred for production of dressings. These results indicate that hydroxypropylated potato starches may serve as a good alternative.

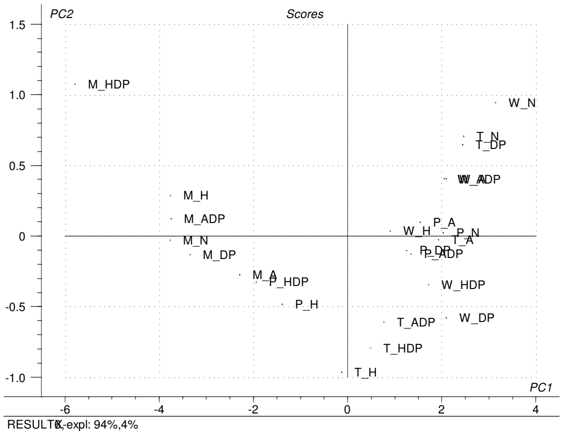

Figure 3. PCA scores plot of all starches based on instrumental analyses of dressings.

Rheological analysis

Data from rheological analyses were also explored by the multivariate strategy applied to the sensory data. The PCA scores plot (Fig. 3) shows the same overall sample grouping as seen from sensory analysis. Maize starches are well separated along PC1 due to high values of G´lin and consistency index K. This is in accordance with sensory data where maize starches produced very gelled dressings. Waxy maize starches are placed to the far left along PC1 followed by tapioca and potato starches. The rheological characteristics of P_H and P_HDP are approaching those of maize starches.

Relation between sensory and rheological properties

To explore relationships between sensory data and rheological data PCA was performed using both sensory and instrumental data. From the loadings plot (Fig. 4) strong relations between sensory attributes and rheological parameters are seen. PC1 explains 78% of the variation in the data set and describes the difference in firmness/gelled texture whereas PC2, which explains another 16% of the variation in the data set, is related to the stringiness and stickiness of the samples. It is seen that the instrumental parameters, storage modulus, G`lin from oscillation, the consistency index, K from viscosity analysis and two parameters from texture analysis are closely correlated to the sensory parameters related to firm and gelled texture. These variables are oppositely related to the flow index, n, the phase angle and spreadmeter results all of which are related to the products' viscous properties. No instrumental parameters are able to describe the sample differences related to stringy texture and sticky and oily mouthfeel.

Partial Least Squares regression analysis (PLS2) was performed in order see whether sensory attributes could be modelled and predicted from the instrumental data. A PLS2 model with 2PCs and cross validation was used. The sensory parameters stringy, sticky and oily were omitted from the model due to poor description from instrumental parameters. The PLS2 model resulted in an explained total variance of the sensory data of 73%. Table 2 lists the correlation coefficients between the actual sensory data and the predicted sensory attributes from the instrumental data using a cross validated prediction model. Correlation coefficients from 0.92 to 0.97 were found when all instrumental parameters were used.

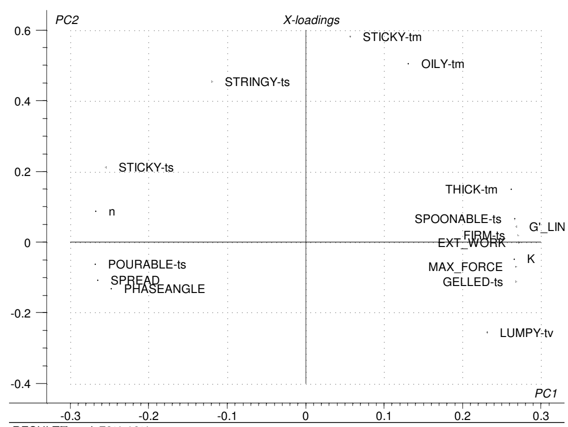

Figure 4. PCA loadings plot of all variables from sensory and instrumental analyses.

Table 3. Correlation coefficients from PLS2 prediction of sensory attributes from instrumental parameters.

	Correlation (predicted vs. measured)	
Sensory attributes	All parameters included	Four parameters included
Firm-ts	0.95	0.94
Pourable-ts	0.97	0.94
Gelled-ts	0.96	0.93
Spoonable-ts	0.95	0.93
Thick-tm	0.92	0.93

When only results from large deformation testing were used the correlation coefficients only dropped slightly to 0.93 to 0.94. This is useful information for food technologists having no access to a rheometer.

CONCLUSION

Sensory and rheological properties of chemically modified food starches from potato, tapioca, maize and waxy maize were characterised. Exploring data by chemometric analysis revealed sample grouping based on starch origin rather than type of modification. Maize starches produced firm and gelled structures while waxy maize starches produced viscous and pourable dressings. This may be ascribed to the large difference in the amylose content in maize and waxy maize starch.

No clear general tendencies of the effect of different types of chemical modification could be drawn. However, modifications including hydroxypropylation seemed to have the highest impact on texture characteristics. Hydroxypropylated potato starch, hydroxypropylated crosslinked potato starch, hydroxypropylated maize starch and acetylated maize starch gave appealing texture properties when tested in dressing. These products all had firm, spoonable consistencies with slightly stringy, sticky and oily mouthfeel. This indicates that potato starches may serve as a good alternative to the traditionally used maize starches.

Strong correlations were found between sensory attributes and rheological parameters from instrumental analysis. Sensory attributes related to firm, gelled and spoonable textures could be predicted from all instrumental parameters with correlation coefficients as high as 0.95 to 0.97. When parameters from viscometry and oscillation analyses were omitted from the model leaving three parameters from spreadmeter analysis and texture analysis the correlation coefficients only dropped slightly to 0.93 to 0.94. This is useful information for food technologists having no access to a rheometer. Sensory attributes related to stringy texture and sticky and oily mouthfeel could not be predicted from instrumental data.

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