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Effects of fruit pulp and sucrose on the compression response of different polysaccharides gel systems

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Effects of addition of increasing proportions of peach pulp (10–40%) to three different polysaccharide gel systems — 0·75% kappa-carrageenan, 0·75% kappa-carrageenan plus 0·3% locust bean gum, and 1% alginate — on their compression behaviour were studied, both in the absence and presence of sucrose.

Addition of peach pulp to carrageenan-based gels decreased both the maximum rupture force and deformability modulus values but no effect was detected in alginate gels. When 55% sucrose was incorporated to carrageenan-based systems, pulp addition rendered weaker (less firm and less resistant to rupture) gels. In kappa-carrageenan plus locust bean gum mixed gels, where sucrose produced a clear loss of rupture resistance, pulp addition reinforced this negative sugar effect and very fragile gels were obtained. In alginate gels with incorporated sucrose, initially stronger than the corresponding water gels, pulp addition also produced decreases in both compression parameters, rendering gels still more resistant to rupture than those without sucrose but less firm than those when the pulp content was over 20%.

INTRODUCTION

Gelled sweet products are mainly represented by traditional jams and jellies gelled principally with high methoxyl pectins. However, more recently other novel products such as fruit bars, fabricated fruit pieces, desserts, snacks, are also formulated with fruit, sugar and combinations of one or more polysaccharide to get the desired texture, along with other functional and sensory characteristics (Glicksman, 1982; Tenn, 1985; Olivier *et al.*, 1988).

A great deal of information is available on the mechanical and rheological properties of different gel systems and on the texture modifications produced by the incorporation of other food components. More dispersed information can be found on the effect of sugars on these types of gel (Rey & Labuza, 1981; Steiner, 1983; Gerdes *et al.*, 1987; Oakenfull *et al.*, 1990). The authors have reported a drastic change in the mechanical properties of carrageenan–locust bean gum (LBG) mixed gels (0·5–1·0% total hydrocolloid concentration) when the sucrose content is higher than 50%, attributable to the formation of a glassy structure due to the combination of polysaccharides and sugars (Fiszman & Durán, 1989).

Less information is available on the effect of fruit content on gelled systems. The use of model systems, where the composition can be controlled and the interactions between the constituent molecules can be evaluated, may provide a more meaningful understanding of the correlation between functional properties of the system and the effects observed during manufacture of a specific product (Bernal *et al.*, 1987).

The objective of this work is to study the effect of different proportions of peach pulp on some mechanical properties of three model gelling systems — kappa-carrageenan, kappa-carrageenan plus LBG, and alginate — with and without sucrose. The effect of the addition of both ingredients — fruit pulp and sucrose — on the syneresis of the three systems was also evaluated.

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MATERIALS AND METHODS

Fruit pulp

Commercial canned peach halves were passed through a 1 mm orifice pulper obtaining a final product of 11° Brix and a pH value of 3·2. This pulp was added to samples at different proportions: 0, 10, 20, 30 and 40%.

Gelling systems

Three different gelling systems were tested: 0·75% kappa-carrageenan (Genugel UPC Type, Copenhagen Pectin Factory, Denmark), 0·75% kappa-carrageenan plus 0·3% LBG (Ceratonia, Hercules, Spain) and 1% alginate (Sobalg FD 155, Grinsted, M/G ratio approx. 1·5:1).

Samples preparation

Carrageenan based samples
Dry hydrocolloid powders were dispersed in deionised water or in a mixture of water and fruit pulp in the appropriate amounts. Solutions were boiled for 1 min to complete dissolution of the ingredients. Water lost by evaporation was replaced and solutions left to set. Gels were stored at 4–6°C and 100% relative humidity overnight.

The formulation was

Carrageenan	0·75 g
LBG (only in mixed gels)	0·30 g
KCl	0·50 g
Deionised water or a mixture of water and peach pulp up to	100·00 g

One set of samples was prepared with 55% sucrose — incorporated together with hydrocolloid powders — and another without sucrose.

Alginate based samples
Alginate solution was previously prepared under vigorous agitation. A slurry containing dicalcium phosphate dihydrate and sodium hexametaphosphate in deinoised water was added to the alginate solution. Separately, glucono-delta lactone was dissolved in the peach pulp and immediately added to the other components while agitating and left to gel. Samples were aged overnight.

The formulation was

Sodium alginate	1·00 g
Dicalcium phosphate dihydrate	0·70 g
Sodium hexametaphosphate	0·50 g
Glucono-delta lactone	1·25 g
Deionised water or a mixture of water and peach pulp up to	100·00 g

One set of samples was prepared with 40% sucrose — incorporated in the alginate solution — and another without sucrose.

Instrumental measurements

Stabilised gels were cut into 17 × 17 mm cylindrical probes as described by Durán *et al.* (1987). Samples were conditioned at room temperature (20 ± 2°C) before measurement.

Compression tests were performed with an Instron model 6021 using a 50 mm diameter plunger and a cross-head speed of 50 mm/min. Tests were conducted up to rupture of gels. Two parameters were recorded: maximum rupture force at the break point (F_{max}) expressed in N, and deformability or apparent Young's modulus (E_{ap}) measured between the compression curve points corresponding to 10 and 20% deformation and expressed in N/m^2. Triplicates of each sample were compressed.

Syneresis index

The extent of the exudate diffusion of recently cut cylindrical probes on a dried (105°C, 24 h) filter paper (Whatman No. 1) for 2 h was taken as a syneresis index of the gel samples. Results were expressed as the difference between the diameter of the wet area and the initial probe diameter (ΔD) in mm (Baidón *et al.*, 1987). Two replicates of each sample were tested.

Data treatment

ANOVA studies were applied to data obtained on compression parameters — F_{max} and E_{ap} — for each gelling system separately. Comparison of means was carried out by the Tukey studentised range method.

RESULTS AND DISCUSSION

The effects of peach pulp addition on the compression behaviour of three different hydrocolloid gels systems — kappa-carrageenan, kappa-carrageenan plus LBG, and alginate — were analysed both in the absence and presence of sucrose. The proportions of sucrose for each system were selected taking into account some previously obtained results: in kappa-carrageenan gels addition of increasing amounts of sucrose up to at least 60% improved gel strength and firmness while in kappa-carrageenan plus LBG mixed gels a fall in mechanical resistance was observed at concentrations around and over 50% sucrose (Fiszman & Durán, 1989); 55% sucrose was then considered convenient for analysing the effects of fruit pulp on these different systems. In the case of alginate, the results of a previous experiment showed that both resistance to rupture and

Table 1. Maximum rupture force (F_{max}) and deformability modulus (E_{ap}) values for 1% alginate gels with different sucrose concentrations[a]

Sucrose (%)	F_{max} (N)	E_{ap} (10^4 N/m^2)
10	20·5	9·8
20	26·2	10·0
30	31·1	14·6
40	36·0	18·4
50	33·4	18·0
60	27·7	16·8

[a]Mean values for three replicates.

firmness were improved by the addition of sucrose up to a concentration of 40% and then reduced (Table 1); consequently, this proportion of sugar was selected as it provided an alginate gel very different in mechanical properties from the corresponding water gels. Both sucrose concentrations chosen lay around the proportions commonly found in commercial fruit gels.

Kappa-carrageenan gels

Addition of peach pulp produced a clear weakening of 0·75% kappa-carrageenan gels (Fig. 1A). Resistance to rupture, represented by the F_{max} values, significantly decreased from 17·9 N, without pulp, to the range 1·3–2·3 N for 10 to 40% added pulp (Table 2). No significant differences were found within this range of pulp concentrations. When sucrose was present, nearly the same evolution pattern was observed, the difference being that here there was also a significant decrease in the F_{max} values from 10 to 40% pulp samples (pulp-sucrose interaction significant) so that at the higher pulp concentration no significant difference was shown between the gels with and without sucrose. Except at this point, maximum rupture force (F_{max}) values for sucrose containing gels were higher than those for gels without sucrose. These results qualitatively and quantitatively confirmed the data reported by the authors for kappa-carrageenan gels without pulp (Fiszman & Durán, 1989). As commented above, additions of peach pulp in increasing amounts weakened the gels, lowering the F_{max} values down to a point where this effect compensated for the strengthening effect of sucrose. Evolution of strain values at rupture followed a pattern similar to that of F_{max} values: gel deformation drastically decreased when adding fruit pulp in any proportion, both in the absence and presence of sucrose (Table 3).

A significant negative effect of the addition of fruit pulp on the gel apparent Young's modulus (E_{ap}) was shown throughout the entire concentration range studied, though the observed decrease from 0 to 10% pulp (ΔE_{ap} = 6·9 × 10^4 N/m^2) appeared to be higher than changes registered between 10 and 40% fruit (Fig. 2A).

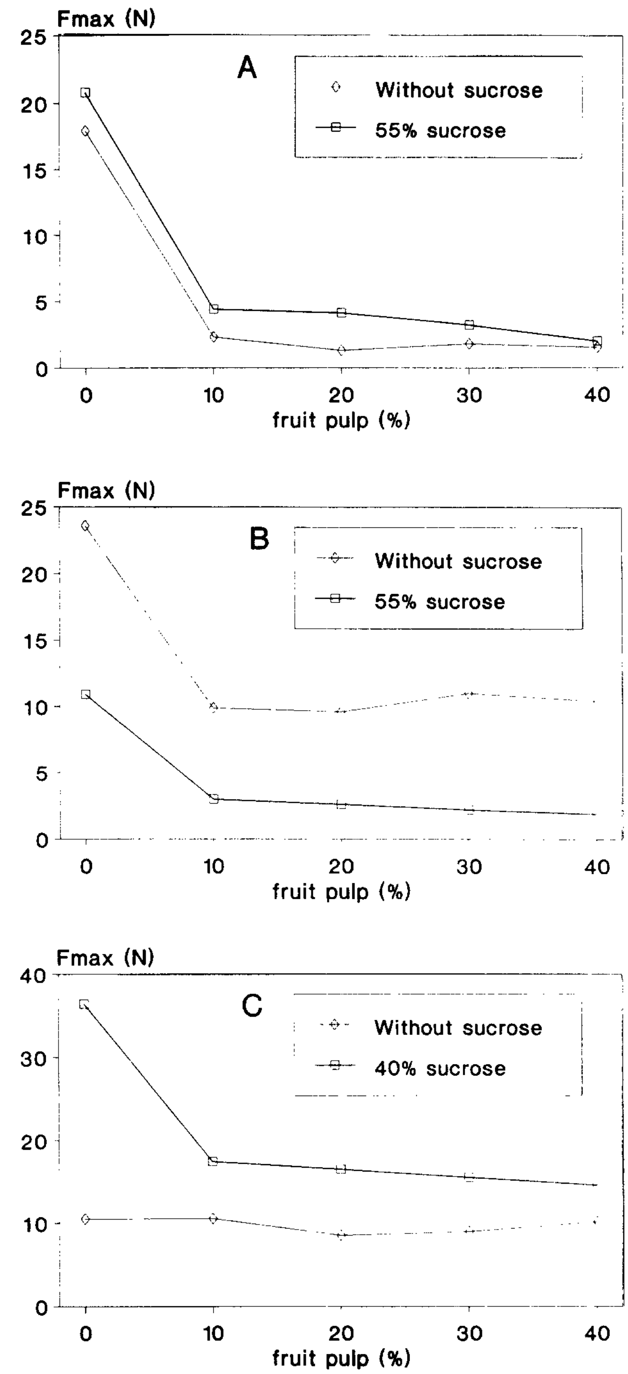

Fig. 1. The maximum rupture force (F_{max}) for three gelling systems with and without incorporated sucrose as a function of peach pulp content. (A) 0·75% kappa-carrageenan, (B) 0·75% kappa-carrageenan plus LBG, (C) 1% alginate.

A difference in deformability modulus in favour of kappa-carrageenan gels with sucrose was observed in the absence of fruit pulp. In sucrose gels, the weakening effect of fruit pulp addition on the gel firmness followed the same pattern as in water gels. In this case the positive effect of sucrose was maintained for all pulp contents (Fig. 2A).

Overall the effect of fruit pulp addition on compression parameters — F_{max} and E_{ap} — appeared to be similar to

Table 2. Statistical F values of the effects of fruit pulp (P), Sucrose (SUC) and their interaction on compression parameters in three gelling systems

Parameter	Effect	Carrageenan	Carrageenan + LBG	Alginate
F_{max}	P	1079[a]	307[a]	315[a]
	SUC	89[a]	1243[a]	1825[a]
	PxSUC	5[a]	18[a]	264[a]
E_{ap}	P	412[a]	—	107[a]
	SUC	436[a]	—	2[b]
	PxSUC	16[a]	—	88[a]

[a]Significant at $P < 0{\cdot}05$.
[b]Not significant.

that of cellulose fibres (Fiszman *et al.*, 1986). Cellulose particles or, in the present case, fruit tissue particles may interfere mechanically with hydrocolloid molecules in the formation of the basic carrageenan network. Low or zero variation of this effect on F_{max} values within the pulp concentration range studied may be explained by the relatively low variation in insoluble solids afforded by the fruit proportions added (assuming 0·5% in the peach pulp, the range will be 0·05–0·2% in final gels). The significant decrease in E_{ap} observed on increasing fruit pulp concentration from 10 to 40% showed that this parameter, that may be considered as a response of the gel network to deformations before rupture and related to other aspects of molecular structure (Mitchell, 1980; Fiszman *et al.*, 1983), was more sensitive than the ultimate strength to small variations in fruit particles content in the final product. Presence of sucrose in this gel system did not modify the above mentioned effects of fruit pulp; it simply improved both resistance to rupture and firmness of kappa-carrageenan–fruit gels, with pulp content up to 30%.

Kappa-carrageenan–LBG gels

Before analysing the effects of fruit pulp addition, attention should be paid to two important differences between these mixed gels and kappa-carrageenan only gels, that confirmed previous findings. The former gels showed more resistance to rupture and the addition of 55% sucrose to them produced a drastic fall in this parameter (Fig. 1B). The latter effect might be attributed to a defective hydration of gum molecules as a consequence of the strong water immobilising action of sucrose (Elfak *et al.*, 1977; Fiszman & Durán, 1990).

Effects of the addition of increasing amounts of peach pulp to this gel system, both in the absence and presence of sucrose, appeared to be qualitatively similar to those found in kappa-carrageenan gels (Fig. 1A and B). Only the decrease in F_{max} values, registered between 0 and 10% pulp content, was higher in water gels (ΔF_{max} = 13·7 N) than in sucrose gels (ΔF_{max} = 7·9 N), this being also significant. Accordingly, here again, pulp–sucrose interaction was significant, but the corresponding statistical F value was much lower than those for single effects (Table 2).

Table 3. Percent deformation at rupture for three gelling systems with addition of fruit pulp and sucrose[a]

Pulp (%)	Carrageenan	Carrageenan + LBG	Alginate
Without sucrose			
0	46	58	41
10	23	12	39
20	20	13	35
30	21	15	36
40	20	14	36
With sucrose			
0	51	32	52
10	33	18	44
20	21	19	45
30	24	19	47
40	20	23	48

[a]Mean values for three replications.

The weakening effect of pulp in this mixed gel system may be explained as for carrageenan gels. It is also important to observe that the negative effect of pulp addition did not completely counterbalance the reinforcing effect of the gum: F_{max} values for mixed gels with fruit pulp were around 10 N while this parameter for kappa-carrageenan gels were around 2 N. However, in the presence of sucrose, the summation of two weakening effects made the F_{max} values for mixed gels with pulp slightly lower than those for only carrageenan gels (Fig. 1A and B). As expected, deformation of carrageenan plus LBG gels was higher than that of only carrageenan gels (58 and 46% respectively) (Table 3). In contrast, a stronger effect of the addition of fruit pulp was observed in mixed gels, final strain values being lower than in carrageenan gels (14% as compared with 20%).

Apparent Young's modulus (E_{ap}) values (programmed to be measured between 10 and 20% deformation) were

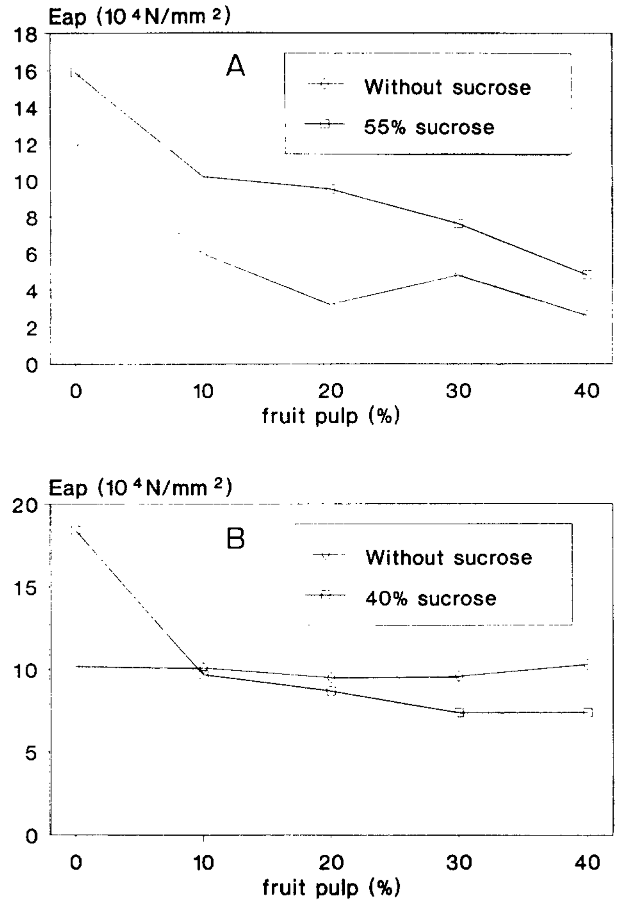

Fig. 2. The deformability modulus (E_{ap}) for two gelling systems with and without incorporated sucrose as a function of peach pulp content. (A) 0·75% kappa-carrageenan, (B) 1% alginate.

not obtained because, as commented above, the gels containing pulp broke before attaining 20% deformation.

Alginate gels

Addition of peach pulp produced no effect on the resistance to rupture of 1% alginate gels at any of the studied concentrations. However, in the much stronger gels obtained when 40% sucrose was added (F_{max} = 36·8 N), incorporation of 10% pulp reduced the F_{max} values down to 17·4 N. A small but significant decrease was also shown between 10 and 40% fruit content (ΔF_{max} = 2·3 N) (Fig. 1C). In spite of this big fall, F_{max} values for sucrose gels continued to be higher than those for water gels up to the highest fruit pulp content studied (40%). Strain values at rupture were not apparently affected by pulp addition but sucrose produced the expected increase (Table 3).

A similar pattern of change was found for the modulus of deformability, with the important difference that here the decrease in E_{ap} values produced by pulp addition to sucrose gels reduced this parameter to values similar and at high levels of pulp addition even lower than those found with corresponding water gels (Fig. 2B). As a consequence, though the registered decrease in E_{ap} between 0 and 10% pulp samples in sucrose gels was large in contrast with the zero change in water gels, the overall effect of sucrose was not significant as shown in the ANOVA study (Table 2).

The absence of the effect of fruit pulp addition on the compression behaviour of alginate gels might be explained by assuming that the expected mechanical interference of fruit tissue particles could be compensated by the reinforcing effect of pectin molecules afforded by them once dispersed in the medium. It is well known that pectin and alginate molecules interact (Thom *et al.*, 1982; Oakenfull *et al.*, 1990) and may improve texture of fruit products containing alginate (Toft, 1982). Another explanation of the observed phenomenon could be that increasing pulp concentration should mean a decrease in pH values and consequently more calcium ion release. Maximum decrease in pH was only 0·2 units; further research is needed to confirm or reject this hypothesis.

As commented above, on adding sucrose to 1% alginate gels, a maximum F_{max} value was obtained at a sucrose concentration of 40%. This result seems to indicate that the amount of water immobilised by sucrose is at the optimum for favouring gel formation; further addition of sugar or of any other ingredient that could 'structure' water would be detrimental for network formation. Addition of fruit components could possibly have such an effect on the mechanical properties of alginate gels with a critical proportion of sucrose.

Effect of fruit pulp on gel syneresis

The degree of syneresis is frequently taken as an indication of gel network stability. In contrast with the different effects of pulp addition on the compression response of the various systems studied, measurement of the extent of syneresis at extreme composition samples showed that fruit pulp addition reduced somewhat the amount of exudate in all cases, this reduction always being lower than that produced by the addition of sucrose (Table 4).

In general terms, it can be said that fruit tissue particles reduce the strength of the hydrocolloids network but may help in the stabilisation of the whole gel system by binding more water. Further information would be necessary to support or reject this hypothesis.

CONCLUSIONS

Influence of peach pulp addition on the compression behaviour of fruit gels was qualitatively and

Table 4. Syneresis index values (ΔD) for three gelling systems with addition of fruit pulp and sucrose

System	Pulp (%)	Sucrose (%)	ΔD (mm)
Carrageenan	10	0	83
	40	0	65
	10	55	17
	40	55	9
Carrageenan + LBG	10	0	70
	40	0	53
	10	55	22
	40	55	9
Alginate	10	0	77
	40	0	65
	10	40	16
	40	40	12

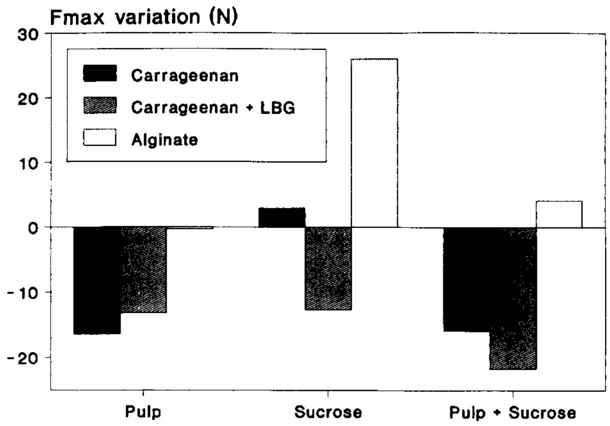

Fig. 3. Variations in maximum rupture force (F_{max}) produced by addition of peach pulp (40%), of sucrose (55% in either carrageenan or carrageenan plus LBG gels and 40% in alginate gels) and of both ingredients in the three gelling systems.

quantitatively different depending on the nature of the hydrocolloid gel system studied. Fruit particles interfered with hydrocolloid molecules in gel formation in carrageenan-based systems, rendering weaker (less firm and less resistant to rupture) gels at any of the concentrations assayed (10–40%) but they did not alter the resistance to rupture nor the deformability modulus in alginate gels.

In kappa-carrageenan gels with added sucrose, the effects of pulp on both compression parameters were parallel to those observed in gels without sucrose, absolute values being almost always higher in sugar gels. In kappa-carrageenan-LBG mixed gels, where the presence of sucrose produced a clear loss of rupture resistance, pulp addition to the system reinforced the negative sugar effect and very fragile gels were obtained. In alginate gels with incorporated sucrose, initially stronger than the corresponding water gels, pulp addition produced decreases in both parameters rendering gels still more resistant to rupture than those without sugar but less firm than those when the pulp content was over 20% (Fig. 3).

The different observed effects of fruit pulp addition on the different gel systems studied are difficult to interpret at a molecular level mainly because of the complex structure and composition of the fruit particles incorporated in the gelling system. A mechanical interference in the hydrocolloid network formation might be assumed though chemical effects like pectin-alginate association could play a role in alginate based systems.

Systematic knowledge of these effects are of direct practical interest for gelled fruit product formulation.

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REFERENCES

Baidón, S., Fiszman, S.M., Costell, E. & Durán, L. (1987). Sinéresis de los geles de agar y de kappa carragenato. Influencia de la adición de gomas de garrofín y de guar. *Rev. Agroquím. Tecnol. Aliment.* **27**, 545–55.

Bernal, V.M., Smajda, C.H., Smith, J.L. & Stanley, D.W. (1987). Interactions in protein/polysaccharide/calcium gels. *J. Fd. Sci.*, **52**, 1121–5, 1136.

Durán, L., Costell, E. & Fiszman, S.M. (1987). Collaborative compression tests on gels. In *Physical Properties of Foods — 2* ed. R. Jowitt, F. Escher, B. McKenna & M. Roques. Essex, Elsevier Applied Science Publishers Ltd, London, pp. 429–43.

Elfak, A.M., Pass, G., Phillips, G.O. & Morley, R.G. (1977). The viscosity of dilute solutions of guar and locust bean gum with and without added sugar. *J. Sci. Fd. Agric.*, **28**, 895–9.

Fiszman, S.M. & Durán, L. (1989). Mechanical properties of kappa carrageenan-locust bean gum mixed gels with added sucrose. *Food Hydrocolloids*, **3**, 209–16.

Fiszman, S.M. & Durán, L. (1990). Mechanical behaviour of fruit gels. Effect of fruit content on the response of kappa carrageenan-locust bean gum mixed gels with sucrose. In *Gums and Stabilisers for the Food Industries — 5*, ed. G.O. Phillips, D.J. Wedlock & P.A. Williams, Oxford, IRL Press, Oxford, pp. 545–8.

Fiszman, S.M., Costell, E. & Durán, L. (1983). Comportamiento reológico de los geles de agar con adición de sacarosa y de fibra. Ensayos de compresión. *Rev. Agroquím. Tecnol. Aliment.*, **23**, 378–86.

Fiszman, S.M., Costell, E. & Durán, L. (1986). Effects of addition of sucrose and cellulose on the compression behaviour of kappa carrageenan gels. *Food Hydrocolloids*, **1**, 113–20.

Gerdes, D.L., Burns, E.E. & Harrow, L.S. (1987). Some effects of gelling agents and sweeteners on high and low sugar content carbohydrate gels. *Lebensm.-Wiss. u. Technol.*, **20**, 282–6.

Glicksman, M. (1982). The hydrocolloids industry in the 80's — problems and opportunities. *Prog. Fd. Nutr. Sci.*, **6**, 299–321.

Mitchell, J. R. (1980). The rheology of gels. *J. Text. Stud.*, **11**, 315–37.

Oakenfull, D., Scott, A. & Chai, E. (1990). The mechanism of formation of mixed gels by high methoxyl pectins and alginates. In *Gums and Stabilisers for the Food Industry* — 5, ed. G.O. Phillips, D.J. Wedlock & P.A. Williams, Oxford, IRL Press, Oxford, pp. 243–6.

Olivier, D., Guigou, B. & Bouillette, T. (1988). Produit alimentaire reconstitué, procédé et mélanger pour sa préparation. European Patent Application EP 0274301 A1.

Rey, D.K. & Labuza, T.P. (1981). Characterization of the effect of solutes on the water-binding and gel strength properties of carrageenan *J. Food Sci.*, **46**, 786–9, 793.

Steiner, E.H. (1983). Stability of food gels. A: Physical properties of gels and gelling agents. British Food Manufacturing Industries Research Association Bulletin No. 402, BMFIRA, London.

Tenn, F.E. (1985). Fruit filler for pastry products and process for its preparation. United States Patent, US 4562080.

Thom, D., Dea, I.C.M., Morris, E.R. & Powell, D.A. (1982). Interchain associations of alginate and pectins. *Prog. Food Nutr. Sci.*, **6**, 97–108.

Toft, K. (1982). Interactions between pectins and alginates. *Prog. Food Nutr. Sci.*, **6**, 89–96.