RHEOLOGY OF WHEY PROTEIN SOLUTIONS AND GELS

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TYPOGRAPHICAL AMENDMENTS

Page

ix	Line 2: for "comparison" read "comparisons"
xxiii	Line 8: for "in press" read "349-361"
5	Line 5: for "compositions" read "composition"
5	Line 4 from bottom: for "with" read "and"
10	Line 9: for "that whey" read "that when whey"
11	Line 7 from bottom: for "theory on" read "theory based on"
11	Last line: for "from" read "form"
12	Line 10 from bottom: for "Flory-Stockmayer" read "Flory and Stockmayer"
31	Line 5: for "surface" read "surfaces"
38	Line 14: for "3.2 (Data provided" read "3.2. (Data were provided".
40	Line 8 from bottom: for "section" read "Section"
45	Last line: for "thick depth" read "deep"
46	Line 4 from bottom: for "rigidity E_t" read "rigidity, E_t"
57	Last line: for "can change" read "changed"
58	Line 7 from bottom: for "Table 2" read "Table 4.2"
104	Line 12 from bottom: for "highest" read "observed maxima"
105	Line 13: for "staff" read "start"
106	Legend on x-axis of Fig. 6.14: for "pH above" read "pH well above"
114	Line 3: for "form 7 to 9" read "from 7 to 9."
120	Line 2: for "$CaCl^2$," read "$CaCl_2$"
	Line 16: for "difference" read "differences"
124	Line 8: for "toward the end" read "for the subsequent duration"
125	Line 7 from bottom: for "experiment" read "experiments"
130	Line 2: for "widen" read "wider"
135	Legend on x-axis of Fig 8.10: for "(C/C_m - 1), (%,w/w)" read "(C/C_m -1)"
136	Line 8: for "was quoted" read "is given"
	Line 9: delete "has been"
	Line 12 from bottom: for "occur" read "occurs"
	Line 4 from bottom: for "be" read "lie"
142	Line 5: for "paper" read "work"
	Line 9 from bottom: for "comparison" read "comparisons"
	Line 6 from bottom: for "above" read "in Chapter 3"
144	Line 2: for "On" read "In"
154	Line 7: for "solution" read "solutions"
	Line 6 from bottom: delete "all"
155	Line 5: for "high" read "higher"
156	Line 11 from bottom: for "straight forward" read "straightforward"

Abstract

The use of whey protein products in foods is governed by their nutritional and functional properties. Whey protein products have increasingly been applied in a variety of food systems as functional ingredients. In order to boost applications of whey protein products and to improve, predict and control their functional attributes in food products knowledge is required about how they behave functionally under different conditions, *e.g.* when product composition, processing history, protein concentration, pH, salt concentration and temperature vary.

The flow properties of whey protein concentrate solutions were studied in a Bohlin rheometer. The effects of protein concentration, temperature, pH and salts on the gelation and gel properties of whey protein concentrates and whey protein isolate were also investigated in the same rheometer. Differences in gelation between whey protein concentrates, whey protein isolate, egg white and ß-lactoglobulin were studied. Differences between dynamic shear properties determined in a Bohlin rheometer and fracture properties determined in an Instron universal testing machine were also studied.

The flow properties of whey protein concentrate solutions changed from Newtonian to pseudoplastic or even thixotropic behaviour, owing to structure formation in the solutions, *i.e.* to increases in protein intermolecular interactions. Such structure formation resulted from increases in protein concentration, temperature or $CaCl_2$ concentration, and from shifting the pH to extreme values.

Gelation of whey protein was dependent on protein concentration, gelation temperature, pH, salt content and lactose content. Salt content was the most important factor in determining the gelling properties of various whey protein concentrate products and whey protein isolate. Consistent gelling properties could only be achieved when salt content was carefully controlled. The degree of protein denaturation and lactose content also led to differences in gelling behaviour of whey protein concentrates.

Whey protein products, when compared with egg white, had a higher gelation

temperature, a higher minimum protein concentration for gelation, lower initial gelation rate and lower gel stiffness. The differences in initial gelation rate and gel stiffness could be compensated by adjustment of the salt content of whey protein products.

Dynamic viscoelastic measurements on whey protein isolate gels in the region of the sol-gel transition exhibited simple power law relationships between the storage (G') and loss (G") moduli and frequency as $G' \propto \omega^{0.54\pm0.02}$ and $G'' \propto \omega^{0.51\pm0.02}$, indicating that the gel in the region of the sol-gel transition could have the geometry of a fractal. The critical exponents calculated from the protein concentration dependence of gelation time and from the site percolation model indicated that the gelation of whey protein is a realization of a percolation process.

Compression rigidity modulus (E_c), penetration rigidity (E_p), tension rigidity (E_t) and storage modulus G' all exhibited a similar pattern of variation with pH. G', E_c, E_p and E_t, which were not closely related to the fracture properties and hardness of whey protein concentrate gels, were controlled by electrostatic interactions. The fracture forces and hardness were determined by both disulphide bonds and electrostatic interactions, while fracture strains were mainly controlled by disulphide bonds.

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List of Publications

The results of this work have been or will be published in part in the following papers.

1. TANG, Q., McCARTHY, O. J. and MUNRO, P. A. 1993. Oscillatory rheological study of the gelation mechanism of whey protein concentrate solutions: effects of physicochemical variables on gel formation. *Journal of Dairy Research* **60**, 543-555.

2. TANG, Q., MUNRO, P. A. and McCARTHY, O. J. 1993. Rheology of whey protein concentrate solutions as a function of concentration, temperature, pH and salt concentration. *Journal of Dairy Research* **60**, in press.

3. TANG, Q., McCARTHY, O. J. and MUNRO, P. A. 1993. Oscillatory rheological characterization of the effects of pH and salts on gel formation in whey protein concentrate solutions. *Journal of Dairy Research*, draft manuscript submitted to supervisors for correction.

4. TANG, Q., McCARTHY, O. J. and MUNRO, P. A. 1993. Gelation of whey proteins: sol-gel transition and critical behaviour of the rheological properties. *Food Hydrocolloids*, draft manuscript submitted to supervisors for correction.

5. TANG, Q., McCARTHY, O. J. and MUNRO, P. A. 1993. Rheological study of gelation of egg white, whey protein concentrates, whey protein isolate and ß-Lactoglobulin. *Journal of Agricultural and Food Chemistry*, draft manuscript submitted to supervisors for correction.

6. TANG, Q., McCARTHY, O. J. and MUNRO, P. A. 1993. pH dependence of whey protein concentrate gel properties: comparison of small deformation (dynamic) and large deformation (failure) testing. *Journal of Texture Studies*, draft manuscript submitted to supervisors for correction.

Abbreviations

EWP	Egg White Powder
TPA	Texture Profile Analysis
TS	total solids
WPC	whey protein concentrate
WPI	whey protein isolate
NZDRI	New Zealand Dairy Research Institute
NZDB	New Zealand Dairy Board
ß-Lg	ß-lactoglobulin powder containing 92% ß-lactoglobulin