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EMULSIFYING AND FOAMING PROPERTIES OF WHEY PROTEIN CONCENTRATES IN THE PRESENCE OF SOME CARBOHYDRATES.

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ABSTRACT

Carbohydrates (glucose, sucrose, fructose, starch and inulin) were added to whey protein concentrates at the ratios of 1, 2 and 3%. The emulsifying and foaming properties of WPC-carbohydrates model systems were examined. 1% of the tested carbohydrates increased significantly ($P < 0.05$) the emulsion activity index (EAI) and emulsion stability index (ESI) of the prepared emulsions. Sucrose showed the highest EAI and ESI followed by fructose, glucose, starch and inulin compared with samples without carbohydrates. Increasing of added starch and inulin to 2 or 3% improved emulsion activity index but decreased emulsion stability index compared to other sugars. Sucrose addition resulted in significant ($P<0.05$) increase in foam stability compared with other carbohydrates, while starch and inulin showed insignificant ($P>0.05$) changes in foam formation or stability.
Keywords: Whey protein, Carbohydrates, Emulsification, Foaming properties

INTRODUCTION

Whey proteins are applied as food ingredients in formulating products due to their nutritional & health benefits (Bryant and McClements 1998; Harper, 2000; Hudson, et al., 2000). Also, whey proteins are widely used as food ingredients because of their good functional properties (Morr and Eyw, 1993). An important functional property of whey proteins is their foaming capacity and formation and stability of emulsions (Dickinson, 2001 and Kinsella & Whitehead, 1989). The quality and functionality of whey protein concentrates depend on the source of cheese and process history (Caric, 1994; Huffman & Harper, 1999; De La Fuente, et al., 2002 and Ji & Haque, 2003). Final processing steps (ultrafiltration technique) improve protein functionality (foaming and emulsifying properties).

Foam formation is a basic step in the manufacture of many foods including cake, bread, ice cream and confectionary products (Campbell and Moougeot, 1999). Producing foam involves the generation of a protein film surrounding a gas bubble and the packaging of gas bubbles into an overall structure. Subsequently, formed foams undergo coalescence and disproportionation (Foegeding et al, 2006).

In Food emulsions, the whey proteins act in the formation and stabilization of the system by adsorption on the oil droplet surface where they form a film that protects the droplets against coalescence. The stability of formed emulsion depends on the continuous phase or the processing and storage conditions. The adsorbed protein molecules may become involved in droplet interactions and affect the product creaming behaviour and its rheological characteristics (Demetriades et al., 1997; and Hunt & Dalgleish, 1994). Emulsions stability against heating at different pH degree and NaCl content was investigated by Kulmyrzaev et al., (2000) and Damianou & Kiosseoglou (2006).

The most popular sugars that can be used in preparing desserts like pudding or ice cream are sucrose, glucose and fructose. Corn starch is applied in food industry as a thickening agent in desserts and pudding. Starch is often used in combination with other ingredients such as milk in pudding and custard (Master and Steeneken, 1997). Rheological properties of starch-milk-sugar systems as affected by starch concentration, sugar type and concentration, milk fat content and heating temperature have been studied by Abu-Jdayil, et al., (2004 a, b) and Mohameed et al., (2006). Inulin has been available as an ingredient for application in food industry where it is used in fat replacement especially in combination with high intensity sweeteners (Flamm et al., 2001 and Kip et al., 2006).

Interaction between proteins and polysaccharides may result in formation of complex with substantially improved emulsifying characteristic (Tesch et al., 2002; Akhtar & Dickinson, 2003; Neirynck et al., 2004; and Einhorn-Stoll et al., 2005) together with significantly improved foaming and rheological properties (Mishra et al., 2001; Tavares & Lopes da Silva, 2003; Giroux & Britten, 2004 and Sanchez et al., 2005).

The aim of the present work was to investigate the foaming and emulsifying properties of whey protein concentrates in the presence of some carbohydrates (glucose, sucrose, fructose, starch and Inulin).

MATERIALS AND METHODS

Sweet whey from Edam cheese manufacture was obtained from Arab Dairy Co., Kaha, kalubia, Egypt. Fat was removed from the whey by a whey cream separator.

Whey was clarified by filtration with cloth and directly concentrated by ultrafiltration to a volumetric concentration factor 20 using a 50 000 molecular weight cut off zirconium oxide membrane installed in a Carbosep pilot plant (modules 151 UF system, Nova-sep, France). Ultrafiltration was carried out in a batch mode at 45-50°C, inlet and outlet pressure of 6 and 3.5 bar, respectively. Diafiltration was continued for resulted whey protein concentrate four times to remove most of lactose contents. Obtained whey protein concentrates was adjusted to pH 6.7 before use.

- Glucose and Fructose were obtained from Merck, KGaA 64271 Darmstadt, Germany,sucrose from Sigma, Aldrich, INC, 3050 Spruce st., st. Louis, Mo63103 USA.,starch purchased from local market produced by National Co. for maize products 10th of Ramadan Cairo Egypt,inulin from Hopkin and Williams Chadwell Heath Essex England, Sunflower oil purchased from local market produced by ARMA oils Co., 10th of Ramadan Cairo Egypt.
- The Chemical composition of prepared whey protein concentrate was determined, total solids (TS) according to AOAC (1990); Total protein, and pH according to Ling 1963. The prepared WPC solution was 11.6% total solids, 10.7% total protein and 6.6 pH .

Whey protein concentrate solution were analysed by the turbidmetric technique for emulsion activity index (EAI) and emulsion stability index (ESI) as described (Webb et al., 2002). Emulsions were prepared with 3% whey protein concentrate solution using 10 ml of sunflower oil by blended using a high speed blender (Hamilton Beach Model 600 AL Almond USA) for 90 sec, and then passed through QP laboratory homogenizer at 500 Psi at room temperature. Immediately after emulsion preparation 1 ml of the formed emulsion was diluted with 0.1% SDS solution in 1 liter. The absorbance of the diluted solution was measured by spectrophotometer (SP-UV 2000, Taiwan) at 500 nm in 1 cm path length cuvettes. The absorbance was read initially and turbidity and EAI were calculated by the following formula:

T = 2.303 A/I
Where T = turbidity
A = absorbance at 500 nm.
I = path length of cuvette (m).
The emulsion activity index EAI was then calculated as:
EAI = 2 (T)/ ϕC
Where T = turbidity (calculated from above equation
ϕ = oil volume fraction (ml).
C = The weight of protein per unit volume g/ml of the protein aqueous phase before emulsion formation.

The emulsions were held at 4°C for 24, 48 and 72 hrs and reanalyzed for emulsion stability(ESI) as described previously.

Foaming properties were detected when carbohydrates were added to whey protein concentrates to obtained final composition of 10% dry matter containing 1, 2 and 3% of carbohydrates as model systems (Table 1).

Table: 1 Model system prepared for foaming properties

Model system	WPC %	Carbohydrates %	Final dry matter %	pH
Control	10	0	10	6.60
WPC-Glucose	9	1	10	6.63
	8	2	10	6.66
	7	3	10	6.58
WPC-Sucrose	9	1	10	6.64
	8	2	10	6.66
	7	3	10	6.59
WPC-Fructose	9	1	10	6.63
	8	2	10	6.66
	7	3	10	6.60
WPC-Starch	9	1	10	6.60
	8	2	10	6.62
	7	3	10	6.61
WPC-Inulin	9	1	10	6.62
	8	2	10	6.61
	7	3	10	6.60

Foam expansion was examined in 50 ml of model systems being whipped at room temperature using Blender (Hamilton Beach Model 600 AL Almond USA) at speed setting 1 whipp for 5 min Foam expansion % was calculated by the following formula (Poole 1989):

Foam expansion %

$$= \frac{\text{Total volume of foam including liquid (ml)- Initial liquid volume (ml)}}{\text{Initial liquid volume (ml)}} \times 100$$

Foam stability was measured at 2 min intervals for 50 min according to decrease of foam volume over time (Abd El-Salam et al. 2007).
All experimental was replicated three times.

The data were analyzed according to Statistical Analysis System (SAS, 1998). Duncan multiple range test (Duncan, 1955) was carried out for separation among means.

RESULTS AND DISCUSSION

Emulsion activity index (EAI) increased significantly (P<0.05) for all model systems with different carbohydrates addition at 1% (Table 2). Sucrose showed the highest EAI of 417.6 m^2/g followed by starch, inulin, fructose and glucose of 403.8, 403.8, 377.7 and 377.7 m^2/g compared with model prepared without carbohydrate addition of 354.6 m^2/g, respectively.

Table (2): Surface diameter (m^2/g) of WPC-emulsions as affected by 1% carbohydrates addition.

	Emulsion capacity (EAI)	**Emulsion Stability (ESI)**		
Carbohydrate type	0 Time	24 hr2	48 hrs	72 hrs
Control	354.6^{af}	181.2^{bh}	168.8^{bch}	145.8^{ch}
WPC-Glucose	377.7^{af}	275.5^{bef}	230.3^{cf}	190.4^{df}
WPC_Sucrose	417.6^{ae}	288.6^{be}	261.0^{ce}	230.3^{de}
WPC-Fructose	377.7^{af}	282.5^{be}	211.9^{cg}	190.3^{df}
WPC-Starch	403.8^{ae}	265.6^{bf}	208.9^{cg}	179.6^{dfg}
WPC-Inulin	403.8^{ae}	236.4^{bg}	181.2^{ch}	165.8^{cg}

Means with different superscripts in the same column are significant (a,b,c and d) (P<0.05).
Means with different superscripts in the same raw are significant (e,f,g and h) (P<0.05).

Also, sucrose showed the highest ESI emulsion stability index after 72 hrs. It was of 230.3 m^2/g followed by fructose, glucose, starch and inulin of 190.3, 190.4, 179.6 and 165.8 m^2/g, respectively, compared with control of 145.8 m^2/g .

Starch addition of 2% increased significantly EAI to 443.7 m2/g (Table 3). On contrast WPC-Sucrose displayed more ESI than WPC-starch at the same ratio of addition. Other sugars addition showed slightly increase but not significant (P < 0.05) in both EAI and ESI.

Further increase of carbohydrates addition to 3% was shown in Table 4. Although increasing of starch and inulin up to 3% addition to WPC have increased emulsion activity index EAI, they decreased emulsion stability index ESI compared to other sugars, sucrose and fructose. Thus because partial aggregation of oil droplets. Polysaccharides, present in continuous emulsion phase caused reversible depletion and flocculation leading to fast serum separation and consequently decreased emulsion stability (Dickinson et al., 1994). That effect can also be explained by the size of added molecules which obstructed protein propagation on oil-water interface (Kim et al 2003).

Table (3): Surface diameter (m^2/g) of WPC-emulsions as affected by 2% carbohydrates addition.

	Emulsion capacity (EAI)	Emulsion Stability (ESI)		
Carbohydrate type	**0 Time**	**24 hr2**	**48 hrs**	**72 hrs**
Control	354.6^{ah}	181.2^{bg}	168.8^{bf}	145.8^{ch}
WPC-Glucose	382.3^{agh}	250.3^{bf}	208.9^{ce}	199.6^{ce}
WPC_Sucrose	391.5^{agh}	257.9^{bf}	211.9^{ce}	205.7^{ce}
WPC-Fructose	428.3^{ae}	261.0^{bf}	221.1^{ce}	196.5^{def}
WPC-Starch	443.7^{ae}	285.6^{be}	218.0^{ce}	187.3^{dfg}
WPC-Inulin	408.3^{aeg}	265.6^{bf}	208.9^{ce}	179.6^{dg}

Means with different superscripts in the same column are significant (a,b,c and d) (P<0.05).
Means with different superscripts in the same raw are significant (e,f,g and h) (P<0.05).

Table (4): Surface diameter (m^2/g) of WPC-emulsions as affected by 3% carbohydrates addition.

	Emulsion capacity (EAI)	Emulsion Stability (ESI)		
Carbohydrate	**Time**	**24 hr2**	**48 hrs**	**72 hrs**
Control	354.6^{bh}	181.2^{bh}	168.8^{bcf}	145.8^{ch}
WPC-Glucose	383.8^{agh}	277.9^{bfg}	219.5^{ce}	207.3^{cefg}
WPC_Sucrose	402.2^{aeg}	317.8^{be}	225.7^{ce}	218.0^{ce}
WPC-Fructose	373.1^{ah}	273.3^{bg}	225.7^{ce}	213.4^{cef}
WPC-Starch	429.9^{ae}	393.2^{bf}	230.3^{ce}	199.6^{dfg}
WPC-Inulin	420.7^{aef}	296.3^{bf}	216.4^{ce}	193.4^{dg}

Means with different superscripts in the same column are significant (a,b,c and d) (P<0.05).
Means with different superscripts in the same raw are significant (e,f,g and h) (P<0.05).

However, Disaccharides, sucrose and fructose, addition caused emulsion stability to increased significantly (P<0.05) because of interactions with proteins, resulted in formation of a system with improved emulsifying properties (Semenova et al., 2002). Also, proteins mainly stabilized emulsion droplets with electrostatic repulsive forces (McClements, 2001 and Tesch et al., 2002).

The foam expansion percent of whey protein concentrate (WPC) with carbohydrates addition are shown in Table 5.

Table 5: Foam expansion % of WPC with different ratio of carbohydrates addition

Carbohydrate ratio %	1	2	3
Carbohydrate Type			
Control	72	76	76
WPC-Glucose	92	72	78
WPC- Sucrose	98	96	88
WPC- Fructose	80	100	92
WPC-Starch	76	94	80
WPC-Inulin	84	90	90

Sucrose displayed the best foaming expansion of 98% followed by glucose and inulin at addition ratio 1%. Increasing the addition ratio of carbohydrates to 2% enhancing foam expansion for fructose, starch and inulin. Fructose showed the largest foam expansion of 100% followed by starch and inulin of 94 and 90%, respectively. Further increasing of carbohydrates ratio to 3% had negligible effect on foam expansion for all samples. Dalgleish (1997) reported that whey proteins forming a strong lamellar layer between air cells, resulting in stable foam.

Foaming stability of WPC with carbohydrates addition of 1% was shown in Fig. 1.

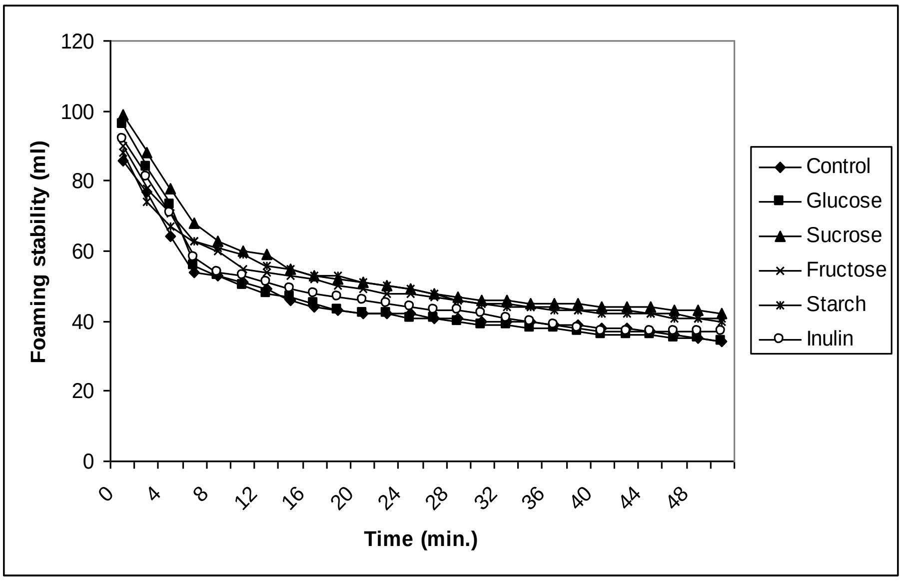

Fig. 1: Foam stability of WPC as affected by carbohydrates addition (1%).

Addition of sucrose at 1% showed the largest foam stability compared with other sugars or control followed by fructose, starch and inulin. Effect of increasing carbohydrates to 2 or 3% on the foam stability of WPC are shown in Fig 2 and 3 respectively.

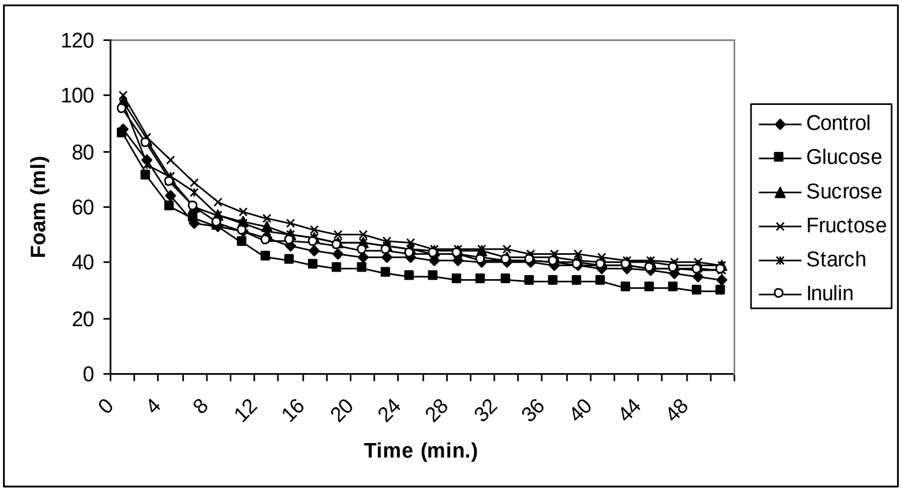

Fig. 2: Foam stability of WPC as affected by carbohydrates addition (2%)

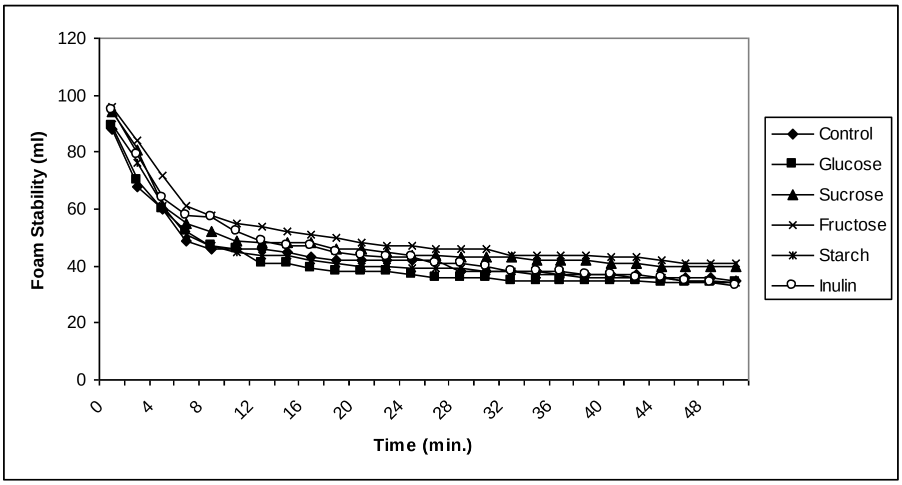

Fig. 3: Foam stability of WPC as affected by carbohydrates addition (3%)

WPC with starch and inulin addition of 2% showed improvement in the foaming stability. The positive effect of carbohydrates addition on foam stability was most evident in sucrose and fructose at 1% ratio, while starch and inulin are more slightly foam stable especially during 10 min from foaming formation, but statistically insignificant. These results agree with the finding of Herceg et al (2007). Bos & Van vliet, (2001) stated that sugars and polysaccharides have no affinity for air-water interface, but they encourage for protein-protein interactions, which leads to development of multilayer cohesive protein film at interface, which prevents foam collapase and enables formation of more stable foam (Adebowale & Lawal, 2003).

CONCLUSIONS

Sucrose displayed the best foaming expansion followed by glucose and inulin at addition ratio 1%. Fructose showed the best foam expansion at addition ratio of 2%. Emulsion activity index EAI and emulsion stability index ESI have increased significantly as affected by addition of carbohydrates to whey proteins concentrates. Sucrose-WPC and fructose-WPC showed the highest values of EAI and ASI compared with control or with other types of sugars. Starch and inulin-WPC improved EAI but they showed lowest ESI values compared with other carbohydrates addition.

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دراسة خواص الاستحلاب و الرغوة لمركزات بروتينات الشرش المضاف اليها بعض انواع الكربوهيدرات

عاطف فراج
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تم تحضير مركزات بروتينات الشرش وذلك من تركيز الشرش الناتج من صناعة الجبن الإيدام وذلك باستخدام طريقة الترشيح الفائق Ultrafiltration ثم تم عمل Diafiltration للتخلص من معظم سكر اللاكتوز الموجود بالشرش وكان تركيب مركز بروتينات الشرش المتحصل عليه يحتوي علي ١١,٦% جوامد كلية ، ١٠,٧% بروتين ، وكانت نسبة البروتين /الجوامد الكلية ٩٢,٢٤% . بعد ذلك تم إضافة بعض انواع الكربوهيدرات مثل الجلوكوز ، السكروز ، الفركتوز ، النشا ، الإينولين بنسب ١ ، ٢ ، ٣% ثم دراسة خاصتي الإستحلاب وتكوين الرغوة لهذه المركزات كأنظمة غذائية وكانت النتائج المتحصل عليها كالتالي:

- أدي اضافة ١% من كل انواع السكريات المضافة الى وجود زيادة معنوية لكل من درجة الإستحلاب Emulsification capacity (EAI) وكذلك درجة ثبات المستحلبات المتكونة Emulsification stability (ESI) مقارنة بالعينات التي لم يضاف اليها الكربوهيدرات.
- أظهر إضافة سكر السكروز زيادة واضحة في درجة تكوين المستحلب ال EAI يليه كل من الفركتوز ثم الجلوكوز ثم النشا وأخيرا الإينولين.
- أدي زيادة نسبة إضافة كل من النشا والإينولين الى ٢ ، ٣% الى تحسين خاصية تكوين المستحلب EAI ولكنها ادت الي انخفاض درجة ثبات هذه المستحلبات ال ESI بعد مرور ٧٢ ساعة وذلك مقارنة بالسكريات الأخري المضافة.
- أدي إضافة سكر السكروز الى زيادة معنوية في درجة تكوين الرغوة مقارنة بالسكريات الأخري المضافة
- أظهر إضافة كل من النشا والإينولين الى تغييرات غير معنوية سواء في درجة تكوين او ثبات الرغوة المتكونة.
- من ذلك نستخلص انه يمكن استخدام مركزات بروتينات الشرش كمصدر جيد ورخيص وعالي القيمة الغذائية كبديل للبن الكامل او الفرز في المنتجات الغذائية التي تحتوي علي سكريات مثل الأيس كريم والبودنج والكيك والحلويات Confectionary .