FLUIDIZED-BED SYSTEM FOR WHEY PROTEIN FILM COATING OF PEANUTS

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ABSTRACT

Complete peanut-surface coverage and strong adhesion are necessary for whey protein-based oxygen barrier coatings to be totally effective in reducing the oxidative rancidity of peanuts. Peanuts coated with a fluidized-bed coating system attained practically complete coverage, and coating efficiency results were consistent and reproducible. Addition of surfactant to the coating solution improved whey protein coating efficiency on blanched/roasted peanuts coated with a bench-scale fluidized-bed coating system. A lower level of surfactant addition to the coating solution was required to attain complete coverage, compared with previous studies on dip coating and pan coating of peanuts. Addition of surfactant to the coating solution and peanut preroughening both imparted good coating adhesion for fluidized-bed-coated peanuts. Compared with pan coating, fluidized-bed coating required application of a greater amount of coating solution because of the loss of coating solution to the fluidized-bed column wall during spraying. Overall, fluidized-bed coating required a shorter processing time and provided the peanuts with better coating efficiency and adhesion. These results suggest that a fluidized-bed coating system is a viable alternative coating process for whey protein coating of peanuts.

INTRODUCTION

Nuts comprise an important segment of the U.S. agricultural and food processing industries. They often add a distinct flavor and a desirable crunch to many foods. Peanuts are predominantly consumed as snack nuts (153.17

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million pounds), peanut butter (336.3 million pounds), confection ingredients (148.76 million pounds) and other products (10.89 million pounds) in the U.S.A. (NASS 2003). Nuts are rich in polyunsaturated fatty acids. Diets with a high ratio of polyunsaturated to saturated fats can reduce the risk of human cardiovascular disease and stroke. However, the high polyunsaturated lipid content of many nuts makes them especially susceptible to oxidative rancidity (Divino *et al.* 1996).

Whey protein films and coatings possess excellent oxygen barrier properties, comparable to synthetic polymer polyvinylidene chloride and ethylene vinyl alcohol films (Trezza and Krochta 2002). Thus, the oxygen barrier properties of whey protein coatings have potential for increasing the shelf life of nuts by decreasing their rate of lipid oxidation. Protein coatings could also potentially reduce the amount of packaging materials required to protect nuts, leading to package cost savings. However, adhesion of the hydrophilic whey protein coatings to hydrophobic foods such as nuts is inherently poor because of differences in the chemical nature of the two surfaces. During the coating of nuts, dewetting of the coating solution tends to occur. Shrinking and cracking of the coating may also occur during drying, as well as flaking and de-adherence of the coating after drying.

Previous research has determined that both surfactant addition to the coating solution and increasing the peanut surface roughness are effective in improving the wettability and coverage of peanuts (Sehgal 2003; Schlake 2004; Lin and Krochta 2005, 2006). When the surfactant concentration in the coating solution is increased sufficiently above the critical micelle concentration (cmc) (i.e., critical concentration above which surfactant forms aggregates in solution), the surface energy of the peanuts increases above the surface energy of the coating solution to enhance coating efficiency. This occurs, presumably, as a result of formation of self-assembled surfactant micelles on the peanut surface (Lin and Krochta 2005). Increasing surface roughness also increases peanut surface energy to improve coating efficiency. In addition, increased solid surface roughness increases peanut surface area in contact with the coating solution, which provides more intermolecular attraction and bonding opportunity (Shuttleworth and Bailey 1948; Zografi and Johnson 1984). Rough surfaces also provide small cavities, which can allow penetration of the coating solution, with subsequent mechanical locking of the coating into the cavities upon drying.

Much previous research on whey protein coating efficiency on peanuts and the potential of whey protein coating for reducing oxidative rancidity was carried out by hand-dip coating technique of individual peanuts (Maté *et al.* 1996; Lin and Krochta 2005; Lin and Krochta 2006). The commercial application of edible coatings presents several challenges. Pan coating is the conventional process used in the food industry for coating confections and in the

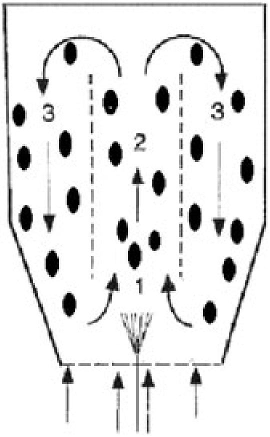

FIG. 1. KEY REGIONS OF THE FLUIDIZED-BED COATING PROCESS
(1) Spraying zone; (2) coating zone; and (3) expansion zone.

pharmaceutical industry for coating tablets. Panning is one of the oldest coating techniques for confections, accomplished by the controlled buildup of coating on a center/core by applying successive layers of a coating material in a revolving pan or turbine and by drying to set the coating. The majority of pans in use worldwide are simple rotating tumblers mounted on angled shafts, which impart horizontal circulation in the pan. Pan coating has long been regarded as an art that requires experience to develop the skill. Food composition, size and shape, coating conditions, and coating solution variables all influence the coating process and the quality of the final coated product (Trezza and Krochta 2002). This art can only be reduced to a repeatable mechanical operation if the critical factors of processing, such as variation of products, coating materials and process conditions, are brought carefully under control (Groves 1992). The studies by Sehgal (2003) and Schlake (2004) investigated the potential of the pan coating operation for applying whey protein coatings to peanuts.

Fluidized-bed coating is the controlled application of a thin film coating of an edible biopolymer onto the surface of a core substrate, by spraying a coating solution into a fluidized bed of the core substrate (Fig. 1). Fluidized-bed coating technology is still new to the confectionery industry; however, many pharmaceutical tablets are coated using this process. Generally speaking, coating with a biopolymer film is difficult in conventional pans. Usually, side-vented pans or fluidizing columns are used. The reason is that the fluidizing action allows a much faster rate of drying than that achieved in conventional pan coating. As the cores are tumbled and fluidized by the volume of air, the coating material is sprayed onto the surface of the tumbling product. Immediately as the spray is formed at the nozzle of the spray gun, the fine droplets begin to dry. As they make contact with the product, they dry, merge and form a continuous film on the surface (Lynch 1992). Coating droplet formation, contact, spreading, coalescence and evaporation are occurring almost simultaneously during the process (Jones 1985). A continuous layer of coating does not occur during a single pass through the coating zone, but relies on many such passes to produce complete coverage of the surface (Guignon *et al.* 2002).

Coating a core in a fluidized bed potentially distributes the film coating uniformly over the entire surface of the substrate (Kelly 1994). The high evaporative efficiency prevents the substrate from becoming overwet. In a fluidized-bed coating process, air is used to raise substrate particles. The air velocity required depends on the size, shape (sphericity) and density of particles; on the porosity of the particle bed; and on the viscosity and density (i.e., temperature) of the air. The air circulation is used to insure a homogenous partition of all particles and also to dry the coating solution sprayed on the particle surface. In the coating zone of the fluidized bed, the spray droplets are brought into contact with the repetitively passed core material. Small drops of the coating solution may dry before reaching the particles, leading to small solid particles of solute, which is a loss for the coating process. The film is then formed by the process of spreading, coalescence and evaporation. The coating zone is part of the up-bed region of the fluidized-bed unit, where the sprayed liquid droplets contact the substrates. In the bottom spray and Wurster-fluid-column coating techniques, the spray is concurrent with the movement of the substrate, and desired film thickness is achieved by repetitive passes of the substrate through the coating zone. The flow of substrate particles in this case is highly organized, and the resulting coating is uniformly distributed throughout (Kelly 1994). Substrate properties are important determinants of the fluidized-bed coating process. The most important properties of the substrate particles are density, diameter and stickiness. Slugging is a frequent problem with the flow in the up-bed coating zone for dense and large substrates (Christensen and Bertelsen 1997). The substrate concentration in the up-bed coating zone must be high enough to secure adherence of all spray droplets to substrate particles. The air velocity in the expansion zone, the down-bed region of the fluid bed unit, must be well below the minimum fluidization velocity. The down-bed expansion zone is where sticking is most likely to occur, because the movement is gentle, and the particles are in close contact with one another (Christensen and Bertelsen 1997).

Fluidized-bed coating supplies the food industry with a wide variety of microencapsulated food ingredients and additives (Arshady 1993; Hegenbart

1993). Coating nuts using a spray in a fluidized bed could produce increased coating uniformity, improved process control, and increased product throughput and efficiency (Strub 1987). Lee *et al.* (2003) demonstrated that spraying can be an effective method for coating peanuts.

To develop the fluidized-bed system as an alternative coating process for peanuts, the ability of the system to evenly distribute coating solution over the peanut surfaces and form dried coatings that remain adhered to the food surface during processing, storage and transportation must be tested. The objectives of this study were to determine the following: (1) optimum processing parameters for a fluidized-bed coating system; (2) effect of coating-solution surfactant level on fluidized-bed coating efficiency on commercially blanched/roasted peanuts and freshly blanched/roasted peanuts; (3) effect of peanut surface roughness on fluidized-bed coating efficiency of freshly blanched/roasted peanuts; (4) coating weight and coating thickness of fluidized-bed-coated peanuts and the correlation between coating weight and coating efficiency; (5) coating durability; and (6) comparison of fluidized-bed coating system with conventional pan coating for peanuts.

MATERIALS AND METHODS

Materials

Whey protein isolate (WPI) was supplied by Davisco Foods International (Le Sueur, MN). Sorbitan monolaurate (Span 20) was purchased from Sigma-Aldrich (St. Louis, MO). Glycerol (Gly) was purchased from Fisher Scientific Co. (Fair Lawn, NJ). Brilliant Blue dye (FD&C Blue No.1 powder) was purchased from Warner Jenkinson Co., Inc. (St. Louis, MO). Raw peanuts and split-blanched dry roasted peanuts (Flavor Runner variety) were supplied by Hershey Foods Corp. (Hershey, PA). The peanuts were divided into 1000-g batches and stored at −40C. One 1000-g bag of peanuts at a time was taken from the −40C freezer and kept stored in a laboratory freezer (−17C) for experimental use.

Fluidized-Bed Coating System

Figure 1 shows the bench-scale bottom-spray fluidized-bed coating system set up by putting together an ERI 4″ Wurster column with a temperature-controlled air blower (Emerson Resources, Inc., Norristown, PA), a digital modular dispensing pump system (model no. 77923-60; Cole-Palmer Instrument Co., Vernon Hills, IL) and an automated A-AU-L/HD spraying gun with AXR aircap (Paasche Airbrush Co., Chicago, IL). In a spray-coating process, coating solutions are delivered to the product by a pumping system and a spray gun. The spray gun atomizes the coating solution by delivering the solution under high pressure through a nozzle with a small opening. The air velocity of forced air was controlled at 5–7 m/s (measured at the bottom of fluidized-bed column). The fluid flow rate of pumping system was controlled at 10 mL/min. The air pressure for automated spraying gun was controlled at 20 lb/in.^{2}

Coating Efficiency and Coating Adhesion Using Fluidized-Bed Coating System

Preparation of WPI Coating Solution. Whey protein coating solutions were prepared as 10% (w/w) solutions of WPI powder in deionized water with Gly (WPI/Gly = 1) as plasticizer. The solution was denatured in 100-mL batches for 30 min in a 90C water bath, cooled in an ice bath and equilibrated to room temperature. A 7% (w/w) aqueous solution of Brilliant Blue dye was added at the level of 0.5-/100.0-g denatured WPI coating solution to enable visualization of coating coverage, and the coating solution was degassed. Span 20 was added at the level of 0.05 g or 0.15-/100.0-g coating solution.

Bench-Scale Blanching/Roasting and Roughening of Raw Peanuts. One hundred-gram batches of freshly blanched/roasted peanuts were prepared from raw peanuts by blanching at 250F (121C) for 9 min, then by roasting at 325F (163C) for 6 min in a turbo convection oven (De'Longhi, Bedford Heights, OH). Heat-processed peanuts were cooled down to 100F (38C) and then tumbled in the ERI 4″ Wurster column (Emerson Resources, Inc.) for 2 min to remove skins and split the peanuts. The water activity of blanched and roasted peanut was approximately 0.25. Peanut-surface roughening was carried out by tumbling the freshly blanched and roasted peanuts in a modified friabilator drop-test drum (model 10805; Vankel Industries, Inc., Edison, NJ) for 6 min. The friabilator drop-test drum was modified with 60-grid sandpaper (ACE Hardware, Davis, CA) attached on the flights.

Optimization of Fluidized-Bed Coating System. Either commercially blanched and roasted peanuts or the bench-scale freshly blanched and roasted peanuts were conditioned at 25C in a 17% relative humidity (RH) chamber overnight. A batch of 100 g of blanched/roasted peanuts was coated with the bottom-spray fluidized-bed coating system for each experiment. The total amount of coating solution for each experiment was applied in small batches to prevent peanut clumping. Thus, the coating solution was sprayed onto peanuts with one of the following combinations of batch numbers, batch sizes and related batch spray times: 18 batches of 4.2 g each (6-s spray per batch), 12 batches of 6.3 g (9-s spray), 9 batches of 8.4 g (12-s spray) or 6 batches of 12.6 g (18-s spray). Each batch of coating solution application was followed by either a 30-s, 45-s or 1-min drying period, during which the peanuts were tumbled in the fluidized-bed column for spreading and drying of the coating solution batch. The temperature of the air blower was controlled at either 75–85F (25–30C) or 110–115F (43–46C) for comparison of effects of drying rate on coating efficiency. Coatings of freshly blanched and roasted peanuts were also carried out at conditions where either whole peanuts or split peanut halves were coated separately for comparison of coating efficiency. The coated peanuts were then stored in a 25C, 11% RH chamber for 48 h, to bring the water activity of peanut to 0.25 ± 0.05.

Image Analysis of Coated Peanuts. Coating efficiency was defined as coating coverage (%) on the peanut surface. The coating coverage on peanut surfaces was determined by obtaining magnified digital images of the peanuts and analyzing the images using the Image-J program (Research Services Branch, National Institutes of Health, Bethesda, MD) that was developed and modified for image analysis (Sehgal 2003; Schlake 2004). Digital images of the peanuts were obtained using a stereo microscope (Wild M8, Wild Heerbrugg, Gais, Switzerland) with an attached camera (model PDMC-2, Polaroid, Pierre Hebert, France). Image analysis of each peanut was obtained for both curved side and flat side of split peanut halves.

Assessment of Peanut Coating Adhesion. The coatings on the peanuts were evaluated for durability by applying the stress of repeated dropping. One hundred grams of peanuts were first coated with the fluidized-bed coating system, after which the water activity of the coated peanuts was readjusted back to 0.25. After weighing, the coated peanuts were placed in a two-chambered Vankel-type drum of a Vanderkamp friabilator (model 10805, Vankel Industries, Inc.). The drum was rotated 200 times at 25 rpm, and the weight of the coated peanuts was measured accurately before and after the testing, with the peanut water activity adjusted to 0.25. Coating adhesion was determined by the percentage weight loss of coated peanuts caused by the stress test.

Statistical Analysis

Differences in whey protein coating efficiency and adhesion on peanuts were analyzed with least standard deviation (Sokal and Rohlf 1981) using the SAS statistical program for physical analyses (SAS Institute, Inc. 1998). The confidence level regarded as significant was $P \leq 0.05$.

TABLE 1.
EFFECT OF COATING SOLUTION BATCH AMOUNT AND DRYING TIME BETWEEN BATCHES ON THE COATING EFFICIENCY FOR COMMERCIALLY BLANCHED AND ROASTED PEANUTS (TOTAL OF 75.6 g OF COATING SOLUTION APPLIED TO 100 g PEANUTS FOR EACH EXPERIMENT)

Coating solution applied each batch (spraying time) – number of batches	Drying time between batches	Coating coverage (%)
12.6 g (18 s) – 6 batches	1 min	86.45 (10.81)$^{\mathrm{DE}}$
	45 s	83.10 (7.11)$^{\mathrm{E}}$
	30 s	87.76 (8.79)$^{\mathrm{CDE}}$
8.4 g (12 s) – 9 batches	1 min	90.77 (8.62)$^{\mathrm{BCD}}$
	45 s	92.84 (6.33)$^{\mathrm{AB}}$
	30 s	93.78 (3.63)$^{\mathrm{AB}}$
6.3 g (9 s) – 12 batches	1 min	96.80 (2.72)$^{\mathrm{A}}$
	30 s (three batches)	
	45 s (five batches)	95.06 (2.85)$^{\mathrm{AB}}$
	1 min (four batches)	
	45 s (two batches)	95.26 (3.62)$^{\mathrm{AB}}$
	1 min (10 batches)	
4.2 g (6 s) – 18 batches	1 min	96.40 (2.36)$^{\mathrm{A}}$
6.3 g (9 s) – 8 batches	1 min	92.61 (4.79)$^{\mathrm{ABC}}$
4.2 g (6 s) – 6 batches	1 min	

Values in the parentheses indicate SE.

$^{\mathrm{A–E}}$ Values for coating coverage with different superscripts are significantly different ($P < 0.05$). Each value is the mean of at least three replicates.

Whey protein coating solution contained 0.15% Span 20 as surfactant.

Solid content of whey protein coating solution was 18%.

RESULTS AND DISCUSSION

Optimization of Fluid-Bed Coating System for Blanched Roasted Peanuts

Coating Solution – Batch Amount and Drying Time. The total amount of coating solution applied to 100 g of peanuts for each experiment was 75.6 g. However, as explained earlier, the coating solution was divided into batches with different sizes and spray times, with different drying times between batches.

Results show that varying the drying time between spraying of either 12.6-, 8.4- or 6.3-g coating solution batches did not have a significant effect on the coating efficiency for commercially blanched and roasted peanuts (Table 1). It should be noted, however, that the shorter drying times required gentle shaking and tapping of the fluid column to prevent the peanuts from sticking to the column wall. In contrast, the amount of coating solution sprayed

TABLE 2.
EFFECT OF PEANUT SHAPE AND COATING SOLUTION BATCH AMOUNT ON THE COATING EFFICIENCY FOR FRESHLY BLANCHED AND ROASTED PEANUTS (TOTAL OF 75.6 g OF COATING SOLUTION APPLIED TO 100 g PEANUTS FOR EACH EXPERIMENT)

Peanut shape, coating solution applied each batch (spraying time) – number of batches	Drying time between batches	Coating coverage (%)
Coating of mixed peanut halves and wholes		
Halves, 6.3 g (9 s) – 12 batches	1 min	98.72 (2.30)^{A}
Wholes, 6.3 g (9 s) – 12 batches		98.63 (0.90)^{A}
Halves, 4.2 g (6 s) – 18 batches	1 min	96.40 (4.69)^{B}
Wholes, 4.2 g (6 s) – 18 batches		98.32 (0.70)^{A}
Coating of separated peanut halves and wholes		
Halves, 4.2 g (6 s) – 18 batches	1 min	99.97 (0.03)^{A}
Wholes, 4.2 g (6 s) – 18 batches		98.69 (0.48)^{A}

Values in the parentheses indicate SE.

^{A,B} Values for coating coverage with different superscripts are significantly different ($P < 0.05$). Each value is the mean of at least three replicates.

Whey protein coating solution contained 0.15% Span 20 as surfactant.

Solid content of whey protein coating solution was 18%.

for each batch was shown to have a significant effect on coating efficiency for a given drying time between batches (Table 1). For example, as the amount of coating solution applied for each batch decreased from 12.6 g/batch (6 batches) to 4.2 g/batch (18 batches), the coating efficiency improved from 86 to 96% (Table 1). The SE of coating efficiency also decreased with decreasing amount of coating solution applied for each batch.

The coating efficiencies for freshly blanched roasted peanuts were equally high (98–99%) when coating peanuts with either 12 batches of 6.3-g coating solution or 18 batches of 4.2-g coating solution, with a drying time of 1 min between batches (Table 2). Because of the difference in blanching and roasting processes between commercially blanched roasted peanuts and freshly blanched roasted peanuts, the freshly blanched roasted peanuts had more whole (unsplit) peanuts. When the wholes and halves (splits) of peanuts were coated together, a large variation in the coating efficiency was observed for the halves (i.e., large SE), whereas the wholes were more consistently well coated (Table 2). When the wholes and halves were coated separately in the coating process, both the wholes and halves were consistently well coated (i.e., smaller SEs) (Table 2). The wholes were heavier than the halves and tended to be sitting at the bottom of the fluid column when coating mixed peanut halves and wholes. The results for mixed peanut halves and wholes may be due to the interference of the wholes with the halves in receiving the coating solution during coating.

TABLE 3.
EFFECT OF THE DRYING TEMPERATURE ON THE COATING EFFICIENCY FOR COMMERCIALLY BLANCHED AND ROASTED PEANUTS (TOTAL OF 75.6 g OF COATING SOLUTION APPLIED TO 100 g PEANUTS FOR EACH EXPERIMENT)

Coating solution applied each batch (spraying time) – number of batches	Drying time between batches	Coating coverage (%)
Drying air temperature: 75–85F (25–30C)		
4.2 g (6 s) – 18 batches	1 min	96.40 (2.36)^{AB}
6.3 g (9 s) – 12 batches	1 min	96.80 (2.72)^{AB}
Drying air temperature: 110–115F (43–46C)		
4.2 g (6 s) – 18 batches	1 min	98.19 (1.99)^{A}
	45 s	95.58 (2.48)^{B}
	30 s	88.60 (6.04)^{C}
6.3 g (9 s) – 12 batches	1 min	97.53 (2.12)^{AB}

Values in the parentheses indicate SE.

$^{A–C}$ Values for coating coverage with different superscripts are significantly different ($P < 0.05$). Each value is the mean of at least three replicates.

Whey protein coating solution contained 0.15% Span 20 as surfactant.

Solid content of whey protein coating solution was 18%.

Drying Temperature. Results show that there was no significant effect of drying temperature on coating coverage for commercially blanched roasted peanuts (Table 3). Also, results obtained with the higher drying air temperature indicate that the drying time could not be reduced. The coating efficiency obtained with the higher drying air temperature dropped as the drying time between batches of coating solution application was reduced (Table 3).

Surfactant Level in Whey Protein Coating Solution. There was no significant difference in coating efficiency for peanuts coated with whey protein coating solution containing either 0.05 or 0.15% Span 20, when the coating solution was applied at 4.2 g/batch for 18 batches (data not shown). However, the peanuts coated with coating solution containing 0.15% Span 20 were observed to be smoother than peanuts coated with coating solution containing 0.05% Span 20. This observation suggests that peanut surface wettability was improved at a surfactant level greater than the surfactant's cmc in the coating solution (Lin and Krochta 2005). The improved wettability of peanut surface with 0.15% Span 20 in the whey protein coating solution may have resulted in a more even spreading of coating solution during the drying period of the fluidized-bed coating process, resulting in a smoother coating appearance. The reduced wettability with 0.05% Span 20 may have been overcome with overlapping built-up layers of coating, albeit with resulting rougher coating surface.

TABLE 4.
COATING UPTAKE AND ADHESION ON FLUIDIZED-BED-COATED PEANUTS

Peanut pretreatment	Stage	Coated peanut weight change (%)
Whey protein coating solution with 0.15% Span 20, 4.2 g/batch, 18 batches		
Roughened	Coated	9.63%↑^{AB}
	Stress tested	0.059%↓^{d}
Unroughened	Coated	9.81%↑^{A}
	Stress tested	0.17%↓^{c}
Whey protein coating solution with 0.05% Span 20, 4.2 g/batch, 18 batches		
Roughened	Coated	9.46%↑^{B}
	Stress tested	0.274%↓^{b}
Unroughened	Coated	9.82%↑^{A}
	Stress tested	0.613%↓^{a}
Whey protein coating solution without surfactant addition, 4.2 g/batch, 18 batches		
Roughened	Coated	1.84%↑^{D}
	Stress tested	0.76%↓^{a}
Unroughened	Coated	3.05%↑^{C}
	Stress tested	0.35%↓^{ab}

% weight increase is based on the weight of uncoated peanuts.

% weight loss is based on the weight of coated peanuts.

[A–D] Values for percentage weight increase after coating with different superscripts are significantly different ($P < 0.05$). Each value is the mean of at least three replicates.

[a–d] Values for percentage weight decrease after stress test with different superscripts are significantly different ($P < 0.05$). Each value is the mean of at least three replicates.

↑, increase; ↓, decrease.

Assessment of Peanut Coating Uptake and Adhesion

Peanut Coating Uptake with Fluidized-bed Coating System. Table 4 shows the coating uptake of peanuts, after coating with the fluidized-bed coating system at different levels of surfactant addition to the whey protein coating solution. The coating uptake, expressed as percentage weight increase, is the weight of solid content increase based on the weight of uncoated peanut. Results show that the coating uptakes at the two levels of surfactant addition to the coating solution were not significantly different. However, the coating uptake by peanuts coated with whey protein solution without addition of Span 20 was significantly smaller compared with peanuts coated with addition of Span 20 at 0.05% (cmc) and 0.15% (>cmc) levels (Table 4). These results confirm the importance of improving peanut surface wettability with surfactant addition to the coating solution. The results also show that for fluidized-bed coating addition of surfactant to the coating solution was much more important than peanut roughening for increasing coating uptake. Peanut roughening had little or no effect on coating uptake when using coating solution with surfactant (Table 4).

Weight Loss of Coated Peanut from Drop Stress Test. Table 4 also shows the weight loss of whey protein-coated peanuts from the drop stress test at different levels of surfactant addition. Effects of surfactant level in the coating solution and peanut surface roughness on coating adhesion, expressed as percentage weight loss from the drop stress test, were significant. Weight losses of peanuts coated with surfactant addition at a higher level (0.15% w/w) were significantly smaller than peanuts coated with surfactant addition at a lower level (0.05% w/w). Coating losses from roughened peanuts were also significantly smaller than losses from unroughened peanuts. The effect of roughening on coating adhesion without surfactant addition to the whey protein coating solution was not significant. This was likely due to the poor coating adhesion to peanuts with whey protein coating solution without surfactant addition.

Coating Efficiency Relationship with Coating Uptake. The relationship between coating efficiency and coating uptake is shown in Fig. 2. The coating uptake increased with increased batches of coating solution applied. At the surfactant level of 0.15% Span 20 in the whey protein coating solution, the coating uptake increased from 2.94 to 6.85 to 9.63% when the coating batches increased from 6 to 12 to 18 batches of 4.2-g coating solution each (i.e., 25.2-, 50.4- and 75.6-g total coating solution, respectively) (Fig. 2). Correspondingly, the coating efficiency increased to over 98% coverage when the coating batch application was 12 batches. No significant increase in coating efficiency was observed with a further increase in coating batches to 18 (Fig. 2). A similar relation between coating efficiency and coating uptake was observed at the surfactant level of 0.05% Span 20 in the whey protein coating solution. The coating uptake increased from 3.17 to 6.33 to 9.46% when the coating batches increased from 6 to 12 to 18 batches, and the coating efficiency increased to over 98% coverage when the coating batch application increased to 12 batches (Fig. 2).

CONCLUSIONS

Surfactant addition to the coating solution was found to improve whey protein coating efficiency on blanched and roasted peanuts coated with a bench-scale fluidized-bed coating system. Surfactant addition to the coating solution and mechanical preroughening of the peanuts were both found to improve whey protein coating adhesion to the peanuts. A nearly complete coverage of peanuts was attained with the fluidized-bed coating system, and results of coating efficiency and adhesion were consistent and easily reproduced. With the high drying efficiency of the fluidized-bed coating system, a

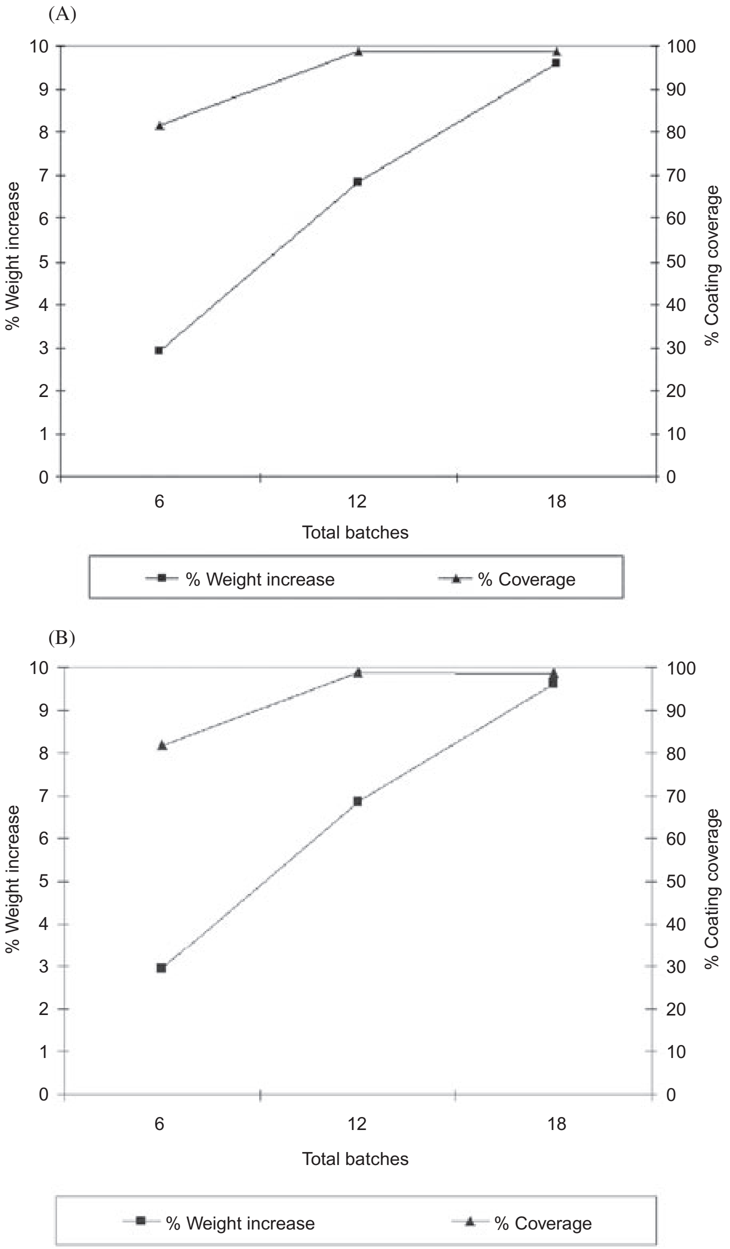

FIG. 2. EFFECT OF THE AMOUNT OF WHEY PROTEIN COATING SOLUTION WITH (A) 0.15 and (B) 0.05% SPAN 20 ON PEANUT COATING UPTAKE AND COVERAGE

Coating solution applied for each batch during fluidized-bed coating was 4.2 g. Coating uptake is based on the weight increase of 100 g of freshly blanched roasted and roughened peanuts after fluidized-bed coating.

lower level of surfactant addition to the coating solution was required to attain nearly complete coverage, compared with previous results with individual dip coating and pan coating. Even without addition of surfactant to the coating solution, the fluidized-bed coating system achieved better coating efficiency than previous dip coating and pan coating. However, coating adhesion was poor without surfactant addition to the coating solution. Addition of a low level of surfactant to the coating solution was required for imparting good coating adhesion for fluidized-bed-coated peanuts. The shorter processing time of fluidized-bed coating and the better coating efficiency and adhesion compared with conventional pan coating potentially make fluidized-bed coating a good alternative to pan coating for application of whey protein coatings on peanuts.

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