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Improving the crispness of microwave-reheated fish nuggets by adding chitosan-silica hybrid microcapsules to the batter

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ABSTRACT

In this study, thermostable microcapsules prepared with a hybrid of chitosan and silica (MC_{CS}) as the shell material and soybean oil with a low specific heat capacity as the nucleus were applied to maintaining the crispness of microwave-reheated battered and breaded fish nuggets. The MC_{CS} added batter at 1 g/100 mL concentration exhibited desirable rheological properties and a 40% pick-up rate, as well as a high cutting force, low deformation and desirable number of peaks in the cutting force profile of the fish nuggets reheated in a microwave oven. After microwave reheating, the moisture content of the crust was lower, and moisture content of the fish meat was higher, in the MC_{CS}-containing nuggets than in the MC_{CS}-free nuggets. This phenomenon suggested that the MC_{CS} facilitated the formation of a water barrier by high temperature and high pressure during microwave reheating, which prevented moisture molecules from migrating from the fish meat to the crust.

1. Introduction

Battered and breaded products in which the meat protein component is the core surrounded by a cereal-based coating are becoming increasing popular as instant foods. Batter coatings enhance the flavour, texture and appearance of food and act as a barrier against the loss of moisture by protecting the natural juices of foods from the effects of freezing or reheating, thereby ensuring that the final product is tender and juicy on the inside and crisp on the outside (Dogan, Sahin, & Sumnu, 2005; Fiszman & Salvador, 2003).

The brittleness or crispness of the crust is a critical element in a consumer's evaluation of a particular deep-fried battered food product. However, such crusts normally absorb significant amounts of water during the microwave reheating that allows fast meal service. The major mechanisms of microwave heating of foods involve orientation polarisation and interfacial (space charge) distribution. Some dielectric materials contain permanent dipoles that tend to reorient under the influence of alternating fields, thus causing orientation polarisation (Metaxas & Meredith, 1983, pp.6–80). Moisture molecules are conducted outward when battered products are heated in a microwave oven. The result is a soggy coating with minimal crispness. Battered and breaded product manufacturers are increasingly demanding the same texture from microwave reheated product that they can achieve in a freshly deep-fried product. In light of the difficulty that microwave reheating has had in achieving this goal, a unique technology for effective development of coated food products must be developed (Loewe, 1993).

Lin (2007) added microcapsules with a high dielectric constant and low specific heat capacity to a battered layer to create a higher temperature in the crust than in the fish nuggets to prevent the water vapour in the fish nuggets from migrating to the crust during microwave heating. The suggested mechanism is that the highly dielectric phase quickly generates frictional heat due to polarisation and the heat is transferred to the low specific-heat-capacity oil to accelerate the temperature increase in the microcapsules and the surrounding crust. However, the thermal stability of these microcapsules, which had a shell consisting of a gelatine-hydroxylpropylmethylcellulose (HPMC) complex, was not sufficient for use in pre-fried battered and breaded products.

Silica can be applied to enhance the stability of nanoparticles (Bahadur et al., 2012). Furthermore, chitosan is a thermally stable and abundant bio-resource material, which finds diverse applications in the foods and biomaterials industry (Zou et al., 2012). Chitosan is a linear positively charged polysaccharide with interspersed D-glucosamine and acetyl-D-glucosamine units (Kang et al., 2010). These functional groups offer the ability of chitosan to form

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stable emulsions with lipids (Wei, Wang, Zou, Liu, & Tong, 2012) and can be utilized to prepare composite materials with silica (Chrissafis, Paraskevopoulos, Papageorgiou, & Bikiaris, 2008). The incorporation of silica as a reinforcing agent substantially improves mechanical properties and thermal stability, as seen for soy protein plastics (Tian, 2012).

To overcome the low thermal stability of the aforementioned microcapsules prepared using the gelatine–HPMC complex, chitosan-silica hybrids and soybean oil were employed as the thermally stable shell and to the nuclear materials of microcapsules (MC_{CS}). The MC_{CS}, which were prepared by sol–gel coacervation of an oil-in-water emulsion, exhibited high thermal stability (Kang, 2010).

In this study, MC_{CS} were added to the batter layer of deep-fried fish nuggets because the shell of the chitosan-silica hybrid was designed to enhance the heat tolerance of the microcapsules for use in deep-fried products. The rheological properties were determined to estimate the coating property of MC_{CS}-containing batter. The transfer of moisture molecules, as well as the physical properties of the crust of battered fish nuggets, were analysed during and after microwave heating to investigate the feasibility of employing MC_{CS} to improve the crispness of microwave-reheated battered products.

2. Materials and methods

2.1. Preparation of the microcapsules

Chitosan with a deacetylation degree of 83% was purchased from Ying Huwa Co., Kaohsiung, Taiwan. The chitosan was dissolved in 0.06 g/100 mL acetic acid to form a 1.5 g/100 mL concentration chitosan solution. Tween 80 (polyoxyethylene (20) sorbitan monooleate, HLB 15, purchased from Sigma Co., Ltd., St. Louis, MO, USA) was dissolved in a 0.6 g/100 mL acetic acid solution at a concentration of 0.04 g/mL. Span 85 (sorbitan trioleate, HLB 1.8, purchased from Sigma Co.) was dissolved in soybean oil at a concentration of 0.07 g/mL. The emulsifier-containing soybean oil was instilled into the emulsifier-containing chitosan solution on a magnetic stirrer and then homogenised using a Silverson L4R homogeniser (Silverson Machines Ltd., Buckinghamshire, UK) at 10,000 rpm for 5 min to form the oil-in-water (O/W) emulsion.

Sodium silicate (Na_2SiO_3) was purchased from Wako Pure Chemical Industries, Ltd. (Osaka, Japan) and was dissolved in 0.06 g/100 mL acetic acid to form a 1.5 g/mL sodium silicate solution, adjusted with 3.65 g/100 mL HCl to pH 5. Tween 80 was dissolved in a sodium silicate solution to a concentration of 0.04 g/100 mL. The O/W type oil/chitosan emulsion was instilled into the emulsifier-containing sodium silicate solution on a magnetic stirrer for 24 h to allow sol–gel coacervation to form an O/W–W emulsion (O/W emulsion surrounded by a hydrophilic phase), which was filtered using a 0.8-μm membrane. The retentate was lyophilised to form microcapsules (MC_{CS}) with soybean oil as the nucleus and the chitosan-silica composite as the shell.

2.2. Preparation of fried battered products for microwave reheating

2.2.1. Batter formulation

The 100 g batter formulation consisted of 30 g low-gluten flour, 30 g high amylase cornstarch, 24 g corn flour (these materials were purchased from Gi Chan Food Co., LTD, Hsin Chu, Taiwan), 1 g emulsifier (sucrose palmitic acid ester P-1570, Gemfont Corporation, Taipei, Taiwan), 1.2 g leavening ($Na_2H_2P_2O_7/NaHCO_3$, Chien Yuan Food Chemicals Co., Ltd., Taipei, Taiwan) 5 g soybean flour, 3 g shortening, 3 g salt and 2.8 g sugar (these materials were purchased from Hsin–Hsin Food Business, I-Lan, Taiwan), including various additives and ingredients. The thoroughly pre-blended powders were mixed with cold water in a ratio of 1/1 (W/W) in a stirring apparatus (K5SS, KitchenAid, St. Joseph, Michigan, USA) for 10 min to form the batter. The MC_{CS} were added to final concentrations of 0.5, 1.0, 2.5 or 5 g in 100 mL batter and stirred well. The MC_{CS}-containing batter was stirred again before battering process to ensure the dispersion of MC_{CS} in batter.

2.2.2. Battered fish nuggets

Sailfish (20 g/piece) was used as the food matrix; pieces were pre-dusted with low-gluten flour, immersed in the batters for 10 s and breaded with 20–40 mesh breadcrumbs which purchased from SCI-MISTRY Co., LTD (Yilan, Taiwan) and sieved. The batter pick-up, the ratio of batter weight to the total nugget after battering, of the fish nuggets was calculated as follows:

$$\text{Pick}-\text{up}(\%) = [(\text{battered fish nugget} - \text{fish meat})/(\text{battered fish nugget})] \times 100\% \quad (1)$$

The battered and breaded fish nuggets were deep-fried at 180 °C for 3 min. The cooled nuggets were frozen at −20 °C for 24 h and then reheated in a microwave oven (NNJ993, Panasonic, Tokyo, Japan) at 2450 MHz/700 W. The actual microwave output power was found to be 645.4 W by using the IMPI (International Microwave Power Institute) 2-L test (Standford, 1990). Three fish nuggets were reheated together of each batch for 90 s to determine their physical properties and conduct the sensory evaluation.

2.3. Moisture content

In accordance with AOAC. (1984), the fish meat and crust samples were dried in an oven at 105 °C until constant weights were achieved to calculate the moisture content. Three replicate experiments were performed.

2.4. Moisture transfer from the batter

2.4.1. Moisture loss by the batter during heating

In order to confirm the addition of MC_{CS} facilitated the temperature rise of batter and accelerated the water molecules removal from batter, 5 g sample of batter with or without MC_{CS} addition was placed on an aluminium foil tray and heated at 180 °C using the Infrared Moisture Determination Balance (FD-610, Kett Electric Laboratory, Tokyo, Japan). The weight loss from batter, no moisture coming from the fish pieces was taking into account, was recorded to simulate the effect of the MC_{CS} on the batter's moisture loss during heating.

2.4.2. Dimensionless moisture content

A 15 g sample of raw fish meat was placed in a 3.5 cm diameter, 25 mL beaker and coated with 1.5 mL of batter. These specimens were microwave heated at 700 W and weighed at 20 s intervals to calculate the dimensionless moisture content (DMC) using the following equation, to evaluate the effect of the MC_{CS} on moisture transfer during microwave heating:

$$\text{DMC} = (W_t - W_0)/(W_i - W_0) \quad (2)$$

W_i and W_t represented the specimen weight before and after heating, respectively. W_0 represented the dried weight of the specimen.

2.5. Rheological properties

The rheological properties of the batter were determined by a small amplitude oscillatory test (SAOT), using a dynamic rheometer (Rheometer AR-550, TA Instruments, New Castle, Delaware, USA). The