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ORIGINAL ARTICLE

Recovery of proteins from coconut milk whey employing ultrafiltration and spray drying

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Abstract The coconut whey (CW) (underutilized by-product of virgin coconut oil production, with 2–3% protein) was subjected to ultrafiltration for concentration of protein and sugar removal prior to spray drying. The process parameters of ultrafiltration were standardised with respect to transmembrane flux, protein retention efficiency and removal of sugar by using 300 kDa membrane cut off, feed pH 4 and 2 bar transmembrane pressure at temperature 25 ± 2 °C. The protein content was found to increase in the retentate after ultrafiltration (termed as concentrated coconut whey, CCW) (from 21 to 46%, w/w) and sugar content to reduce (from 59 to 34%, w/w). The color lightness (L*) values of the CW and CCW powders obtained by spray drying were found to be 83.81 ± 0.33 and 80.70 ± 0.47, respectively. Both the samples of coconut protein powders were found to be microbiologically safe having water activity index for CCWP of 0.27 and CWP of 0.26. Carr index values for CCW (32.95) and CW (33.14) powders indicate both of them to have fair flowability. The powders have high potential as new source of protein or as a functional ingredient in the food processing industries.

Keywords Ultrafiltration · Coconut milk · Coconut whey · Spray drying · Coconut protein powder

Introduction

The coconut (*Cocos nucifera* L.) palm is having several commercial applications and hence described as "Kalpavriksha". Coconut provides a good nutritional value and balanced amino acid profile (Srinivasan et al. 1964). Vegetable source of protein is having demand in several industries. Copra meal serves as economical alternative source for protein but currently not used for human consumption as they may be contaminated with microbes during solar drying. Wet or aqueous processing of coconut overcomes this problem and the protein acquired through this route is of good edible quality.

Coconut milk is a liquid expelled from the solid endosperm of mature coconut with or without addition of water for consumption (Carolina and Sandra 2019). Coconut milk press cake is the spent endosperm residue obtained after expelling of coconut milk, can be utilised to extract protein under alkaline conditions. These edible proteins have been characterized by electrophoresis and mass spectrometry techniques (Chambal et al. 2012). Another important source of edible protein is coconut whey (CW), the aqueous by-product obtained during production of virgin coconut oil. Coconut whey is an alternate source of vegetable protein. Coconut whey protein with good quality can meet the demand of industries for further utilisation into

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various products. Whey is obtained from wet processing of coconut which is used in Ayurveda as it is having several health benefits. Coconut whey proteins can be concentrated by various methods. Thus, it is essential to optimize recovery and concentration of CW protein which is currently discarded as waste.

In response to the concerns about protein recovery, membrane filtration technology provides exciting opportunities on a large-scale. Ultrafiltration (UF) is one of the many membrane separation technologies used in industry and research for purifying and concentrating macromolecular (10^3–10^6 Daltons) solutions, especially protein solutions. UF was employed for concentration and recovery of proteins from skim milk (Al-Akoum et al. 2002), soy milk (Jinapong et al. 2008) and cheese whey (Akpinar-Bayizit et al. 2009; Pereira et al. 2015). However, sufficient attention has not given to CW proteins and its separation from CW. UF membrane efficiency decreases and fouling occurs due to complex protein mixture (such as coconut skim milk or coconut whey). UF studies of coconut skim milk have reported different fouling mechanisms which includes complete blocking, intermediate blocking, standard blocking and cake formation with a 20 kDa polysulfone membrane and 60 °C feed temperature (Ng et al. 2014). Hence, it is essential to study the effect of various process parameters in order to attain maximum yield with minimum fouling.

Fresh coconut kernel is having protein content in the range 2.6–5.6% on a wet basis (w.b.) (Kwon et al. 1996a; Lamdande et al. 2017). Five protein fractions, namely, albumins (21% w/w), globulins (40% w/w), prolamines (3.3% w/w), glutelins-1 (14.4% w/w) and glutelins-2 (4.8% w/w) were obtained from defatted coconut flour and characterized (Kwon et al. 1996b). Globulin 11S or cocosin is the major coconut protein in the endosperm, which amounts 86% (w/w) of total globulin while 7S was only 14% (w/w) with native molecular weights of 326 kDa and 156 kDa, respectively (Garcia et al. 2005). Cocosin have excellent emulsifying ability in the absence of salt which forms basis for developing new processed foods (Angelia et al. 2010). Coconut protein was observed to have anti-diabetic effect in experimental rats (Salil et al. 2011) and cardio protective effect on alcohol and isoproterenol treated rats (Mini and Rajamohan 2002). However, the literature available on recovery of edible proteins from CW is very less. The major factor responsible for these effects is attributed to the high content of L-arginine present in coconut protein. The aim of the present work is to concentrate coconut whey protein using membrane technology (ultrafiltration) to reduce the water load in the subsequent unit operation of dehydration (spray drying) besides quality evaluation of the final product (protein enriched coconut whey powder).

Materials and methods

Materials

Fresh and mature coconuts (10–12 months) were purchased from the local market. Folin–Ciocalteu phenol reagent and sodium azide were purchased from Sisco Research Laboratory Pvt. Ltd., Mumbai. Sodium Phytate was procured from Sigma-Aldrich, St. Louis, USA. Membranes namely, Pelicon TFF polyethersulfone (PES) membrane (Biomax 300) cassette of molecular weight cut off (MWCO) of 300 kDa and ultrafiltration discs (Biomax PES, 47 mm) of MWCO of 5, 50, 100 and 300 kDa were purchased from EMD Millipore Corporation, USA. Chemicals such as petroleum ether, diethyl ether, ethanol, phenol, sulfosalicylic acid, iron chloride hexahydrate, anthrone, sulphuric acid, hydrochloric acid, sodium hydroxide and ammonia of analytical grade were procured from Merck chemicals, Mumbai.

Preparation of coconut whey

Fresh, matured and pared coconuts were subjected for disintegration by using rotary wedge cutter (Krauss maffei, Germany) and expelling of coconut milk was carried out with hydraulic press (B Sen Barry and Co., New Delhi). The coconut milk (4.0 kg) was centrifuged to obtain cream (1.8 kg), aqueous phase (coconut whey, CW) (2.1 kg) and protein precipitate (22 g). Sodium azide (0.02%) was added to CW to avoid microbial growth. Pre-filtration of coconut whey was carried out with Whatman filter paper no. 1. About 50 coconuts were processed as mentioned above to obtain CW without addition of sodium azide, for lab scale UF by Tangential flow filtration (TFF) of CW.

Ultrafiltration of coconut whey

Dead-end filtration

In order to study the effect of different process parameters on UF of CW, solvent resistant stirred cell (model: XFUF04701, Millipore, USA) was employed. UF of coconut whey was carried out up to volume reduction factor/volume concentration factor, CF—5 (i.e. 10 mL) using different MWCO membranes (5, 50, 100 and 300 kDa) at different pH range (4, 6 and 8). Different transmembrane pressures (TMP) (2, 3 and 4 bar) were employed for ultrafiltration at fixed stirring speed of 300 rpm. The permeate flux was measured at regular time intervals of 10 min. Permeate flux is defined as the mass is permitted through the membrane per unit of area and per

unit time. Permeate flux was calculated by the following equation.

$$J = \frac{Mp}{A \times t}$$

where, J is the permeate flux (L/m^2/h), M_p (kg) is the mass of permeate at time t (h) and A is the permeation area (m^2). The retentate and permeate were collected and analysed for protein and carbohydrate contents.

Tangential flow filtration

To obtain concentrated coconut whey (CCW) on a relatively large quantities, tangential flow filtration (TFF) system (model: XX42LSS12, Millipore, USA) was used, in which 2.5 L (500 mL each run) of CW was concentrated to 500 mL (100 mL each run) using 300 kDa membrane. The conditions of TFF were: 2 bar TMP, feed pH 4 and temperature 25 ± 2 °C.

Spray drying of coconut whey

Spray drying of coconut whey (CW) was carried out by using a co-current pilot scale spray dryer (Bowen Engineering, BE 1216, Indianapolis, USA, drying chamber height—0.72 m, diameter—0.76 m, and cone height—0.74 m) having 5 kg/h of water evaporation capacity equipped with inlet air temperature and air flow controllers, peristaltic pump for feed control, and cyclone separator for powder collection. Tangential flow filtration (TFF) was employed to concentrate CW to obtain concentrated coconut whey (CCW). The spray dryer was fed with distilled water, once thermal equilibrium and steady state are reached, the feed was changed over to coconut whey solution. 2 kg of CW and 400 g of CCW were subjected to spray drying separately. CW was fed to the spray dryer at a flow rate of 30 mL/min at ambient temperature (25 ± 2 °C) by a peristaltic pump. Spray dryer inlet air temperature was set at 150 ± 2 °C and 110 ± 2 °C was the outlet air temperature. Nozzle type atomizer with 2 mm diameter was employed at 3 bar air pressure in a co-current mode air flow system. The dried powder collected and stored in an air tight container at 4 °C. A flow diagram illustrating the preparation of both the CW and CCW powders is given in Fig. 1. The dried powder samples from each experiment were analysed for composition, phytate content, polyphenol content, water activity and physical characteristics such as colour and flow properties.

Analytical methods

Proximate analysis

The proximate analysis (moisture, ash, proteins and fat contents) of all the samples were carried out by using AOAC standard methods (AOAC 2007) and total carbohydrate content was calculated by difference.

The protein content of UF samples (retentate and permeate) were estimated by using Bradford method for liquid samples using bovine serum albumin (BSA) as standard (Bradford 1976) and micro-Kjeldahl for powder samples. Dubois method was used for estimation of sugar content of liquid samples using D-glucose as standard and total carbohydrate content of powder samples was calculated by difference by AOAC method (AOAC 2007).

Bradford reagent was prepared with Coomassie Brilliant Blue G-250 (100 mg) in 95% ethanol (50 mL) then 85% (w/v) phosphoric acid (100 mL) was added and volume was made up to 1 L with distilled water. The solution was filtered through Whatman no. 1 paper. Bradford reagent (2 mL) was added to 1 mL test solution/standard BSA (10–100 µg/mL). The sample mixture was incubated at ambient temperature (25 ± 2 °C) for 15 min and absorbance recorded at 595 nm by using spectrophotometer (Shimadzu UV spectrophotometer, model 160A).

The total nitrogen content of CW powders was estimated by using micro-Kjeldahl method (AOAC 2007) with minor variations. Sample (0.5 g) digestion was carried out with concentrated sulphuric acid (15 mL) and digestion mixture (1 g) in a digestion flask until clear solution was appeared and neutralized with 50% NaOH solution (50 mL). The distillate was collected in 10 mL of 2% boric acid having 2 drops of mixed indicator and titrated against 0.01N HCl until color changed to colorless and the titre value was recorded. A blank was digested and distilled to obtain the blank titre value. These titre values were used to calculate nitrogen content using the equation:

$$\text{Nitrogen content } (\%) = \frac{(\text{titre value} - \text{blank titre value})\,(\text{Normality of HCl}) \times 1.4007}{\text{Weight of sample } (g)}.$$

The protein content was calculated by multiplying 6.25 (nitrogen–protein conversion factor) to nitrogen content and 1.4007 is a nitrogen correction value. The protein content was expressed as g/kg of sample.

For Dubois method (Dubois et al. 1956), in 1.8 mL concentrated sulphuric acid and 300 µl of phenol solution (5%) were added into 0.5 mL sample/standard solutions (10–100 µg/mL), and incubated at room temperature (25 ± 2 °C) for 15 min. Absorbance of mixture was

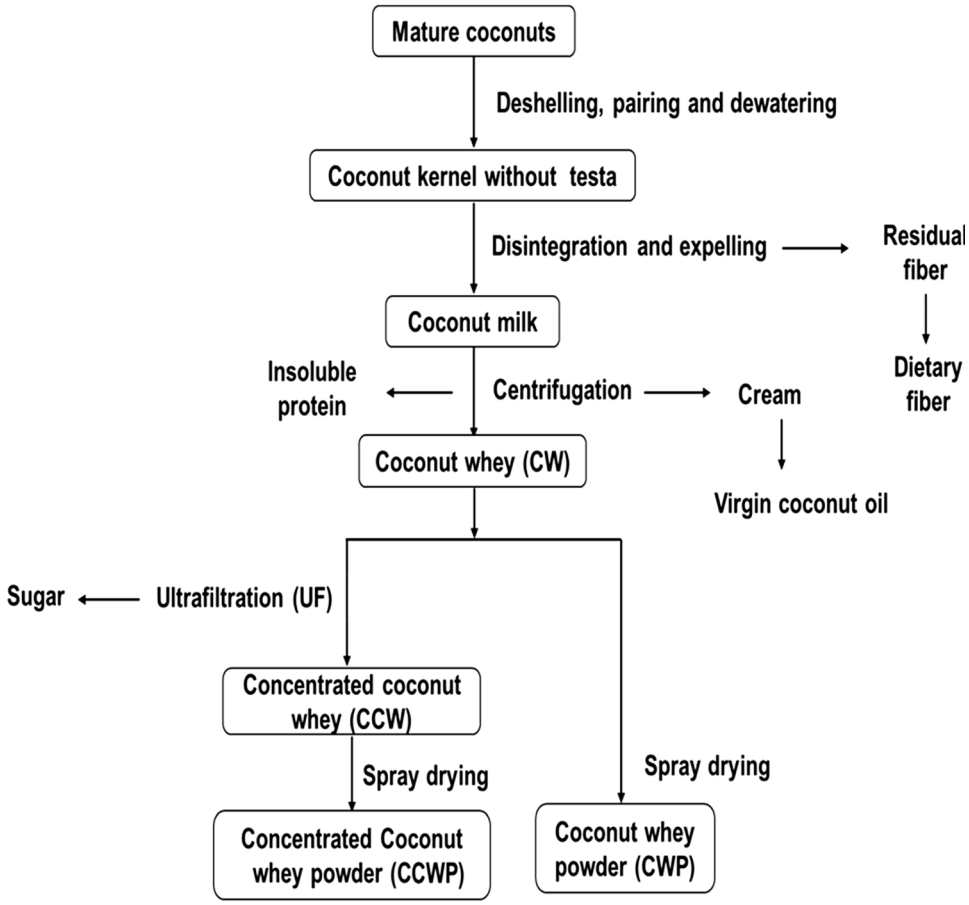

Fig. 1 Flow diagram of the production of coconut whey powder (CWP) and concentrated coconut whey powder (CCWP)

recorded at 490 nm by using an UV spectrophotometer (model 160A, Shimadzu, Japan).

The total carbohydrate content in powder samples was calculated by estimating the balance left after subtracting moisture, ash, fat, and proteins (by difference) and expressed as g/kg of sample.

Polyphenol content

Total polyphenol content of samples was determined by Folin–Ciocalteu colorimetric method as described by Kumazawa et al. (2004). Powder sample (5 g) was mixed with 40 mL methanol for 1 h at 25 ± 2 °C. The suspension was centrifuged for 10 min at 3000 g and 25 ± 2 °C. Supernatant was collected into volumetric flask and volume was made to 50 mL using methanol. The extract was mixed with 2 mL of 10% of Na_2CO_3 and 1 mL of 1 N Folin–Ciocalteu reagent and incubated for 1 h atF ambient temperature and absorbance was measured at 765 nm.

Phytate estimation

Powder samples (0.5 g) were thoroughly mixed with 10 mL of HCl (2.4%) in tubes. Sample tubes were agitated for 16 h on shaker (model: 3040, Tarsons, India) and centrifuged at 1000 g at 10 °C for 20 min. From each experiment, the supernatant was transferred to tubes containing 1 g NaCl and mixed uniformly to dissolve the salt. These tubes were then allowed to rest at 4 °C for 60 min followed by centrifugation at 1000*g* at 10 °C for 20 min. The clear supernatant samples (referred as NaCl treated supernatant) were collected. One ml of the NaCl treated supernatant diluted for 25 times with distilled water. Around 1 mL of modified Wade reagent (0.03% $FeCl_3$.$6H_2O$ + 0.3% sulfosalicylic acid) was added into 3 mL of this diluted solution and mixed thoroughly on a vortex and centrifuged at 1000*g* for 10 min at 10 °C. Standard graph was obtained with series of calibration standards containing 0, 2, 4, 6, 8 and 10 µg/mL of sodium phytate (Gao et al. 2007). Absorbance of samples and standards were noted at 500 nm with an UV spectrophotometer (Model 160A, Shimadzu, Japan).

Water activity

Water activity was measured using a portable water activity measurement system (Pawkit, version 8, Decagon devices Inc.). Sample cup was filled with powder samples

such that the bottom of the cup was entirely covered. After inserting the sample cup in the meter, the meter was placed on a flat surface, switched on and not disturbed until it gives "beep sound" indicating the completion of measurement. The water activity of the sample at the corresponding temperature was recorded.

Powder flowability and cohesiveness

The bulk density (ρ_{bulk}) of powder was calculated with mass/volume in 100 mL measuring cylinder. Tapped density of samples was measured by tapping the cylinder 250 times using tapped density meter (model ETD-1020, Electrolab, India). Tapped density (ρ_{tapped}) was calculated by mass/volume. Carr Index (CI) (Carr 1965) and Hausner ratio (HR) (Hausner 1967) were used to evaluate the flowability and cohesiveness of the powder samples respectively with the help of following equations:

$$CI = \left[\frac{\rho_{tapped} - \rho_{bulk}}{\rho_{tapped}}\right] \times 100 \quad (1)$$

$$HR = \frac{\rho_{tapped}}{\rho_{bulk}} \quad (2)$$

The values of Carr's index in the range from 5 to 15 shows excellent flow, 16–18 indicates good flow, between 19 and 21 shows moderately good flow, 22–35 indicates poor flow and the Carrs index values in the range of 36–40 indicates very poor flow properties. The powder shows low, intermediate and high cohesiveness when the HR values are less than 1.2, 1.2–1.4 and more than 1.4, respectively.

Colour analysis

L*, a*, and b* values (CIE-Commission Internationale de L'Eclairage) of both the powders (obtained by different drying methods) were observed by using a colorimeter (model: CM-5, Konica Minolta, Japan). Instrument was calibrated with a standard white reflector plate. The colour values were measured by using illuminant D_{65} and 10° observer angle.

Particle size analysis

The particle size distribution of powder samples was evaluated by using particle size analyser (Model S3500 series, Microtrac, Pennsylvania, USA). The particle size analyser works on the principle of laser dispersion. Sample of 1 g was loaded for each analysis and measurements were carried out in triplicates.

Protein solubility

Protein solubility of powder samples was analysed according to the modified method described by Tang (2007). Spray dried protein powder samples (0.1% w/v) were dissolved into distilled water with stirring for 15 min using magnetic stirrer. The pH of samples was adjusted to 10 with HCl or NaOH. Samples were centrifuged for 15 min at 8000*g* and 25 °C, and the protein content of the supernatant was determined by AOAC method. Percent protein solubility was calculated as

$$\text{Protein Solubility}\,(\%) = \left(\frac{Protein\ content\ of\ supernetent}{Total\ protein\ content}\right) \times 100.$$

Powder solubility

Whey powders (2.5 g each) were distributed in 25 mL of distilled water at 30 ± 1 °C and prepared suspension was mixed thoroughly by vortexing followed by centrifugation at 3500 rpm for 15 min. The supernatant was collected in pre-weighed petri dish and dried into hot air oven at 100 °C for 5 h. Final weight of the petri dish with solids was noted and the solubility (%) was calculated based on the weight difference according to method (Shittu and Lawal 2007). All the experiments were carried out in triplicate.

Wettability

The wettability of the powder samples was measured by using procedure described in A/S Niro Atomizer (1978). Around 100 mL of distilled water was taken in a 250 mL beaker. A glass funnel was kept above the beaker on a ring stand and 5 cm distance was maintained between the bottom of funnel and the water surface. A test tube was placed inside the funnel, and powder (0.1 g) was poured around the test tube. The test tube was lifted and the powder was allowed to fall into the beaker. The time was recorded for the powder to become completely wetted (visually assessed as when all the powder particles penetrated the surface of water) using stop watch.

Results and discussion

The present study was carried out for the concentration of coconut whey protein using membrane processing (ultrafiltration) followed by dehydration (spray drying). Quality evaluation of the final products was carried out. The observed results were discussed in the following subsections.

Ultrafiltration of coconut whey

Ultrafiltration (UF) can be a very efficient process for separating the components that are suspended or dissolved in a liquid depending on their size/molecular weight, a suitable membrane is selected and the process parameters are optimized to achieve the maximum yield. The choice of parameters, made with respect to retention of the key components in this study: molecular weight cut off (MWCO) of membrane, feed pH and Transmembrane Pressure (TMP). Their effect was studied on transmembrane flux, protein retention and sugar removal.

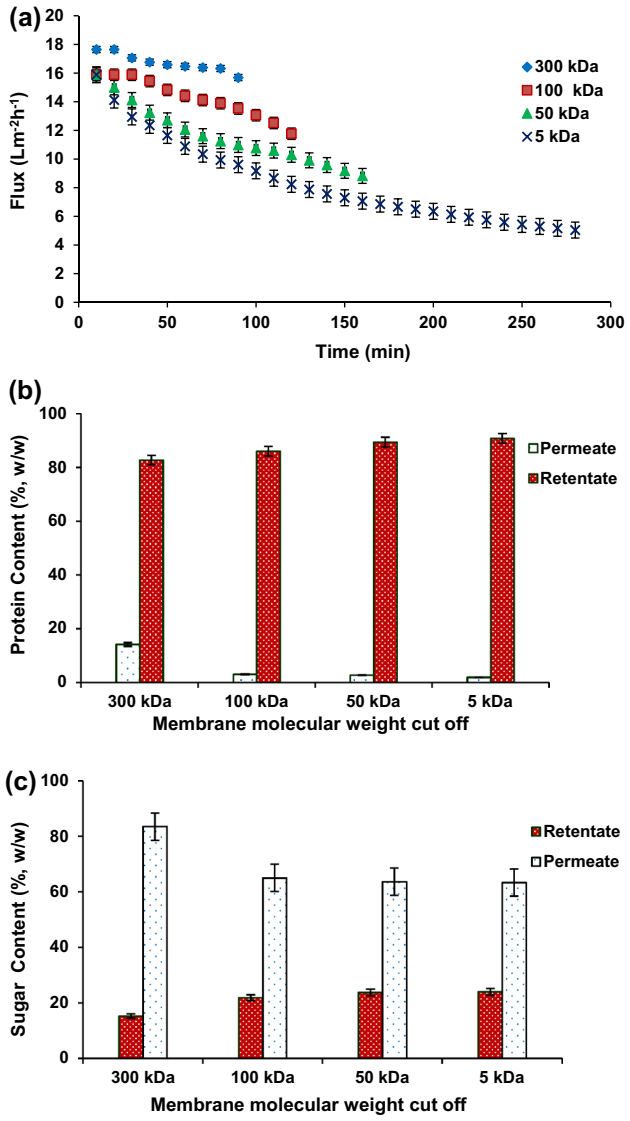

Fig. 2 Effect of membrane molecular weight cut off (MWCO) on **a** transmembrane flux, **b** protein retention, and **c** sugar removal

Selection of membrane molecular weight cut-off

The effect of molecular weight cut-off (MWCO) of UF membranes on transmembrane flux is shown in Fig. 2a. The TMP was maintained at 3 bar and stirring speed at 300 rpm. It can be seen from the figure that the permeate flux is much higher during UF for membrane of high MWCO and decreased with a decrease in MWCO mainly due to the variation offered by the membrane. The required concentration factor (CF—5) was obtained about 3 times faster in case of 300 kDa membrane compared to 5 kDa membrane.

The retention of proteins after UF of coconut whey is shown in Fig. 2b. As expected lower MWCO membranes were more effective in retaining protein in the retentate. Only about 83% (w/w) protein could be retained in case of 300 kDa membrane, while about 86–90% protein retention was observed in permeates using 100, 50 and 5 kDa membranes. Kwon et al. (1996b) reported protein retention to be ~ 80% and ~ 90% using 10 and 5 kDa membranes, respectively, during production of coconut protein concentrate from 1% coconut protein solution at 1 bar TMP using pilot scale hollow fiber ultrafiltration unit. Ultrafiltration is typically used for achieving concentration of proteins, desalting or buffer exchange and for removal of sugars, non-aqueous solvents, low molecular weight compounds etc. (Meena et al. 2015).

The effect of membranes MWCO on removal of sugar from coconut whey samples is shown in Fig. 2c. The sugar removal was found to be the highest in case of 300 kDa membrane (~ 84%), while it is ranged from 63 to 65% (w/w) for other MWCO membranes.

Based on these results of effective sugar removal and protein retention with least processing time, the 300 kDa membrane was selected for subsequent experiments.

Effect of feed pH

The inherent pH of CW is 6 and can be altered by addition of acid or base. In order to study the effect of feed pH (4, 6 and 8) on permeate flux, UF was carried out using 300 kDa membrane at TMP of 3 bar and stirring speed of 300 rpm and the results are shown in Fig. 3a. It can be observed that the initial flux at feed pH 4 to be twice that of the feed at pH 6 and 8. The high permeate flux at feed pH 4 led to faster UF of CW i.e. it consumed only about 2/3rd time compared to that at pH 6 and 8. The drop in flux could be due to quick rejection of protein forming more concentration polarisation. The flux was almost similar for UF for feed pH 6 and 8 and fairly constant throughout the UF process.

The effect of feed pH on retention of protein content in coconut whey in UF is shown in Fig. 4b. Most coconut

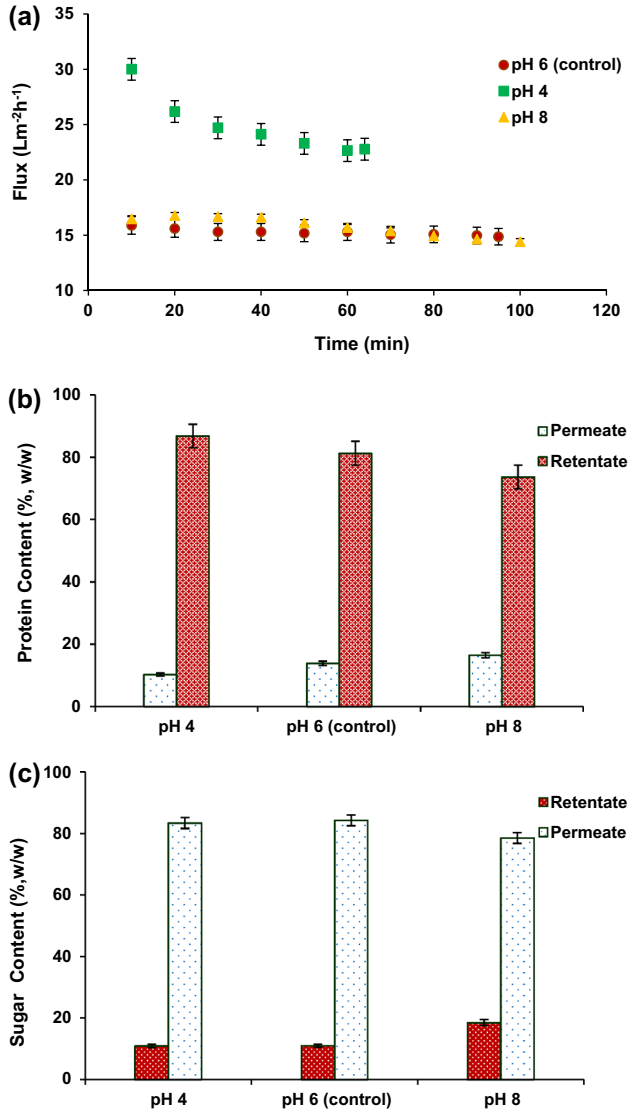

Fig. 3 Effect of Feed pH on **a** transmembrane flux, **b** protein retention, and **c** sugar removal. Membrane MWCO 300 kDa

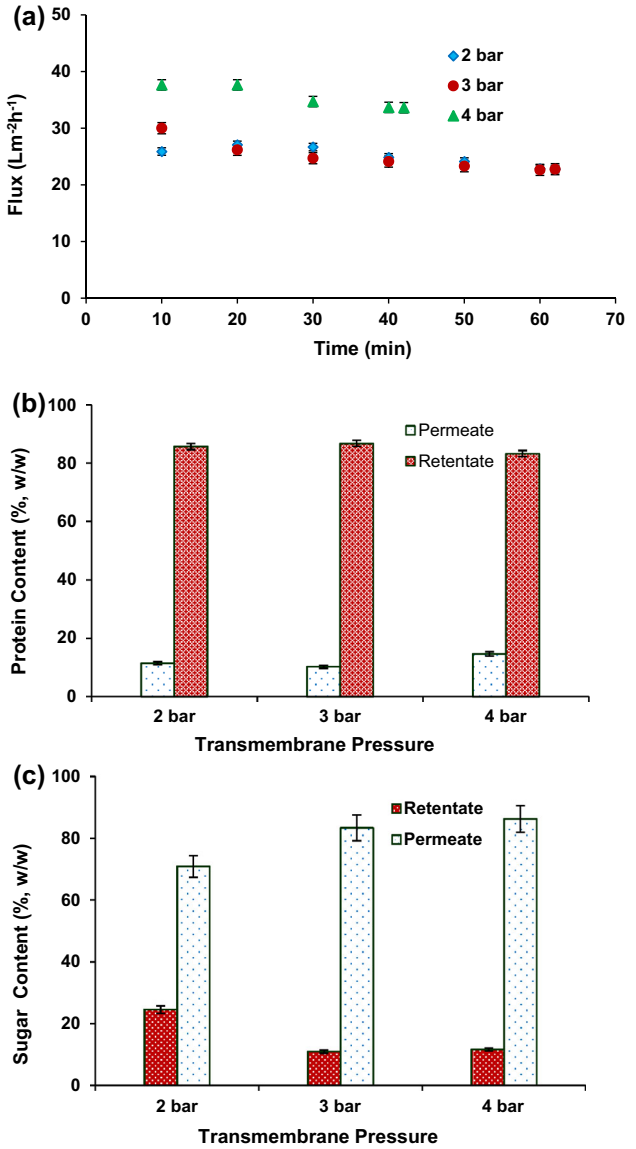

Fig. 4 Effect of transmembrane pressure on **a** transmembrane flux, **b** protein retention, and **c** sugar removal. Membrane MWCO 300 kDa and feed pH 4

proteins have about pH 4 as their isoelectric point (pI) when they exhibit minimum solubility at this pH as the net primary charge of a protein becomes zero (Tangsuphoom and Coupland 2009; Naik et al. 2012). At pH below and above the pI, the proteins will have predominantly positive and negative net charge, respectively. This leads to electrostatic repulsion among proteins. But at pI, where the net surface charge is zero, the surface of the protein will be least solvated or hydrated leading to aggregation of protein molecules. These aggregates precipitate out of the solution and is known as "isoelectric precipitation". Formation of large aggregates at pI (pH 4 for coconut protein) during UF led to the highest protein retention (∼ 87%, w/w) compared to that at pH 6 (∼ 81% w/w) and further away from pI at pH 8 (∼ 74%, w/w).

The effect of feed pH on sugar removal from coconut whey during UF is presented in Fig. 3c. The sugar removal was similar for the feed at pH 4 and 6 (∼ 84% w/w) while for that at pH 8, it was ∼ 79% (w/w). In view of the highest flux, as well as protein retention and reasonable sugar removal, pH 4 of feed (CW) were selected for further experiments using 300 kDa MWCO membrane.

Effect of transmembrane pressure

The effect of Transmembrane pressure (TMP) on transmembrane flux, protein retention and sugar removal during UF of CW using 300 kDa MWCO membrane and feed pH 4 is shown in Fig. 4. It can be observed from the Fig. 4a,

that initial flux is higher at higher TMP. However, after 20 min, fluxes for 2 bar and 3 bar TMP were almost similar. Higher flux and lower processing time can be achieved by UF of CW using higher TMP. Protein retention was found to be similar for 2 and 3 bar TMP (∼ 86% and ∼ 87% (w/w), respectively) but slightly reduced at 4 bar TMP (∼ 83%) (Fig. 4b). Sugar removal was maximum at 4 bar (∼ 86%) and decreased with a decrease in TMP (Fig. 4c). Therefore, it can be inferred that although high flux and sugar removal is possible by increasing TMP, it results in some loss of protein in permeate during UF of CW.

Proximate analysis of coconut whey and spray dried powders

Tangential flow filtration (TFF) was employed to concentrate coconut whey (CW) to obtain concentrated coconut whey (CCW). CW (2 kg) and CCW (400 g) were spray dried to yield 103.5 g and 80.2 g of powder sample, respectively.

The proximate analysis of CW, CCW, spray dried coconut whey (SDCW) and spray dried concentrated coconut whey (SDCCW) are presented in Table 1. It can be observed from the table that protein and fat contents in CCW increased by twofold over that of CW (from 2.52 and 0.49 to 6.93 and 0.75% (w/w), respectively). On the other hand, ash and carbohydrate contents were found to reduce slightly after UF. Comparison between SDCW and SDCCW composition shows practically no difference in moisture content (∼ 3%, w/w w.b.) while protein and fat contents were observed to increase by twofold (from 21 and 46 and ∼ 5 and ∼ 9% w/w). The carbohydrate contents of SDCW and SDCCW were found to reduce from 59 to 34% (w/w), after concentration by UF prior to spray drying. Similar trends were observed when Soy protein concentrate was produced by UF followed by freeze drying (Rao et al. 2002) and UF followed by spray drying (Jinapong et al. 2008).

Analysis of spray dried protein powder

Polyphenol and phytate content

Antinutritional factors such as phytic acid and certain polyphenols limit the use of oilseed proteins for human consumption (Tan et al. 2011). In many oilseed protein sources, polyphenolic compounds are responsible for the development of adverse flavours and colors in food products. They also bind to essential nutrients and alter their chemical and functional properties especially of proteins. It can be observed from Table 2 that the amount of total polyphenols reduced (from 2.56 to 1.84 mg/g) by ultrafiltration of coconut whey prior to its spray drying.

Phytic acid (hexaorthomono phosphate ester of myo-inositol) occurs in legumes, cereals and oil seeds as the calcium magnesium salt, phytin. Phytic acid is known for its metal chelating properties and reduces the bioavailability of various essential minerals by interacting with proteins and multivalent cations to form complexes (Cheryan and Rackis 1980). Both spray dried CW and CCW powders contain about 0.2% (w/w) phytate which is much lower than 2–3% (w/w) present in commercial soy protein isolates (Okubo et al. 1975). Ultrafiltration was unable to lower the phytic acid content in SDCCW powder, could be due to the presence of protein-phytic acid complex in CW.

Water activity and powder properties

Most of the unit operations used in food processing involve stabilization of food material by removal of water either by drying or concentrating, and water activity serves as an index of determining the efficiency of controlling the behaviour of water in food systems (Rockland 1987). The water activity values of both CW and CCW powders were similar (0.26 and 0.27, respectively) at 25.7 °C which indicates that the powders are microbiologically stable.

Classification of flowability and cohesiveness of spray dried CW and CCW powders are presented in Table 2. Flow properties of both the powders were not much different indicated by Carr Index (∼ 33 which indicates fair flowability). Similarly, the cohesiveness was almost

Table 1 Proximate analysis of coconut whey and dry powders

Sample name	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Carbohydrate (%)
CW	84.88 ± 0.39	2.52 ± 0.16	0.49 ± 0.09	1.08 ± 0.06	6.34 ± 0.44
CCW	79.18 ± 0.30	6.93 ± 0.61	0.75 ± 0.01	0.99 ± 0.00	6.41 ± 0.18
SDCWP	2.99 ± 0.21	21.43 ± 0.34	4.78 ± 0.22	8.52 ± 0.39	59.27 ± 1.53
SDCCWP	3.09 ± 0.27	45.49 ± 1.94	9.49 ± 0.12	6.03 ± 0.37	34.00 ± 3.80

Values are averages ± standard deviation from three replicate analysis

CW coconut whey, *CCW* concentrated coconut whey, *SDCWP* spray dried coconut whey powder, *SDCCWP* spray dried concentrated coconut whey powder

Table 2 Parameters of spray dried coconut whey powders

Parameter	SDCWP	SDCCWP
Polyphenol content (mg/g)	2.56 ± 0.08	1.84 ± 0.04
Phytate content (mg/g)	2.11 ± 0.01	2.15 ± 0.03
Water activity (a_w)	0.26 ± 0.01	0.27 ± 0.00
Flowability	Fair	Fair
CI (%)	33.14	32.95
Cohesiveness	High	High
HR	1.47	1.5
Particle diameter of 50% particles (μm)	< 78.81	< 69.50
Wettability (s)	21 ± 0.01	23 ± 0.05
Protein solubility (%)	97 ± 0.05	93 ± 0.01
Powder solubility (%)	97 ± 0.05	95 ± 0.01
Color		
L*	83.81 ± 0.10	80.70 ± 0.05
a*	− 0.83 ± 0.02	0.54 ± 0.01
b*	12.37 ± 0.08	15.21 ± 0.02

Values are averages ± standard deviation from three replicate analysis

SDCWP spray dried coconut whey powder, *SDCCWP* spray dried concentrated coconut whey powder, *CI* Carr Index, *HR* Hausner ratio, *L** color lightness, *a** color redness, *b** color yellowness

identical for spray dried CW and CCW powders based on Hausner ratio (∼ 1.5 which indicated high cohesiveness). Colour analysis, as indicated in Table 2, revealed less lightness and more yellow colour (indicated by lower L* and higher b* values in CIE colour measurement system) in spray dried CCW powder compared to spray dried CW powder. Both the powders looked alike and off-white in colour. The L* values of spray dried coconut whey powders were comparable to that of L* values of freeze dried coconut skim milk powder reported by Naik et al. (2014).

Particle size, wettability and solubility

The particle size distribution of spray dried coconut whey powder was determined by calculating the average particle diameter. It can be seen from Table 2, the average diameter of SDCW powder (50% particles) was observed to be less than 78.81 μm. In spray-dried powder samples the voids between big particles are filled with smaller particles and hence bulk density increased and less volume occupied (Schubert 1993). Powder solubility (97% for SDCW and 95% for SDCCW powders) is very important physical property, as the particle size decreases the total surface area of the powder increases, which leads to greater affinity for moisture and possibility of cake formation during storage (Hogekamp and Schubert 2003). The protein solubility of SDCW and SDCCW powders was found to be 97 and 93%, respectively, shown in Table 2. In addition, the particle size affects the rehydration properties. The small particles present in the particulate system results in poor instantaneous properties and affect powder wettability (Hogekamp and Schubert 2003).

Wettability is the property of a liquid to penetrate into a porous agglomerate system, and usually measured as the time required for all particles to be completely wetted. The wettability of SDCW and SDCCW powders was observed to be 21 and 23 s (Table 2).

Conclusion

A process was developed for the recovery of proteins from coconut whey, which is discarded as waste during wet processing for production of VCO. Membrane processing at standardised conditions significantly reduced the sugar while retaining the proteins. As a result, spray dried coconut whey powder enriched in protein could be produced with good flow properties, stability and sensory quality. The powders have high potential as new source of protein or as a functional ingredient in the food processing industries.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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