INTISARI

Pemanfaatan sorgum merah (*Sorghum bicolor* L. Moench) sebagai sumber karbohidrat pendukung ketahanan pangan terkendala oleh tingginya kadar fenolik dalam perikarp (*bran*) biji sehingga memerlukan penyosohan sebelum penepungan. Senyawa fenolik yang didominasi proantosianidin tersebut berpotensi sebagai antioksidan kuat untuk bahan tambahan pangan dan obat-obatan.

Penelitian mengembangkan teknik ekstraksi dari biji sorgum merah sebagai solusi berbagai kendala dalam pemungutan *crude-sorghum-extract* (CSE) dari *bran* sorgum. Percepatan ekstraksi dengan *natural-deep-eutectic-solvent* (NaDES) meliputi *citric acid-sucrose* (CAS) dan *citric acid-fructose* (CAF) dilakukan agar aman bagi produk antioksidan atau biji pasca-ekstraksi sehingga ekstraksi CSE, pengurangan kadar proantosianidin, dan *annealing treantment* biji sebelum penepungan terintegrasi. Evaluasi kuantitatif dengan pendekatan model matematis diperlukan dalam penentuan konsentrasi efektif NaDES dan variabel proses setiap teknik percepatan ekstraksi yang diterapkan (*conventional extraction* (CE), *ultrasound-assisted extraction* (UAE), dan *moderate-ohmic extraction* (MOE)).

Penelitian bertujuan untuk mengevaluasi kuantitatif penentuan konsentrasi efektif NaDES serta kondisi terbaik CE, UAE, dan MOE untuk mempercepat ekstraksi proantosianidin dari biji sorgum. Penelitian juga bertujuan untuk menentukan formula enkapsulan dan suhu pengeringan untuk mempercepat *foam-mat drying* (FD) dalam enkapsulasi CSE.

Evaluasi kuantitatif kinerja ekstraksi didasarkan pada peningkatan kadar proantosianidin CSE pada beberapa konsentrasi NaDES dan variabel proses setiap teknik ekstraksi. Formulasi enkapsulan didasarkan pada profil sifat fisik foam selama *whipping*. Kinerja FD didasarkan pada perubahan kadar air foam selama pengeringan. Deskripsi kuantitatif kinerja ekstraksi maupun FD dilakukan dengan 3 macam model matematika, 2 diantaranya dikembangkan berdasarkan mekanisme transfer massa proses. Model mekanistik dikembangkan untuk menentukan nilai parameter transfer massa serta memprediksi unjuk kerja.

Screening menggunakan *liquid-chromatography-mass spectrometry* menunjukkan keberhasilan kedua NaDES dalam ekstraksi proantosianidin. Variabel proses (variasi putaran pengaduk dan suhu pada CE, amplitudo pada UAE, serta jarak dan luas elektroda pada MOE) serta konsentrasi NaDES menentukan kinerja ekstraksi. Diantara ketiga model matematika ekstraksi, model mekanistik yang diusulkan (model 3) menunjukkan akurasi terbaik dalam memprediksi kadar proantosianidin CSE dan setiap lapisan perikarp untuk menentukan ketuntasan ekstraksi. Model tersebut juga berfungsi baik dalam menentukan nilai difusivitas efektif (D_{eP}), koefisien perpindahan massa antarfasa (k_c), serta menggambarkan fenomena setiap teknik ekstraksi. Kinerja tertinggi dihasilkan MOE dengan IML 55 V/cm, KS 11,3 cm, dan nilai RVM 10:1 mL/g menggunakan CAS atau CAF 0,169% dengan kadar proantosianidin mencapai 2,787 mg/mL dan 2,595 mg/mL. Peningkatan kinerja oleh elektropermeabilisasi-elektroporasi digambarkan model 3 dengan peningkatan D_{eP} dan k_c. Masing-masing NaDES dengan konsentrasi 10% belum efektif mempercepat CE tetapi efektif mempercepat UAE beramplitudo 0,0064 cm

dengan kadar proantosianidin 2,104 mg/ mL dan 1,990 mg/mL melalui sonopermeabilisasi-sonoporasi.

Model matematika mekanistik FD berfungsi baik dalam memprediksi kadar air *foam* dan setiap lapisan *foam* untuk menentukan ketuntasan FD dan menghindari *overheating*. Kualitas dan stabilitas *foam* terbaik dengan nilai D_{ef_FD} dan K_{FD} tertinggi dihasilkan dari penambahan 0,5% *xanthan gum*, 10% *whey protein isolate*, dan 20% *arabic gum* pada CSE.

Enkapsulasi dengan FD pada suhu 40 °C menghasilkan *powder* CSE terenkapsulasi berkadar proantosianidin tertinggi (9,227 mg/g) dan ukuran partikel 425,3-508,5 nm. *Powder* CSE tanpa enkapsulasi memiliki aktivitas antioksidan pengikatan radikal bebas DPPH dengan IC_{50} sebesar 5,989 ppm dan kapabilitas pengikatan 128,37 mg_{DPPH}/g, sedangkan CSE terenkapsulasi memiliki IC_{50} sebesar 30,299 ppm dan kapabilitas pengikatan 25,37 mg_{DPPH}/g.

Kata kunci: antioksidan, ekstraksi, sorgum, *green solvent*, fenolik, proantosianidin, CE, UAE, MOE, enkapsulasi, *drying*.

ABSTRACT

Utilization of red sorghum (*Sorghum bicolor* L. Moench) as a source of carbohydrates supporting food security is constrained by the high phenolics content in their pericarp (bran), requiring dehulling before milling. The phenolic compounds predominantly by proanthocyanidins are potential as strong antioxidants for food additives and medicines.

The research developed an extraction technique from red sorghum grains to solve several constraints in collecting crude-sorghum extract (CSE) from sorghum bran. Acceleration of extraction is carried out applying natural-deep-eutectic-solvent (NaDES) consisting of citric acid-sucrose (CAS) and citric acid-fructose (CAF) that is safe for antioxidant products or post-extraction grains, so the CSE extraction, phenolics reduction, and annealing treatment for grains before milling can be integrated. Quantitative evaluation using a mathematical model approach is needed to determine the effective NaDES concentration and process variables in each technique of extraction acceleration (conventional extraction (CE), ultrasound-assisted extraction (UAE), and moderate-ohmic extraction (MOE)).

This study aimed to evaluate quantitatively the determination of the effective concentration of NaDES and the best conditions for CE, UAE, and MOE to accelerate the proanthocyanidins extraction from sorghum grains. The research also aimed to determine the encapsulant formula and drying temperature to accelerate foam-mat drying (FD) in CSE encapsulation.

Quantitative evaluation of the extraction performance was based on the increase of proanthocyanidin content in CSE at several concentrations of NaDES and process variables in each extraction technique. The formulation of encapsulation is based on the physical properties profile of foam during whipping. The FD performance is evaluated based on the changes in foam moisture content during drying. Quantitative descriptions of extraction and FD performance were carried out using 3 kinds of mathematical models, 2 of them were developed based on the mass transfer process mechanism. A mechanistic model was developed to describe the mass transfer parameters and predict their performance.

Screening using liquid-chromatography-mass spectrometry showed the success of both NaDES in proanthocyanidin extraction. Process variables (variation of agitation speed and temperature at CE, amplitude at UAE, and the distance and area of electrode at MOE) and NaDES concentration affected the extraction performance. Among the three extraction mathematical models, the proposed mechanistic model (model 3) showed the best accuracy in predicting the proanthocyanidin levels in CSE and each pericarp layer to determine the extraction completeness. The model also works well in determining the value of effective diffusivity (D_{eP}), interphase mass transfer coefficient (k_c), and describes the phenomenon of each extraction technique. The highest performance was obtained by MOE with IML of 55 V/cm, KS of 11.3 cm, and RVM value of 10:1 mL/g using CAS or CAF 0.169% reaching proanthocyanidin levels of 2.787 mg/mL and 2.595 mg/mL. The performance improvement by electropermeabilization-electroporation is described by model 3 with the increase in D_{eP} and k_c. Each NaDES with a concentration of 10% has not been effective in accelerating CE but effective in accelerating UAE with an amplitude of 0.0064 cm reaching proanthocyanidin levels of 2.104 mg/mL and 1.990 mg/mL through sonopermeabilization-sonoporation.

The mechanistic mathematical of the FD model works well in predicting the moisture content in foam and each foam layer to determine the completeness of FD and avoid overheating. The best foam quality and stability with the highest value of D_{ef_FD} and K_{FD} have resulted from the addition of 0.5% xanthan gum, 10% whey protein isolate, and 20% Arabic gum in CSE.

Encapsulation with FD at 40 resulted in encapsulated CSE powder with the highest proanthocyanidin content (9,227 mg/g) and particle size of 425.3-508.5 nm. Powder of CSE without encapsulation has antioxidant activity in DPPH radical scavenging with IC_{50} of 5.989 ppm and scavenging capacity of 128.37 mg_{DPPH}/g, while the encapsulated CSE has IC_{50} of 30.299 ppm and scavenging capacity of 25.37 mg_{DPPH}/g.

Key words: antioxidant, extraction, sorghum, green solvent, phenolic, proanthocyanidin, CE, UAE, MOE, encapsulation, drying.