國立臺灣海洋大學食品科學系碩專班
專題討論書面報告

以酵素處理與雙螺桿擠壓機擠壓膨發對糙米及其米糠活性成份含量的影響

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何宥緗

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摘要

稻穀在去除稻殼之後成為糙米(brown rice) 留著米糠及胚乳的部分，糙米之最外層為米糠，因糙米及其米糠富含高膳食纖維可作為機能性產品開發使用。選用適當的酵素可以破壞植物細胞壁釋出酚類化合物，改善米糠粗糙質地；擠壓技術為具有高溫短時間、連續化、高產率及高能效率等多項優點的加工技術。本次專題討論探討以酵素處理與雙螺桿擠壓機所產生擠壓膨發對糙米及其米糠的影響性。第一篇研究用不同α-澱粉酶濃度擠壓的糙米，其還原糖，總酚，總抗氧化活性和單個酚酸含量，探討還原糖與酚類物質保留之間的關係，以糙米在酶催化擠壓過程中，其還原糖與酚類保留量呈正相關。因此，酶催化擠壓是糙米獲得較高酚類化合物保留率，為較佳加工技術。另一篇使用中溫α-澱粉酶（mesophilic α-amylase，EMA）處理與上篇的耐高溫α-澱粉酶（thermostable α-amylase，ETA）處理進行比較，顯示 EMA 處理糙米具有較高游離酚、游離抗氧化活性、游離總酚酸和游離類黃酮的保留率。EMA 為糙米改善營養更好的加工技術。第三篇探討米糠經酶處理改善膳食纖維的特性，米糠富含非水溶性膳食纖維(insoluble dietary fiber，IDF)，其水溶性膳食纖維(water-soluble dietary fibre，SDF)含量低，水溶性膳食纖維已證明對人體健康有益。將 RB-IDF(Rice Bran-insoluble dietary fiber) 轉化為 RB-SDF(Rice Bran- water-soluble dietary fibre)。將有利於米糠作為功能性食品成分的增值。米糠必須經水洗來除去水溶性化合物，為了增加可轉化為 SDF 的總膳食纖維（IDF + SDF）比例。洗滌米糠濃縮物以擠壓蒸煮處理，其 SDF 含量提高；以順序式擠壓-酶處理顯高 SDF 含量四倍，尤其可溶性戊聚醣含量。綜觀上述，糙米與其米糠透過酶催化擠壓方法，具有提高其營養價值。

前言

稻穀在去除稻殼之後成為糙米(brown rice) 留著米糠及胚乳的部分，糙米之最外層為米糠，碾米工廠之副產品米糠是稻米麩皮、胚芽及糊粉層的混合物，雖然米糠及胚芽僅占糙米重量的 8%左右，但稻米 60%以上的營養素都存在於米糠中。米糠中含有豐富蛋白質、維生素、礦物質、多元不飽和脂肪酸和許多天然的抗氧化劑，酶催化擠出是穀物擠出的種新型形式，其中將擠出和酶（通常為澱粉酶）同時應用於高澱粉穀物，以達到同時液化，糊化和生物轉化，或提高發酵效率。(De Pilli et al., 2004; De Pilli et al., 2009; Solihin et al., 2007; Xu et al., 2015a)在穀物類產品（例如木聚醣酶）中使用酶降解胞壁來改善 soluble dietary fiber (SDF)。因此本研究將探討擠壓技術對糙米及副產品之影響，以改善糙米及副產物的烹煮困難缺點，在未來有潛力發展成機能性食品。

二、酶催化膨化糙米中還原糖與酚類保留的關係

Zeng 等人(2017) 將糙米經磨碎後，樣品製備方面為傳統擠壓樣品(糙米粉+30%水)與酶催化擠壓膨出樣品(操米粉+30%水+ thermostable α-amylase)，以雙螺桿擠壓機進行擠壓膨出，來評估在不同濃度α-amylase 濃度(0.1%，0.5%，1%, w/w)擠壓糙米，其還原糖、總酚含量、總抗氧化劑活性與各個酚酸，通過 Pearson 相關分析， 探討酶促擠壓後還原糖與糙米的酚類保留之間的關係。

在生和擠壓的糙米中還原糖含量（圖 1），酶促擠壓後還原糖顯著增加，與酶濃度呈正相關，表明澱粉在酶促擠出過程中被降解；在游離酚，結合酚和總酚含量(圖 2)，隨著酶濃度的增加，酶促擠壓明顯增加游離酚和總酚的保留率。故添加熱穩定的α-澱粉酶可提高糙米中酚類的保留率；在抗氧化活性影響(表 1)，與酚含量的變化相似，主要游離抗氧化劑活性的提高。

糙米中的主要酚酸是阿魏酸，對香豆酸和咖啡酸，主要以結合形式存在。擠壓後，大多數游離酚減少，結合酚酸增加；1％澱粉酶的酶促擠出物的總游離酚酸比原料高 3.4 倍， 酶促擠出過程中游離酚極大改進。

綜合上述實驗結果得知，糙米添加耐熱性 α-澱粉酶提高糙米中的酚類保留率，透過酶催化擠壓過程中，證實還原糖可以在酶催化擠壓過程中保護酚類化合物，糙米獲得較高酚類化合物保留率的加工技術。

三、經中溫α-澱粉酶擠壓後糙米的酚類保留

Zeng 等人(2018)將糙米經研磨後，以耐高溫α-澱粉酶（thermostable α-amylase，ETA）的糙米的酚類保留率與中溫α-澱粉（mesophilic α-amylase，EMA）的糙米的酚類保留率和還原糖的影響進行比較及黃酮類化合物的保留率研究。在擠壓後糙米中黃酮類化合物的殘留量方面(Fig 5b)，隨酶含量添加，EMA 提高游離類黃酮的保留率。生糙米和膨化糙米中的酚類特徵均以反式阿魏酸(trans-ferulic acid)，反式咖啡酸(trans-caffeic acid)和反式對香豆酸(trans-p-coumaric acid)為主，大多以結合形式存在。尤其低溫擠壓所游離酚酸總量顯著增加，有助於保留糙米中的酚酸。還原糖與游離酚、游離類黃酮、游離 DPPH 值、游離 FRAP 值及游離 ABTS 值呈正相關；澱粉降解程度與酚類保留量呈正相關。

綜合以上實驗結果，經酶催化水解引起的澱粉降解和還原糖，有利於改善糙米的酚類保留。EMA 產生還原糖低於 ETA；用 EMA 處理的糙米顯示的游離酚含量、游離抗氧化活性和總游離酚酸的保留率高於 ETA 處理的糙米。EMA 提高游離類黃酮的保留率。EMA 可能為糙米改善營養的加工技術。

四、使用酶和擠壓蒸煮法改變米糠膳食纖維濃縮物

Dang 等人(2019)將米糠粉（50 g）懸浮在 250mL 水中，使用 Waring®攪拌器以 22000rpm 的轉速攪拌 2 分鐘，然後用 75μm 的篩網粗篩，殘留在篩子上的殘留物主要是不溶性膳食纖維，被稱為纖維截留物 1.，再將滲餘物 1 再洗滌兩次以獲得纖維滲餘物 3，然後在 50℃下烘箱乾燥過夜以獲得纖維濃縮物。分別以獨立或結合水洗過的米糠透過物理性的擠壓和酶催化（木聚醣酶）技術，來最大化米糠中的水溶性戊聚醣含量。

米糠和其水洗纖維濃縮物的產量和組成(Table 7)，顯示本研究中使用的麸皮樣品的化學成分，米糠的主要成分是 TDF（IDF 和 SDF，其中一個重要部分是戊聚醣），脂質，澱粉，蛋白質和灰分（包括肌醇六磷酸和磷）。 總體而言， 安定化米糠的 TDF 量最高；安定化米糠和天然米糠的脂質含量較高；商業脫脂米糠的灰分高；商業脫脂米糠所含戊聚醣的比例最高，天然米糠和安定化米糠中總磷含量較高。米糠中的澱粉含量在 10％到 55％之間；TDF 的主要成分是 IDF，而米糠中的 SDF 很少(Saunders, 1990)。

米糠經水洗可得到 9.8－26.0％的纖維濃縮物，水洗明顯減少澱粉，蛋白質，脂質，可溶性膳食纖維（SDF），植酸，磷和灰分； 增加不溶性膳食纖維（IDF），總膳食纖維（TDF）和戊聚醣含量。水洗天然米糠的中澱粉含量降低幅度最大；水

洗實驗室脫脂米糠所含 IDF 和蛋白質含量高，表明用乙醇進行脂肪提取影響蛋白質和戊聚醣對米糠結構複合物基質的粘附。

顯微結構形態（Fig.7 與 Fig. 8）水洗後大部分殘留物是纖維（約 75%），其結構組織為蜂窩狀細胞壁。水洗天然米糠及安定化米糠顯示脂質含量降低 52%；經擠壓蒸煮後米糠的蜂窩狀細胞壁結構破裂，表示複雜矩陣的解離程度很大；擠壓前處理分解米糠細胞壁的剛性結構，使天然細胞壁水解酶（例如木聚醣酶）易於滲透細胞壁結構(Hwang, Park, & Yun, 2003)。連續擠壓酶處理，米糠細胞壁細胞壁塌陷並崩解。

木聚醣酶處理過的米糠濃縮液中熱水和溫水可溶物的成分(Table 9)，所有酶處理均增加米糠的總可溶性含量。在 100˚C 熱水可溶物含量，Ali 木聚醣酶和 Bio-cat 木聚醣處理，總可溶物含量最高，Multifect 720 木聚醣酶效果最低，Enzeco 木聚醣酶作用介於 Ali 木聚醣酶和 Bio-cat 木聚醣之後；以水洗實驗室脫脂米糠的戊聚醣較高；Bio-cat 木聚醣酶處理，總戊聚醣、澱粉、蛋白質和灰分佔熱水可溶物的 82%，18%是非澱粉寡糖，其主要與米糠中的半纖維素和阿拉伯木聚醣共存 (Shibuya & Iwasaki, 1985) 。在 37 ℃溫水可溶物含量，經 Multifect 720 和 Enzeco 木聚醣酶處理，水洗實驗室脫脂米糠其總可溶性含量與個別可溶性含量在溫水比熱水提取中低，儘管提取時間長。溫水總可溶物含量低，主要原因是澱粉和戊聚醣含量低；Ali 和 Bio-cat 處理的水洗實驗室米糠，溫水總可溶性含量高於熱水總可溶性含量，而在溫水中所有個別可溶性成分均較低。

無添加酶的擠出商業脫脂米糠纖維濃縮物的組成(Table 10)，在 37˚C 時溫水可溶物加水量低（<45%）的擠壓處理不顯著增加溫水總可溶物的產量，而加水量高（≥45%）時，膨化米糠明顯的高產量；在 50 rpm 的螺桿轉速下，僅添加 45%水的擠出可溶物高；在 100 rpm 的螺桿轉速下，45%和 60%水的添加量均將可溶物含量增加；加水量和螺桿速度的增加與溫水溶性戊聚醣和澱粉含量增加呈正相關。擠壓樣品的可溶性蛋白質含量降低；在 100 rpm 的螺桿轉速與高含水量結合，可溶性灰分增加。

Bio-cat 木聚醣酶同時和順序處理的膨化米糠中總可溶物和可溶性戊聚醣含量變化(Fig. 10)，單獨擠壓和同時擠壓-酶處理，37˚C 溫水的總可溶物和可溶性戊聚醣含量無差異；順序擠壓-酶處理的熱水溶性戊聚醣的含量約為溫水戊聚醣的兩倍。當酶添加量從 1%增加 2%時，溫水和熱水總可溶物平均增加約 10%。則可溶性戊聚醣含量沒變化。

綜合上述實驗結果得知，米糠經水洗可以用作生產膳食纖維濃縮物的有效方法。經洗滌程序除去非纖維化合物，例如澱粉和脂質，增加總膳食纖維（IDF + SDF）的含量。酶處理改善膳食纖維特性，洗滌米糠纖維濃縮物提高 SDF 含量 50％以上。來自不同來源的木聚醣酶顯示出不同的木聚醣分解效率，擠壓蒸煮提高洗滌後的米糠濃縮物的 SDF 含量，以順序式擠壓-酶處理提高 SDF 含量四倍，尤其是可溶性戊聚醣含量。該方法可在工業上用於調節米纖維濃縮物並提高其營養價值。

從實用的工業角度來看，用水洗滌米糠是有利的，因為從濾液（副產物）中收集的殘留物具有高的澱粉含量和其他具有營養價值的成分，例如米蛋白。需要進行試驗和商業規模的試驗，以確認整個過程的商業實用性。

五、結論

綜合以上實驗結果得知，酶催化擠壓加工技術，讓糙米獲得較高酚類化合物保留率，以中溫-α-澱粉酶處理糙米，其游離酚、游離抗氧化活性、游離酚酸的保留率高，對於糙米改善營養有良好效果；米糠透過水洗來生產膳食纖維濃縮物有效方法，以 Ali 和 Bio-cat 的木聚醣酶有高分解效率；酶處理將米糠濃縮物的 SDF 含量提高，以順序擠壓-酶處理 SDF 含量提高，透過擠壓和酶水解的組合過程，調節糙米及其副產物(米糠)，來提高營養價值。

Abbreviation：

Total dietary fiber，TDF：總膳食纖維

Insoluble dietary fiber，IDF：非水溶性膳食纖維

Soluble dietary fiber，SDF：水溶性膳食纖維

Stabilized rice bran obtained commercially ，SRB：安定化米糠

Native rice bran obtained commercially，NRB：天然米糠

Commercial Defatted Rice Bran，CDRB：商業脫脂米糠

Lab Defatted Rice Bran，LDRB：實驗室脫脂米糠

六、問題與回答

糙米及其米糠透過雙軸擠壓機的優缺點有哪些？

擠壓機將電能、機械能轉變為熱能，而使溫度升高，達到物料烹煮之目的，物料中的大分子物質特性及組織結構受到影響，其作用包括；澱粉湖化與裂解、蛋白質變性及

成分物質間交互作用等，使結構變成具有多孔狀，產品食用口感酥脆，如目前市售的喜瑞兒穀類營養早餐、穀物棒、乖乖產品都是擠壓膨化類產品。

缺點如下：

雙軸擠壓機適用於高進料水分(＞40%)範圍，但其設備成本頗高；擠壓時金屬的流動不均勻，製品表層與中心、頭部與尾部的組織性能不均勻現象。

米穀粉之粒徑分佈會影響粒子於固定時間下之吸水量，因而影響其受熱後之糊化度，以濕磨粉製成之產品，品質較佳；濕磨過程中會產生大量之廢水，引發環保問題。

優點如下

雙螺旋擠壓機提供多重生成階段，即可揉練和攪拌，有較高剪切力及生產效能；高溫及封閉之擠壓膨化系統；1 料滯留螺管（套筒與螺軸之空間）時間好控制，對熱敏感物料較有利；2.可適用含水率較低之原料，剪力較小且能源消耗更低，且產品樣式多變；具有製程低汙染、低水活性成品且微生物不易生長。

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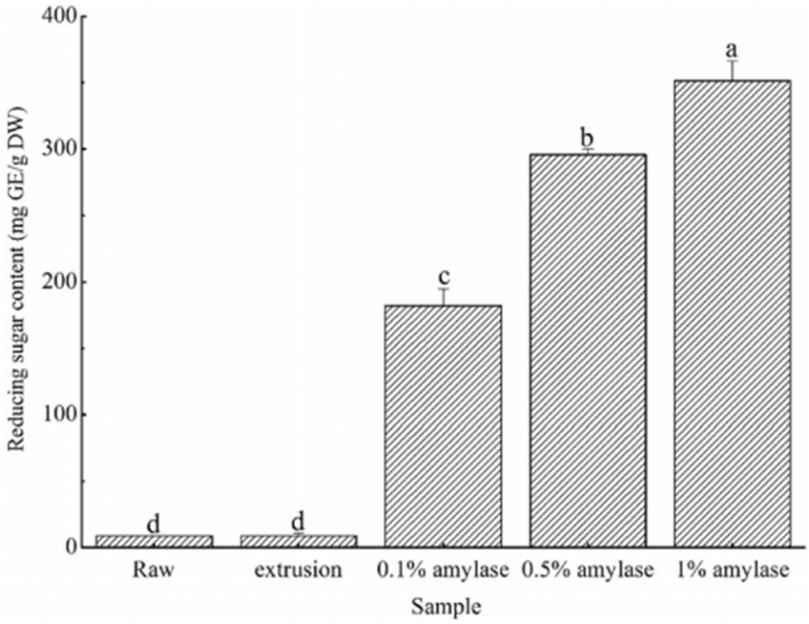

Fig. 1. Reducing sugars in raw and extruded brown rice. Bars represent standard deviation (n = 3). Different letters mean a significant difference ($P < 0.05$).

(Zeng et al.,2017)

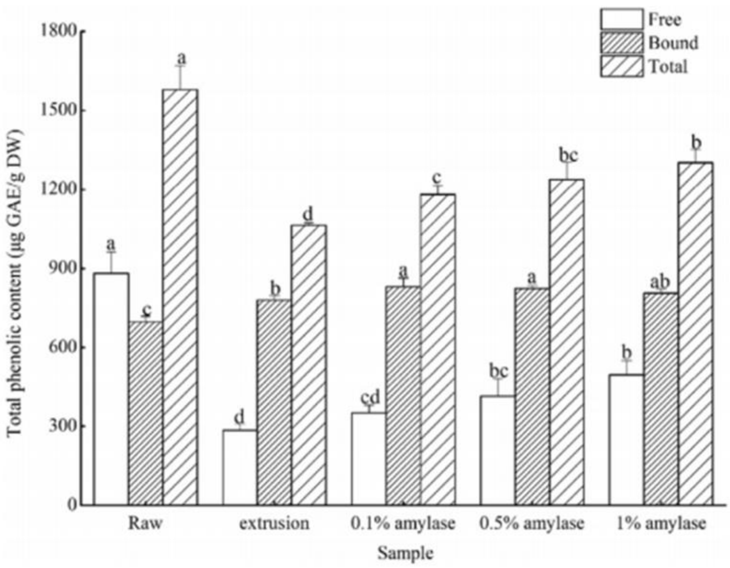

Fig. 2. Free, bound and total phenolics in raw and extruded brown rice. Bars represent standard deviation (n = 3). Different letters in the same panel mean a significant difference ($P < 0.05$).

(Zeng et al.,2017)

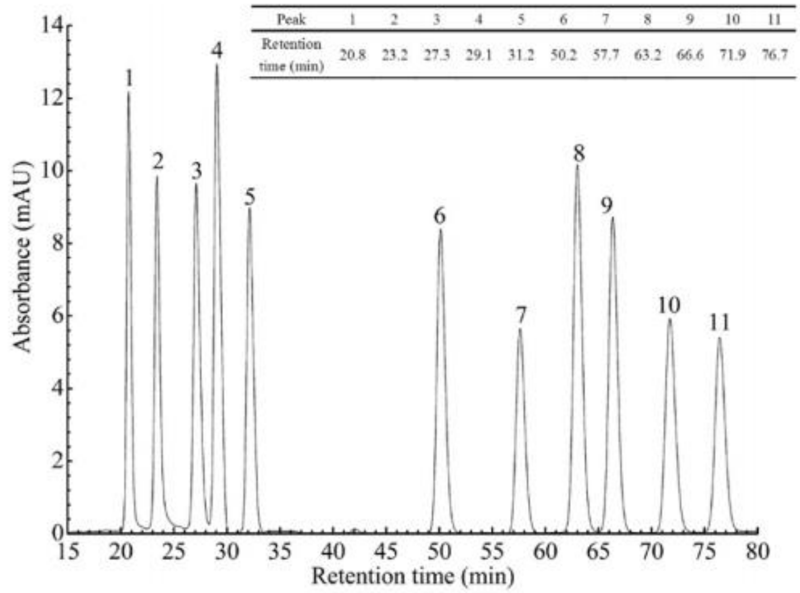

Fig. 3. HPLC chromatogram of phenolic acid standards. 1: *p*-hydroxybenzoic acid; 2: chlorogenic acid; 3: vanillic acid; 4: *trans*-caffeic acid; 5: syringic acid; 6: *trans-p*-coumaric acid; 7: *cis-p*-coumaric acid; 8: *trans*-ferulic acid; 9: *trans*-sinapic acid; 10: *cis*-ferulic acid; 11: *cis*-sinapic acid.

(Zeng et al.,2017)

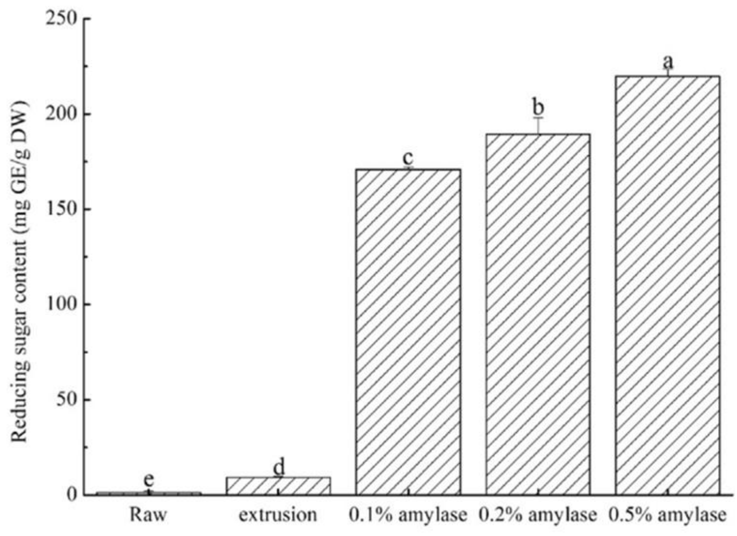

Fig. 4. Reducing sugars in raw and extruded brown rice. Bars represent standard deviation (n = 3). Different letters mean a significant difference ($P < 0.05$).

(Zeng et al.,2018)

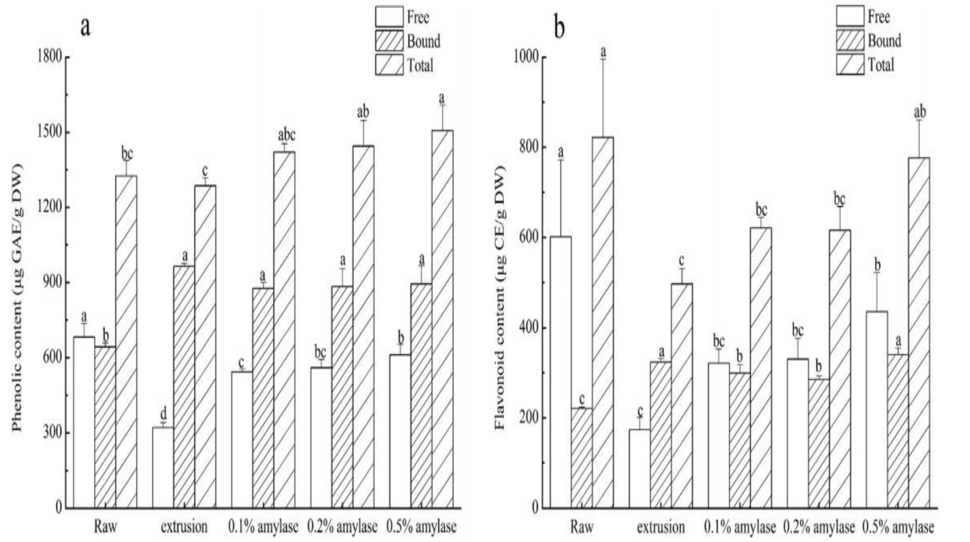

Fig. 5 . The content of phenolics (a) and flavonoids (b) in raw and extruded brown rice. Bars represent standard deviation (n = 3). Different letters in the same panel mean a significant difference ($P < 0.05$).

(Zeng et al.,2018)

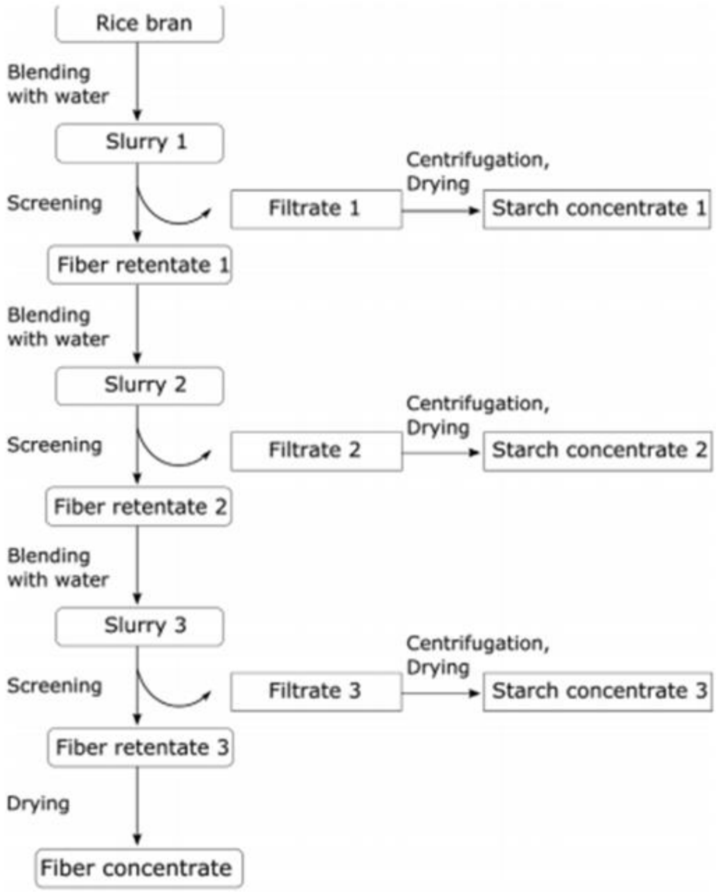

Fig. 6 . Protocol for triple water washing of rice bran to produce a fiber concentrate.

(Tem Thi Dang, Thava Vasanthan,2019)

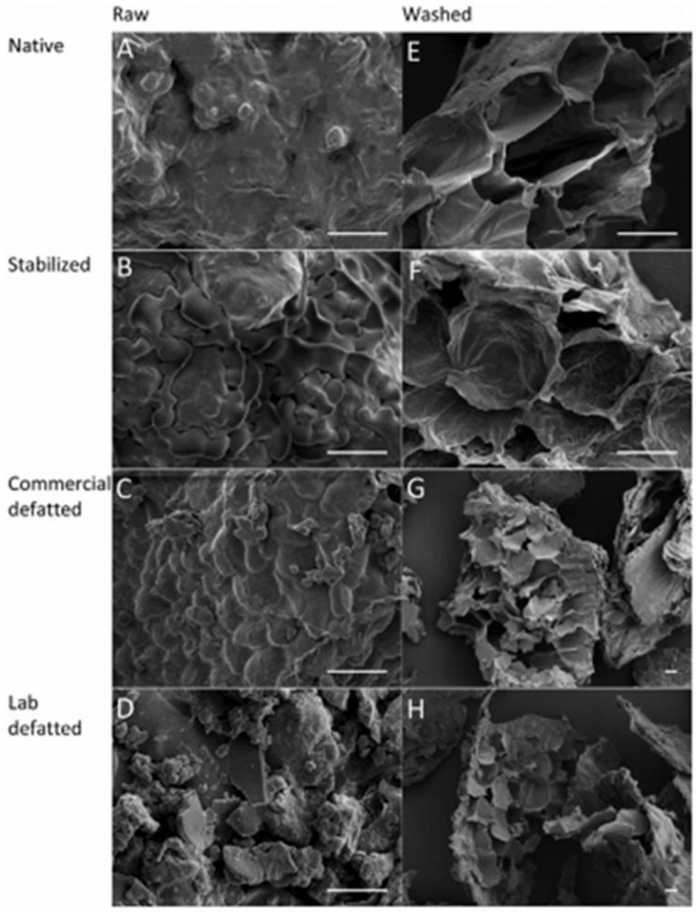

Fig. 7. Scanning electron micrographs of raw and washed rice brans. NRB (A), SRB (B), CDRB (C), LDRB (D), WNRB (E), WSRB (F), WCDRB (G) and WLDRB (H). Scale bar = 10 µm. Magnification = 2500× (A–F) and 500× (G–H).

(Tem Thi Dang, Thava Vasanthan,2019)

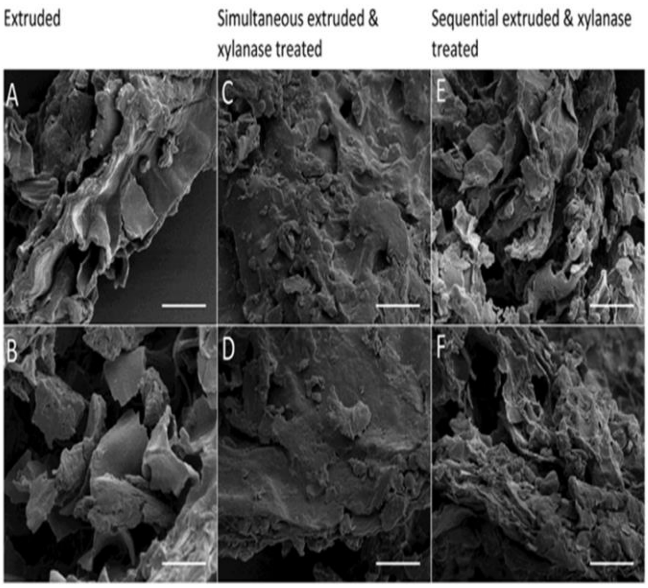

Fig. 8. Scanning electron micrographs of extruded, simultaneous extruded & xylanase treated, and sequential extruded & xylanase treated rice brans. Extruded 0/45/100* (A), Extruded 0/60/100 (B), simultaneous extruded & xylanase treated 1/45/100 (C), simultaneous extruded & xylanase treated 1/60/100 (D), sequential extruded & xylanase treated 1/60/100 (E), and sequential extruded & xylanase treated 2/60/100 (F). Scale bar = 10 µm. Magnification = 2500×.*% xylanase/% water addition/rpm screw speed.

(Tem Thi Dang, Thava Vasanthan,2019)

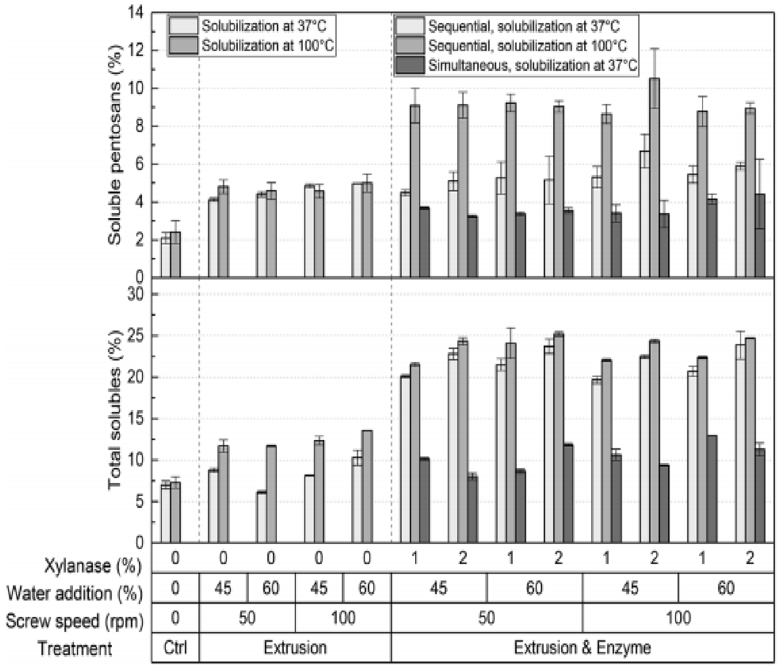

Fig. 9. Changes in the total solubles and soluble pentosans of untreated (Ctrt), extruded, simultaneous and sequential extruded-xylanase treated CDRB fiber concentrates.

(Tem Thi Dang, Thava Vasanthan,2019)

Table 1

Antioxidant activity of raw and extruded brown rice (The unit of antioxidant activity was μg Trolox/g DW).

Antioxidant activity assay		Sample				
		Raw	Extrusion	0.1% amylase	0.5% amylase	1% amylase
DPPH	Free	903.0 ± 15.6 a	261.5 ± 19.5 d	310.8 ± 26.8 d	403.7 ± 3.0 c	507.1 ± 51.1 b
	Bound	795.3 ± 24.9 b	983.9 ± 27.6 a	1014.5 ± 66.7 a	1022.2 ± 27.1 a	980.7 ± 19.1 a
	Total	1698.3 ± 39.4 a	1245.4 ± 37.7 d	1325.3 ± 81.5 cd	1426.0 ± 30.1 bc	1487.8 ± 69.9 b
ABTS	Free	880.2 ± 18.0 a	272.8 ± 31.5 d	288.5 ± 29.8 d	410.0 ± 16.1 c	576.0 ± 17.1 b
	Bound	416.7 ± 22.9 b	472.1 ± 14.2 a	486.0 ± 15.0 a	487.8 ± 17.2 a	478.4 ± 10.7 a
	Total	1296.9 ± 29.6 a	744.9 ± 37.4 d	774.5 ± 41.6 d	897.9 ± 10.4 c	1054.4 ± 26.5 b
FRAP	Free	1216.8 ± 75.2 a	422.3 ± 9.1 d	464.1 ± 9.3 d	548.8 ± 41.7 c	659.0 ± 17.2 b
	Bound	928.9 ± 41.6 b	1237.9 ± 39.9 a	1289.2 ± 117.4 a	1280.3 ± 29.6 a	1246.0 ± 11.9 a
	Total	2145.7 ± 114.9 a	1660.2 ± 39.6 d	1753.3 ± 122.9 cd	1829.1 ± 19.8 bc	1905.0 ± 27.4 b

Values in the same row with no letters in common are significantly different ($P < 0.05$).

(Zeng et al.,2017)

Table 2

The content of phenolic acids in raw and extruded brown rice (The unit of the phenolic acid content was μg/g DW).

Phenolic acid		Sample				
		Raw	Extrusion	0.1% amylase	0.5% amylase	1% amylase
p-hydroxybenzoic acid	Free	0.44 ± 0.02 d	0.65 ± 0.09 c	1.01 ± 0.24 b	1.46 ± 0.02 a	1.66 ± 0.04 a
	Bound	3.00 ± 0.58 c	7.88 ± 0.48 a	7.84 ± 0.28 a	7.97 ± 0.06 a	7.11 ± 0.23 b
	Total	3.44 ± 0.56 c	8.53 ± 0.50 b	8.85 ± 0.06 ab	9.43 ± 0.06 a	8.77 ± 0.19 ab
chlorogenic acid	Free	2.18 ± 0.35 b	0.83 ± 0.12 d	1.12 ± 0.04 cd	1.64 ± 0.79 bc	3.30 ± 0.18 a
	Bound	7.72 ± 0.68 d	12.28 ± 1.58 cd	15.02 ± 2.96 bc	21.58 ± 3.57 a	19.53 ± 2.95 ab
	Total	9.90 ± 0.54 c	13.10 ± 1.68 bc	16.14 ± 2.94 b	23.22 ± 2.98 a	22.83 ± 2.77 a
vanillic acid	Free	0.79 ± 0.07 a	0.35 ± 0.08 c	0.40 ± 0.08 c	0.54 ± 0.04 b	0.69 ± 0.04 a
	Bound	1.62 ± 0.20 c	2.70 ± 0.25 ab	2.74 ± 0.11 ab	2.86 ± 0.06 a	2.48 ± 0.08 b
	Total	2.41 ± 0.25 b	3.05 ± 0.31 a	3.14 ± 0.10 a	3.39 ± 0.10 a	3.17 ± 0.06 a
trans-caffeic acid	Free	4.57 ± 0.02 a	4.34 ± 0.19 c	4.38 ± 0.03 bc	4.44 ± 0.03 abc	4.54 ± 0.03 ab
	Bound	90.22 ± 8.63 b	104.26 ± 2.28 a	100.00 ± 2.55 a	104.39 ± 3.05 a	97.89 ± 3.78 ab
	Total	94.79 ± 8.61 b	108.61 ± 2.33 a	104.38 ± 2.54 a	108.83 ± 3.09 a	102.43 ± 3.78 ab
syringic acid	Free	1.26 ± 0.23 a	0.64 ± 0.06 b	0.65 ± 0.01 b	0.65 ± 0.03 b	0.78 ± 0.01 b
	Bound	5.10 ± 0.86 b	6.40 ± 0.59 a	5.15 ± 0.21 b	5.19 ± 0.04 b	5.51 ± 0.16 b
	Total	6.37 ± 1.09 ab	7.04 ± 0.55 a	5.80 ± 0.22 b	5.84 ± 0.01 b	6.28 ± 0.16 ab
trans-p-coumaric acid	Free	1.69 ± 0.62 c	1.54 ± 0.58 c	2.50 ± 0.27 b	2.96 ± 0.03 b	3.95 ± 0.09 a
	Bound	91.61 ± 2.78 a	83.02 ± 3.92 b	87.19 ± 2.29 ab	91.05 ± 0.78 a	82.98 ± 1.36 b
	Total	93.30 ± 2.46 a	84.56 ± 4.47 c	89.69 ± 2.24 ab	94.01 ± 0.81 a	86.93 ± 1.32 bc
cis-*p*-coumaric acid	Free	0.49 ± 0.05 a	0.33 ± 0.00 c	0.34 ± 0.04 c	0.41 ± 0.02 b	0.44 ± 0.01 b
	Bound	9.83 ± 0.33 a	8.57 ± 0.49 b	8.76 ± 0.25 b	9.46 ± 0.53 ab	10.07 ± 0.82 a
	Total	10.32 ± 0.32 a	8.90 ± 0.49 b	9.10 ± 0.22 b	9.87 ± 0.52 ab	10.51 ± 0.82 a
trans-ferulic acid	Free	3.54 ± 0.35 d	5.96 ± 1.75 c	9.60 ± 0.54 b	11.14 ± 0.11 b	14.10 ± 0.35 a
	Bound	344.57 ± 3.07 bc	340.77 ± 10.01 c	357.95 ± 8.63 ab	358.58 ± 6.44 a	348.53 ± 5.05 abc
	Total	348.11 ± 2.77 b	346.72 ± 11.45 b	367.56 ± 8.12 a	369.72 ± 6.46 a	362.63 ± 4.70 a
trans-sinapic acid	Free	- e	0.67 ± 0.15 d	1.38 ± 0.10 c	2.80 ± 0.25 b	4.56 ± 0.24 a
	Bound	10.83 ± 0.56 c	33.16 ± 2.50 a	34.04 ± 1.58 a	32.26 ± 1.27 a	28.79 ± 0.40 b
	Total	10.83 ± 0.56 b	33.82 ± 2.64 a	35.42 ± 1.60 a	35.06 ± 1.39 a	33.36 ± 0.49 a
cis-ferulic acid	Free	1.76 ± 0.23 cd	1.14 ± 0.08 d	3.91 ± 0.33 c	13.07 ± 2.13 b	23.33 ± 2.00 a
	Bound	40.96 ± 1.77 ab	39.97 ± 3.52 ab	38.42 ± 2.10 b	43.89 ± 1.31 a	40.52 ± 1.73 ab
	Total	42.71 ± 1.97 c	41.11 ± 3.44 c	42.33 ± 2.42 c	56.96 ± 2.49 b	63.85 ± 0.84 a
cis-sinapic acid	Free	–	–	–	–	–
	Bound	- c	5.36 ± 0.65 a	4.29 ± 0.41 b	4.81 ± 0.54 ab	3.99 ± 0.63 b
	Total	- c	5.36 ± 0.65 a	4.29 ± 0.41 b	4.81 ± 0.54 ab	3.99 ± 0.63 b
Total phenolic acids	Free	16.72 ± 1.87 d	16.45 ± 2.99 d	25.29 ± 0.88 c	39.11 ± 3.12 b	57.34 ± 2.23 a
	Bound	605.45 ± 11.39 c	644.36 ± 11.98 b	661.40 ± 11.44 b	682.05 ± 10.19 a	647.40 ± 3.79 b
	Total	622.17 ± 9.52 d	660.81 ± 14.56 c	686.69 ± 10.56 b	721.16 ± 13.25 a	704.74 ± 3.62 ab

Values in the same row with no letters in common are significantly different ($P < 0.05$).

(Zeng et al.,2017)

Table 3
Correlation coefficients of reducing sugars and total phenolic content, total antioxidant activity, and individual free phenolic acids.

	RS	TPC	DPPH	FRAP	ABTS
RS	1	0.915[b]	0.882[b]	0.861[b]	0.867[b]
p-hydroxybenzoic acid	0.943[b]	0.857[b]	0.890[b]	0.900[b]	0.856[b]
chlorogenic acid	0.778[b]	0.761[b]	0.884[b]	0.848[b]	0.913[b]
vanillic acid	0.843[b]	0.779[b]	0.931[b]	0.910[b]	0.929[b]
trans-caffeic acid	0.595[a]	0.584[a]	0.702[a]	0.658[a]	0.704[a]
syringic acid	0.606[a]	0.643[a]	0.794[b]	0.768[b]	0.844[b]
trans-*p*-coumaric acid	0.917[b]	0.831[b]	0.927[b]	0.911[b]	0.903[b]
cis-*p*-coumaric acid	0.862[b]	0.801[b]	0.906[b]	0.929[b]	0.924[b]
trans-ferulic acid	0.943[b]	0.840[b]	0.930[b]	0.912[b]	0.894[b]
trans-sinapic acid	0.914[b]	0.869[b]	0.956[b]	0.960[b]	0.976[b]
cis-ferulic acid	0.892[b]	0.853[b]	0.944[b]	0.946[b]	0.975[b]
Total phenolic acids	0.920[b]	0.864[b]	0.959[b]	0.954[b]	0.971[b]

RS, reducing sugars; TPC, total phenolic content.
[a] Significant at $P < 0.05$.
[b] Significant at $P < 0.01$.

(Zeng et al.,2017)

Table 4
Antioxidant activity (μg Trolox/g DW) of raw and extruded brown rice.

Antioxidant activity assay		Sample				
		Raw	Extrusion	0.1% amylase	0.2% amylase	0.5% amylase
DPPH	Free	700.4 ± 10.8 a	385.3 ± 22.9 d	586.4 ± 10.6 c	595.7 ± 11.1 c	624.0 ± 10.0 b
$Y = 613.67X-0.1012$ ($R^2 = 0.9925$)	Bound	825.9 ± 66.0 b	1098.9 ± 45.5 a	1012.1 ± 33.1 a	967.2 ± 35.2 a	972.6 ± 144.3 a
	Total	1526.3 ± 73.2 a	1484.2 ± 59.2 a	1598.5 ± 37.9 a	1562.9 ± 31.0 a	1596.6 ± 149.0 a
FRAP	Free	1358.8 ± 119.8 a	470.8 ± 42.2 d	891.9 ± 39.8 c	967.5 ± 67.3 c	1139.4 ± 93.3 b
$Y = 12.171X+0.0399$ ($R^2 = 0.9917$)	Bound	899.5 ± 13.2 d	1410.4 ± 55.2 a	1201.6 ± 52.9 b	1135.6 ± 41.8 bc	1076.2 ± 30.5 c
	Total	2258.3 ± 117.2 a	1881.3 ± 91.0 b	2093.4 ± 35.3 a	2103.0 ± 61.6 a	2215.6 ± 103.4 a
ABTS	Free	881.7 ± 42.8 a	539.5 ± 14.9 c	805.6 ± 27.8 b	858.8 ± 4.2 a	895.2 ± 19.7 a
$Y = 279.35X-0.6595$ ($R^2 = 0.9999$)	Bound	2355.7 ± 32.6 c	3097.9 ± 84.4 a	2891.8 ± 192.8 a	3082.1 ± 135.7 a	2639.9 ± 103.6 b
	Total	3237.5 ± 72.7 b	3637.4 ± 92.7 b	3697.4 ± 205.1 b	3940.9 ± 138.7 a	3535.2 ± 98.6 b

Values are means ± SD for triplicates.
Values in the same row with no letters in common are significantly different ($P < 0.05$).

(Zeng et al.,2018)

Table 5
The content (μg/g DW) of phenolic acids in raw and extruded brown rice.

Phenolic acid	Sample					
		Raw	Extrusion	0.1% amylase	0.2% amylase	0.5% amylase
p-hydroxybenzoic acid	Free	0.91 ± 0.25 d	2.78 ± 0.05 a	1.92 ± 0.04 b	1.18 ± 0.03 c	0.99 ± 0.06 cd
$Y = 33.007X - 0.8141$ ($R^2 = 0.9998$)	Bound	2.48 ± 0.38 d	9.06 ± 0.17 a	5.83 ± 0.25 b	5.40 ± 0.21 b	4.80 ± 0.38 c
	Total	3.39 ± 0.38 e	11.84 ± 0.21 a	7.75 ± 0.25 b	6.58 ± 0.20 c	5.79 ± 0.42 d
chlorogenic acid	Free	1.66 ± 0.80 c	1.87 ± 0.18 c	3.04 ± 0.09 b	3.65 ± 0.66 b	6.92 ± 0.35 a
$Y = 9.1999X + 0.1491$ ($R^2 = 0.9993$)	Bound	7.10 ± 1.09c	12.39 ± 1.13 bc	24.32 ± 4.44 a	19.94 ± 7.55 ab	16.15 ± 1.47 b
	Total	8.76 ± 0.76 b	14.26 ± 0.95 b	27.36 ± 4.36 a	23.59 ± 7.31 a	23.06 ± 1.24 a
vanillic acid	Free	0.47 ± 0.17 b	0.22 ± 0.03 c	0.61 ± 0.03 ab	0.64 ± 0.01 a	0.70 ± 0.07 a
$Y = 40.786X - 0.9484$ ($R^2 = 0.9994$)	Bound	1.32 ± 0.03 d	2.88 ± 0.13 a	2.52 ± 0.14 b	2.42 ± 0.12 bc	2.26 ± 0.15 c
	Total	1.80 ± 0.15 b	3.10 ± 0.12 a	3.12 ± 0.16 a	3.06 ± 0.12 a	2.97 ± 0.21 a
trans-caffeic acid	Free	- d	4.38 ± 0.03 b	4.55 ± 0.03 a	4.50 ± 0.07 a	4.18 ± 0.04 c
$Y = 60.576X - 229.79$ ($R^2 = 0.9972$)	Bound	140.12 ± 24.68 a	118.66 ± 8.73 ab	113.59 ± 8.14 b	100.58 ± 2.21 b	141.83 ± 13.32 a
	Total	140.12 ± 24.68 ab	123.05 ± 8.73 abc	118.14 ± 8.12 bc	105.08 ± 2.23 c	146.00 ± 13.36 a
syringic acid	Free	1.12 ± 0.04 a	0.53 ± 0.16 b	0.28 ± 0.02 b	0.35 ± 0.01 b	0.46 ± 0.25 b
$Y = 71.173X - 1.203$ ($R^2 = 0.9998$)	Bound	6.00 ± 0.35c	8.15 ± 0.30 a	6.78 ± 0.57 b	6.95 ± 0.19 b	6.08 ± 0.08 c
	Total	7.12 ± 0.35 bc	8.68 ± 0.14 a	7.06 ± 0.59 bc	7.30 ± 0.19 b	6.54 ± 0.33 c
trans-p-coumaric acid	Free	1.69 ± 0.21 e	3.78 ± 0.09 d	4.03 ± 0.06 c	4.39 ± 0.03 b	4.66 ± 0.10 a
$Y = 119.11X - 36.002$ ($R^2 = 0.9993$)	Bound	80.42 ± 0.96 d	106.37 ± 0.51 bc	111.09 ± 6.19 ab	115.29 ± 2.81 a	102.00 ± 7.05 c
	Total	82.11 ± 0.96 d	110.15 ± 0.56 bc	115.12 ± 6.20 ab	119.68 ± 2.83 a	106.66 ± 7.15 c
cis-p-coumaric acid	Free	0.60 ± 0.09 a	- b	- b	- b	- b
$Y = 119.11X - 36.002$ ($R^2 = 0.9993$)	Bound	7.26 ± 0.12 c	9.02 ± 0.20 a	9.34 ± 0.51 a	9.65 ± 0.11 a	8.21 ± 0.60 b
	Total	7.87 ± 0.06 b	9.02 ± 0.20 a	9.34 ± 0.54 a	9.65 ± 0.11 a	8.21 ± 0.60 b
trans-ferulic acid	Free	2.79 ± 0.14 e	16.49 ± 0.84 d	18.77 ± 0.40 c	23.10 ± 0.24 b	25.70 ± 0.64 a
$Y = 78.829X - 60.922$ ($R^2 = 0.9999$)	Bound	310.36 ± 11.93 c	404.49 ± 8.66 a	387.78 ± 15.96 ab	384.76 ± 6.57 ab	372.17 ± 15.74 b
	Total	313.15 ± 11.95 b	420.98 ± 9.49 a	406.54 ± 16.20 a	407.86 ± 6.73 a	397.88 ± 16.18 a
trans-sinapic acid	Free	- c	1.15 ± 0.23 ab	1.22 ± 0.05 a	1.25 ± 0.01 a	1.00 ± 0.03 b
$Y = 30.724X - 2.1972$ ($R^2 = 0.9991$)	Bound	8.41 ± 0.19 e	29.00 ± 1.02 a	18.62 ± 0.38 b	16.04 ± 2.13 c	13.22 ± 1.00 d
	Total	8.41 ± 0.19 e	30.15 ± 1.03 a	19.84 ± 0.40 b	17.30 ± 2.13 c	14.23 ± 1.03 d
cis-ferulic acid	Free	1.66 ± 0.06 b	1.43 ± 0.02 c	1.78 ± 0.00 a	1.80 ± 0.04 a	1.65 ± 0.03 b
$Y = 78.829X - 60.922$ ($R^2 = 0.9999$)	Bound	38.03 ± 3.19 b	42.72 ± 1.87 a	41.03 ± 1.76 ab	40.96 ± 0.83 ab	38.19 ± 1.64 b
	Total	39.69 ± 3.18 b	44.15 ± 1.89 a	42.81 ± 1.76 ab	42.77 ± 0.80 ab	39.84 ± 1.64 b
Total identified phenolic acids	Free	10.91 ± 1.02 e	32.65 ± 0.86 d	36.19 ± 0.62 c	40.88 ± 0.88 b	46.28 ± 0.92 a
	Bound	601.52 ± 8.86 b	742.74 ± 21.55 a	720.91 ± 13.85 a	701.98 ± 19.76 a	704.92 ± 38.36 a
	Total	612.43 ± 9.17 b	775.39 ± 22.23 a	757.10 ± 14.16 a	742.87 ± 19.73 a	751.19 ± 38.87 a

Values are means ± SD for triplicates.
Values in the same row with no letters in common are significantly different ($P < 0.05$).

(Zeng et al.,2018)

Table 6
Correlation coefficients of reducing sugars and free form of phenolic content, flavonoid content, antioxidant activity, and individual phenolic acids.

	RS	PC	FC	DPPH	FRAP	ABTS
RS	1	0.983**	0.876**	0.990**	0.971**	0.990**
p-hydroxybenzoic acid	−0.941**	−0.915**	−0.845**	−0.908**	−0.940**	−0.945**
chlorogenic acid	0.760**	0.776**	0.873**	0.719**	0.854**	0.742**
vanillic acid	0.983**	0.974**	0.852**	0.982**	0.955**	0.982**
trans-p-coumaric acid	0.849**	0.841**	0.829**	0.818**	0.898**	0.871**
trans-ferulic acid	0.843**	0.840**	0.846**	0.809**	0.900**	0.858**
cis-ferulic acid	0.815**	0.776**	0.523	0.838**	0.689*	0.826**
Total identified phenolic acids	0.843**	0.848**	0.883**	0.809**	0.913**	0.848**

RS, reducing sugars; PC, phenolic content; FC, flavonoid content.
* Significant at $P < 0.05$.
** Significant at $P < 0.01$.

(Zeng et al.,2018)

Table 7

Yield and composition of rice brans and water-washed fiber concentrates (%, dry basis).

Treatment	RB	Yield	Starch	Protein	Lipid	IDF	SDF	TDF	Pentosan	Phytate	P	Ash
Raw	NRB	NA	19.5 ± 2.1^{a}	17.7 ± 0.0^{b}	20.7 ± 0.3^{b}	33.7 ± 3.7^{ab}	4.1 ± 1.1^{a}	37.8 ± 1.4^{b}	8.9 ± 0.6^{a}	7.9 ± 0.9^{a}	2.2 ± 0.3^{a}	8.1 ± 0.1^{b}
	SRB	NA	19.9 ± 2.0^{a}	17.8 ± 0.0^{b}	22.9 ± 0.1^{a}	39.9 ± 0.7^{a}	4.1 ± 0.3^{a}	44.0 ± 0.3^{a}	8.9 ± 1.4^{a}	7.0 ± 0.3^{a}	1.9 ± 0.1^{a}	8.2 ± 0.0^{b}
	CDRB	NA	20.2 ± 0.5^{a}	19.3 ± 0.3^{a}	5.5 ± 0.0^{c}	32.5 ± 0.1^{b}	4.5 ± 0.9^{a}	36.9 ± 0.9^{b}	11.3 ± 0.3^{a}	5.1 ± 0.1^{b}	1.4 ± 0.0^{b}	15.6 ± 0.1^{a}
Washing	WNRB	19.8	4.0 ± 0.5^{c}	14.5 ± 0.2^{c}	10.1 ± 0.1^{b}	74.0 ± 1.2^{a}	0.8 ± 0.8^{a}	74.8 ± 1.9^{a}	25.7 ± 1.9^{a}	1.4 ± 0.1^{d}	0.4 ± 0.0^{d}	3.0 ± 0.0^{bc}
	WSRB	20.7	9.1 ± 0.4^{a}	16.5 ± 0.1^{b}	10.8 ± 0.1^{a}	70.0 ± 3.4^{ab}	1.6 ± 1.5^{a}	71.5 ± 4.9^{ab}	21.6 ± 1.0^{b}	1.7 ± 0.1^{c}	0.5 ± 0.0^{c}	2.6 ± 0.1^{c}
	WCDRB	26.0	10.3 ± 0.9^{a}	16.4 ± 0.2^{b}	5.0 ± 0.2^{c}	63.8 ± 2.5^{b}	1.7 ± 0.2^{a}	65.5 ± 2.2^{b}	21.9 ± 0.6^{b}	2.4 ± 0.1^{a}	0.7 ± 0.0^{a}	8.6 ± 0.2^{a}
	WLDRB	22.8	6.4 ± 0.1^{b}	17.7 ± 0.1^{a}	4.3 ± 0.0^{d}	71.2 ± 2.7^{a}	2.0 ± 0.3^{a}	73.2 ± 2.9^{ab}	23.5 ± 0.7^{ab}	1.9 ± 0.0^{b}	0.5 ± 0.0^{b}	3.1 ± 0.0^{b}

Each value in the table is the mean $\pm$ standard deviation of two replicates. Values in the same column within the same treatment (Raw or Washing) with different letters are significantly different at $p < 0.05$, based on LSD test. NRB = native rice bran obtained commercially; SRB = stabilized rice bran obtained commercially; CDRB = Commercial-defatted rice bran obtained commercially; WNRB = washed native rice bran; WSRB = washed stabilized rice bran; WCDRB = washed commercial defatted rice bran; WLDRB = washed lab defatted stabilized rice bran; IDF = Insoluble dietary fiber; SDF = Soluble dietary fiber; TDF = Total dietary fiber = IDF + SDF; P = Total phosphorus = 28.2% of phytic acid. NA = not applicable.

(Tem Thi Dang, Thava Vasanthan,2019)

Table 8

Yield and composition of rice brans and water-washed fiber concentrates (%, dry basis).

Treatment	RB	Yield	Starch	Protein	Lipid	IDF	SDF	TDF	Pentosan	Phytate	P	Ash
Raw	NRB	NA	19.5 ± 2.1^{a}	17.7 ± 0.0^{b}	20.7 ± 0.3^{b}	33.7 ± 3.7^{ab}	4.1 ± 1.1^{a}	37.8 ± 1.4^{b}	8.9 ± 0.6^{a}	7.9 ± 0.9^{a}	2.2 ± 0.3^{a}	8.1 ± 0.1^{b}
	SRB	NA	19.9 ± 2.0^{a}	17.8 ± 0.0^{b}	22.9 ± 0.1^{a}	39.9 ± 0.7^{a}	4.1 ± 0.3^{a}	44.0 ± 0.3^{a}	8.9 ± 1.4^{a}	7.0 ± 0.3^{a}	1.9 ± 0.1^{a}	8.2 ± 0.0^{b}
	CDRB	NA	20.2 ± 0.5^{a}	19.3 ± 0.3^{a}	5.5 ± 0.0^{c}	32.5 ± 0.1^{b}	4.5 ± 0.9^{a}	36.9 ± 0.9^{b}	11.3 ± 0.3^{a}	5.1 ± 0.1^{b}	1.4 ± 0.0^{b}	15.6 ± 0.1^{a}
Washing	WNRB	19.8	4.0 ± 0.5^{c}	14.5 ± 0.2^{c}	10.1 ± 0.1^{b}	74.0 ± 1.2^{a}	0.8 ± 0.8^{a}	74.8 ± 1.9^{a}	25.7 ± 1.9^{a}	1.4 ± 0.1^{d}	0.4 ± 0.0^{d}	3.0 ± 0.0^{bc}
	WSRB	20.7	9.1 ± 0.4^{a}	16.5 ± 0.1^{b}	10.8 ± 0.1^{a}	70.0 ± 3.4^{ab}	1.6 ± 1.5^{a}	71.5 ± 4.9^{ab}	21.6 ± 1.0^{b}	1.7 ± 0.1^{c}	0.5 ± 0.0^{c}	2.6 ± 0.1^{c}
	WCDRB	26.0	10.3 ± 0.9^{a}	16.4 ± 0.2^{b}	5.0 ± 0.2^{c}	63.8 ± 2.5^{b}	1.7 ± 0.2^{a}	65.5 ± 2.2^{b}	21.9 ± 0.6^{b}	2.4 ± 0.1^{a}	0.7 ± 0.0^{a}	8.6 ± 0.2^{a}
	WLDRB	22.8	6.4 ± 0.1^{b}	17.7 ± 0.1^{a}	4.3 ± 0.0^{d}	71.2 ± 2.7^{a}	2.0 ± 0.3^{a}	73.2 ± 2.9^{ab}	23.5 ± 0.7^{ab}	1.9 ± 0.0^{b}	0.5 ± 0.0^{b}	3.1 ± 0.0^{b}

Each value in the table is the mean $\pm$ standard deviation of two replicates. Values in the same column within the same treatment (Raw or Washing) with different letters are significantly different at $p < 0.05$, based on LSD test. NRB = native rice bran obtained commercially; SRB = stabilized rice bran obtained commercially; CDRB = Commercial-defatted rice bran obtained commercially; WNRB = washed native rice bran; WSRB = washed stabilized rice bran; WCDRB = washed commercial defatted rice bran; WLDRB = washed lab defatted stabilized rice bran; IDF = Insoluble dietary fiber; SDF = Soluble dietary fiber; TDF = Total dietary fiber = IDF + SDF; P = Total phosphorus = 28.2% of phytic acid. NA = not applicable.

(Tem Thi Dang, Thava Vasanthan,2019)

Table 9

Composition of hot and warm-water solubles in xylanase-treated washed rice bran concentrates (%, dry basis).

Samples	Concentrate	Total solubles	Pentosan	Pentose	Starch	Protein	Ash	Ethanol& water Solubles	Ethanol& water-soluble Starch
Hot-water solubles (@ 100 °C)									
Untreated	WCDRB	7.29 ± 0.71^{g}	2.41 ± 0.61^{d}	1.24 ± 0.08^{b}	2.59 ± 0.02^{e}	0.44 ± 0.03^{b}	1.23 ± 0.56^{c}	7.24 ± 0.31^{e}	0.50 ± 0.12^{f}
	WLDRB	8.93 ± 0.67^{f}	2.29 ± 0.53^{d}	1.26 ± 0.08^{b}	1.98 ± 0.00^{f}	0.44 ± 0.02^{b}	1.15 ± 0.28^{c}	7.93 ± 0.61^{e}	0.57 ± 0.09^{e}
Enzeco	WCDRB	14.28 ± 0.25^{d}	6.17 ± 1.23^{bc}	1.48 ± 0.02^{a}	2.57 ± 0.01^{e}	0.91 ± 0.07^{a}	2.51 ± 0.03^{ab}	13.23 ± 0.06^{c}	2.17 ± 0.35^{cde}
	WLDRB	15.57 ± 0.28^{cd}	6.37 ± 0.37^{bc}	1.44 ± 0.03^{a}	3.44 ± 0.19^{d}	0.49 ± 0.14^{b}	1.27 ± 0.03^{c}	15.19 ± 0.58^{b}	2.63 ± 0.49^{cbd}
Multifect 720	WCDRB	10.35 ± 0.36^{e}	5.39 ± 0.50^{c}	1.45 ± 0.02^{a}	2.72 ± 0.23^{e}	0.95 ± 0.08^{a}	2.75 ± 0.55^{ab}	10.84 ± 0.83^{d}	2.02 ± 0.17^{ed}
	WLDRB	10.64 ± 0.40^{e}	6.09 ± 0.25^{bc}	1.41 ± 0.05^{a}	1.85 ± 0.07^{f}	0.56 ± 0.11^{b}	1.22 ± 0.21^{c}	10.91 ± 0.59^{d}	3.16 ± 0.38^{ab}
Ali	WCDRB	16.39 ± 0.14^{bc}	6.79 ± 0.54^{bc}	1.47 ± 0.06^{a}	4.11 ± 0.05^{ab}	0.96 ± 0.09^{a}	2.99 ± 0.18^{a}	14.30 ± 0.20^{b}	2.80 ± 0.22^{abc}
	WLDRB	17.75 ± 0.82^{a}	9.19 ± 1.62^{a}	1.43 ± 0.08^{a}	3.81 ± 0.31^{bc}	0.55 ± 0.11^{b}	2.27 ± 0.14^{b}	17.52 ± 0.14^{a}	1.65 ± 0.19^{e}
Bio-cat	WCDRB	16.26 ± 1.15^{bc}	7.32 ± 0.82^{b}	1.46 ± 0.04^{a}	4.25 ± 0.16^{a}	1.13 ± 0.29^{a}	3.03 ± 0.09^{a}	14.25 ± 0.29^{bc}	2.60 ± 0.37^{cbd}
	WLDRB	17.26 ± 0.26^{ab}	9.19 ± 1.06^{a}	1.42 ± 0.07^{a}	3.60 ± 0.20^{cd}	0.59 ± 0.06^{b}	1.54 ± 0.13^{c}	16.84 ± 0.44^{a}	3.40 ± 0.21^{a}
Warm-water solubles (@ 37 °C)									
Untreated	WCDRB	6.99 ± 0.48^{e}	2.09 ± 0.30^{e}	1.04 ± 0.01^{f}	0.60 ± 0.09^{e}	0.55 ± 0.03^{b}	0.90 ± 0.01^{cd}	4.33 ± 0.88^{g}	0.50 ± 0.12^{f}
	WLDRB	6.03 ± 0.95^{e}	2.45 ± 0.31^{e}	1.08 ± 0.01^{ef}	0.67 ± 0.02^{e}	0.73 ± 0.01^{a}	1.64 ± 0.15^{a}	5.82 ± 0.36^{f}	0.57 ± 0.09^{f}
Enzeco	WCDRB	13.90 ± 0.68^{c}	3.34 ± 0.31^{cde}	1.20 ± 0.03^{a}	1.73 ± 0.43^{d}	0.63 ± 0.15^{ab}	1.18 ± 0.10^{bc}	12.97 ± 0.59^{c}	1.79 ± 0.02^{d}
	WLDRB	15.64 ± 0.87^{b}	3.85 ± 0.30^{cd}	1.17 ± 0.01^{ab}	2.59 ± 0.43^{bc}	0.22 ± 0.09^{c}	0.93 ± 0.29^{cd}	13.93 ± 1.61^{bc}	2.21 ± 0.12^{cd}
Multifect 720	WCDRB	9.83 ± 0.95^{d}	2.89 ± 0.70^{de}	1.12 ± 0.01^{cd}	1.50 ± 0.14^{d}	0.66 ± 0.03^{ab}	0.69 ± 0.13^{d}	8.59 ± 0.61^{e}	1.24 ± 0.11^{e}
	WLDRB	10.85 ± 0.39^{d}	3.86 ± 0.17^{cd}	1.12 ± 0.02^{cde}	1.24 ± 0.01^{d}	0.26 ± 0.01^{c}	1.34 ± 0.09^{ab}	10.06 ± 1.09^{d}	0.97 ± 0.13^{ef}
Ali	WCDRB	15.51 ± 2.54^{bc}	4.21 ± 0.48^{bc}	1.10 ± 0.02^{ed}	2.46 ± 0.07^{c}	0.64 ± 0.04^{ab}	1.05 ± 0.20^{bc}	14.23 ± 0.67^{b}	2.55 ± 0.19^{bc}
	WLDRB	19.30 ± 1.38^{a}	5.23 ± 0.29^{b}	1.17 ± 0.04^{ab}	3.27 ± 0.20^{a}	0.33 ± 0.08^{c}	1.61 ± 0.26^{a}	17.03 ± 0.49^{a}	3.03 ± 0.12^{ab}
Bio-cat	WCDRB	14.51 ± 0.36^{bc}	4.32 ± 0.56^{bc}	1.15 ± 0.01^{bc}	2.95 ± 0.48^{abc}	0.69 ± 0.01^{ab}	0.92 ± 0.03^{cd}	14.30 ± 0.98^{b}	2.77 ± 0.41^{ab}
	WLDRB	18.38 ± 1.14^{a}	6.79 ± 1.29^{a}	1.19 ± 0.00^{ab}	3.00 ± 0.05^{ab}	0.35 ± 0.01^{c}	1.53 ± 0.39^{a}	17.19 ± 0.65^{a}	3.18 ± 0.51^{a}

Each value in the table is the mean ± standard deviation of two replicates. For each temperature set, values in the same column with different letters are significantly different at $p < 0.05$, based on LSD test. WCDRB = washed commercial defatted rice bran; WLDRB = washed lab defatted rice bran.

(Tem Thi Dang, Thava Vasanthan,2019)

Table 10

Composition (warm-water soluble @ 37 °C) of extruded CDRB fiber concentrates without enzyme addition (%, dry basis).

Sample	Total solubles	Pentosan	Starch	Protein	Ash	Pentose
WCDRB (control)	6.99 ± 0.48^{c}	2.09 ± 0.30^{e}	0.60 ± 0.09^{h}	0.55 ± 0.03^{a}	0.90 ± 0.01^{cd}	1.04 ± 0.01^{g}
25/50*	6.63 ± 0.30^{cd}	3.52 ± 0.01^{d}	2.42 ± 0.12^{defg}	0.38 ± 0.01^{bcd}	0.27 ± 0.1^{d}	1.57 ± 0.01^{ab}
30/50	6.05 ± 0.20^{de}	3.98 ± 0.00^{cd}	2.49 ± 0.05^{defg}	0.35 ± 0.02^{cde}	0.63 ± 0.13^{d}	1.54 ± 0.01^{bc}
35/50	5.72 ± 0.63^{e}	4.18 ± 0.08^{bcd}	2.87 ± 0.00^{d}	0.37 ± 0.00^{bcde}	0.89 ± 0.25^{cd}	1.50 ± 0.01^{cde}
40/50	5.65 ± 0.19^{e}	4.36 ± 0.08^{abc}	2.17 ± 0.34^{fg}	0.32 ± 0.00^{de}	0.00 ± 0.00^{d}	1.52 ± 0.03^{cde}
45/50	8.76 ± 0.24^{b}	4.12 ± 0.09^{cd}	4.64 ± 0.22^{b}	0.32 ± 0.03^{e}	0.45 ± 0.13^{d}	1.52 ± 0.00^{cde}
60/50	6.10 ± 0.15^{de}	4.41 ± 0.13^{abc}	2.29 ± 0.01^{efg}	0.32 ± 0.04^{e}	0.36 ± 0.00^{d}	1.48 ± 0.02^{e}
25/100	6.99 ± 0.30^{c}	4.46 ± 0.59^{abc}	2.74 ± 0.25^{de}	0.42 ± 0.00^{b}	0.00 ± 0.00^{d}	1.53 ± 0.01^{bc}
30/100	6.27 ± 0.23^{cde}	4.20 ± 0.20^{bc}	2.68 ± 0.19^{def}	0.41 ± 0.04^{bc}	0.54 ± 0.26^{d}	1.53 ± 0.02^{bcd}
35/100	5.85 ± 0.01^{de}	4.89 ± 0.81^{a}	2.72 ± 0.60^{de}	0.37 ± 0.06^{bcde}	1.78 ± 0.01^{bc}	1.58 ± 0.00^{a}
40/100	6.23 ± 0.29^{cde}	4.91 ± 0.20^{a}	1.99 ± 0.03^{g}	0.34 ± 0.02^{cde}	1.88 ± 0.12^{b}	1.57 ± 0.03^{ab}
45/100	8.11 ± 0.06^{b}	4.85 ± 0.11^{ab}	4.05 ± 0.20^{c}	0.36 ± 0.05^{bcde}	3.17 ± 1.42^{a}	1.49 ± 0.02^{de}
60/100	10.29 ± 0.9^{a}	4.96 ± 0.02^{a}	5.93 ± 0.27^{a}	0.40 ± 0.03^{bc}	1.62 ± 0.25^{bc}	1.51 ± 0.01^{cde}

Each value in the table is the mean ± standard deviation of two replicates. Values in the same column with different letters are significantly different at $p < 0.05$, based on LSD test. WCDRB = washed commercial defatted rice bran.

* % water addition (w/w)/screw speed (rpm).

(Tem Thi Dang, Thava Vasanthan,2019)