

# Extrusion Processing of Rice-Based Breakfast Cereals Enhanced with Tocopherol from a Chinese Medical Plant

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## ABSTRACT

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Brown rice flour was mixed with a Chinese medical plant (*Euryale ferox* Salisb.) and processed to make ready-to-eat breakfast cereals using twin-screw extrusion. Levels of 15 and 20% feed moisture in flour, and 200 and 250 rpm screw speed were set, and the physicochemical properties and content of  $\alpha$ -,  $\beta$ -,  $\gamma$ -, and  $\delta$ -tocopherols were determined. The data showed that 15% feed moisture gave a low bulk density and water absorption index but a high expansion ratio and water solubility index.

High screw speed (250 rpm) produced a result similar to that of 15% feed moisture. A sample with 85% brown rice flour with 15% *E. ferox* Salisb. retained the highest content of  $\alpha$ -,  $\beta$ -,  $\gamma$ -, and  $\delta$ -tocopherols (125, 6, 78, and 9  $\mu\text{g/g}$ ), respectively. The optimum extrusion conditions determined were 15% *E. ferox* Salisb. mixed with brown rice at 15% feed moisture and at 250 rpm screw speed.

Brown rice has an outer layer of bran, which is an excellent source of protein, fiber, fat, and vitamin E, as well as oryzanol (Hammond 1994; Lloyd et al 2000). The hypocholesterolemic effects of rice bran and some of its fractions have been studied (Suzuki 1982; Saunders 1986; Seetharamaiah and Chandrasekhara 1988; Raghuram et al 1989; Kahlon et al 1996). In human studies, Hegsted et al (1993) showed that total cholesterol levels decreased 7.0% when subjects consumed rice bran product. Rice bran also contains a number of nonfiber constituents in the nonsaponifiable oil fraction that have been implicated as factors in lowering cholesterol, including oryzanol (Seeharamaiah and Chandrasekhara 1988; Yoshino et al 1989).

It is well known that *Euryale ferox* Salisb. (Qian Shi) obtained from seed is commonly used as a traditional medicine in China to benefit kidney function and to stop diarrhea (Chang 1980). Yeh and Su (1993) reported that *E. ferox* Salisb. had the highest tocopherol content in 100 Chinese medical plant materials. It is a valuable source of antioxidants and can be used with brown rice to formulate functional foods for human consumption. Tocopherols, which exist in four homologous isomers ( $\alpha$ -,  $\beta$ -,  $\gamma$ -, and  $\delta$ -) are the most powerful fat-soluble antioxidants (Engberg et al 1993; Kontush 1999; Jiang et al 2001) that can terminate chain reactions and thus protect cell membranes against lipid peroxidation (Halliwell and Gutteridge 1999).

With the advantages of economic and versatility, extrusion cooking has been widely used to manufacture snacks and breakfast cereals (Harper 1981), but very few studies are reported in the literature concerning the nutritional significance of tocopherols in rice-based extruded foods. The objective of this study was to investigate the effect of processing variables (feed moisture content, screw speed) on chemical composition, physical characteristics, and sensory attributes of extrudates from brown rice flour and *E. ferox* Salisb.

## MATERIALS AND METHODS

### Sample Preparation

Brown rice (Tainung sen 19, TNS19), a variety of rice high in amylose content, was obtained from the Taichung District Experimental Station (Taiwan) and was dry-milled to flour using a pin

mill (F200, Yi-Ta, Taiwan). The brown rice flour was then mixed to yield formulations with 0, 5, 10, and 15% *E. ferox* Salisb. Based on the weight of brown rice flour and *E. ferox* Salisb., sugar (4%), soybean oil (3%), and salt (1.5%) were added. A total of 32.55 kg of mixture was prepared for each formulation.

### Extrusion Parameters

A co-rotating, intermeshing twin screw extruder (TX57, Wenger) with 3.5-mm  $\times$  0.8-mm diameter die was used for extrusion. Tap water was fed into the first barrel section of the extruder to maintain feed moisture contents of 15% (M15) and 20% (M20) on total weight basis. The barrel temperature profile, from feed to die, was 80, 100, 100 and 110°C, respectively. Screw speeds were 200 rpm (S200) and 250 rpm (S250). The feed rate of each treatment was 12 rpm. Extrudates were collected and dried in an air oven at 80°C for 15 min, and then the dried extrudates were vacuum-packaged with a bag (Tung-Shi, Taiwan) and held at room temperature before further analysis.

### Proximate Analysis

Moisture, crude protein, crude lipid, and ash contents were determined in triplicate according to Approved Methods 44-15A, 46-11A, 30-10, and 08-01, respectively (AACC 2000). The conversion factor ( $N \times 5.95$ ) was applied to convert nitrogen to crude protein content.

### Color Determination

The color of the extrudates was determined by an  $\Sigma 80$  Color System (Nippon Deshoku Industry Co., Japan). The  $L^*$ ,  $a^*$ , and  $b^*$  scales were respectively used as the light to dark, red to blue, and yellow to green indices, respectively.

### Expansion Ratio

The diameter of 20 extrudates was measured with an electronic caliper. Each value was an average of two readings. The degree of expansion was calculated as the ratio of extrudate diameter to die diameter (Pan et al 1998).

### Bulk Density

The bulk density of extrudates was measured following the method of Pan et al (1998). The volume of the expanded sample was measured by using a 100-mL graduated cylinder by rapeseed displacement. The volume of 20-g randomized samples was measured for each test. The ratio of sample weight and the replaced volume in the cylinder was calculated as bulk density (w/v).

### Water Absorption Index and Water Solubility Index

Water absorption index (WAI) and water solubility index (WSI) were measured according to a modification of the method of

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**TABLE I**  
Effect of Feed Moisture and Screw Speed on Chemical Composition of Extruded Brown Rice Flour with Added *Euryale ferox* Salisb.<sup>a-c</sup>

Feed Moisture/ Screw Speed	E0	E5	E10	E15
<b>Moisture</b>				
M15-S200	8.50bw <sup>d</sup>	8.54bw	8.60bw	8.51bw
M15-S250	8.59bw	8.79bw	8.74bw	8.66bw
M20-S200	9.53aw	9.80aw	9.70aw	9.71aw
M20-S250	9.78aw	9.97aw	9.85aw	9.75aw
<b>Protein</b>				
M15-S200	7.35ay	7.55ax	7.84awx	7.96bw
M15-S250	7.46ax	7.63ax	7.84aw	8.12aw
M20-S200	7.24ay	7.34bxy	7.56bx	7.93bw
M20-S250	7.30ax	7.44abx	7.53bx	7.93bw
<b>Lipid</b>				
M15-S200	1.93aw	1.63ax	1.50ax	1.46ax
M15-S250	1.95aw	1.66ax	1.42ay	1.43ay
M20-S200	1.85aw	1.65awx	1.55ax	1.54ax
M20-S250	1.87aw	1.66ax	1.47axy	1.44ay
<b>Ash</b>				
M15-S200	2.62aw	2.51aw	2.52aw	2.52aw
M15-S250	2.62aw	2.51aw	2.50aw	2.50aw
M20-S200	2.62aw	2.46aw	2.49aw	2.44aw
M20-S250	2.58aw	2.46aw	2.43aw	2.43aw

<sup>a</sup> Means of triplicates.

<sup>b</sup> E0: 100% brown rice flour; E5: 95% brown rice flour +5% *E. ferox* Salisb.; E10: 90% brown rice flour +10% *E. ferox* Salisb.; E15: 85% brown rice flour +15% *E. ferox* Salisb.

<sup>c</sup> M15-S200: feed moisture 15%, screw speed 200 rpm; M15-S250: feed moisture 15%, screw speed 250 rpm; M20-S200: feed moisture 20%, screw speed 200 rpm; M20-S250: feed moisture 20%, screw speed 250 rpm.

<sup>d</sup> Means within the same column with different letters (a–d) or row with different letters (w–z) are significantly different ( $P < 0.05$ ).

**TABLE II**  
Effect of Feed Moisture and Screw Speed on Color of Extruded Brown Rice Flour with Added *Euryale ferox* Salisb.<sup>a-c</sup>

Feed Moisture/ Screw Speed	E0	E5	E10	E15
<b>L</b>				
M15-S200	76.01bw <sup>d</sup>	74.89bx	74.08by	71.08cz
M15-S250	75.73bw	74.92bx	73.93by	72.11bz
M20-S200	79.67aw	78.25ax	77.49ay	75.54az
M20-S250	79.30aw	78.06ax	77.53ax	75.68ay
<b>b</b>				
M15-S200	9.45ay	9.73ax	9.84ax	10.13aw
M15-S250	9.41ax	9.77aw	9.76aw	10.09aw
M20-S200	4.84by	5.21bx	5.18bx	5.34bw
M20-S250	4.85by	5.08bx	5.10bx	5.36bw
<b>c</b>				
M15-S200	17.76bw	17.66aw	17.18abw	17.19cw
M15-S250	17.54bw	17.47abw	17.74abw	18.51aw
M20-S200	17.16cx	17.06bx	18.05aw	17.80bw
M20-S250	18.28aw	17.30abx	16.90bx	17.53bcx

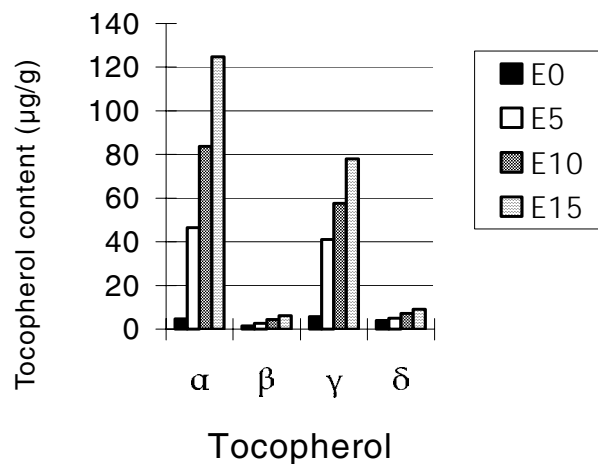
<sup>a</sup> Means of triplicates.

<sup>b</sup> E0: 100% brown rice flour; E5: 95% brown rice flour +5% *E. ferox* Salisb.; E10: 90% brown rice flour +10% *E. ferox* Salisb.; E15: 85% brown rice flour +15% *E. ferox* Salisb.

<sup>c</sup> M15-S200: feed moisture 15%, screw speed 200 rpm; M15-S250: feed moisture 15%, screw speed 250 rpm; M20-S200: feed moisture 20%, screw speed 200 rpm; M20-S250: feed moisture 20%, screw speed 250 rpm.

<sup>d</sup> Means within the same column with different letters (a–d) or row with different letters (w–z) are significantly different ( $P < 0.05$ ).

Anderson et al (1969). The extrudate was ground to pass through a 60-mesh screen. A 2-g (dry basis) ground extrudate sample was mixed with 25 mL of water and put in a centrifuge tube with a vortex mixer. After heating for 30 min in a water bath at 30°C, the heated solution was centrifuged at 3,000 × *g* for 10 min. The WAI and WSI were determined as: WAI = wt of sediment/wt of dry sample solids; WSI (%) = (wt of dissolved solids in supernatant/wt of dry sample solids in the original sample) × 100.



**Fig. 1.** Effect of *Euryale ferox* Salisb. on tocopherol content (µg/g) of extrudates. E0: 100% brown rice flour; E5: 95% brown rice flour + 5% *E. ferox* Salisb.; E10: 90% brown rice flour + 10% *E. ferox* Salisb.; E15: 85% brown rice flour + 15% *E. ferox* Salisb.

### Determination of Tocopherols

According to a modification of the method of Su (1992), 10 g of ground extrudate powder was mixed with 60 mL of 6% pyrogallol in ethanol and 40 mL of 60% KOH solution for 2–3 sec using a vortex mixer, and then heated for 20 min in a water bath at 70°C. The mixture was extracted with 300 mL of distilled water and *n*-hexane (1:1 ratio).

Reagent grade α-, β-, γ-, and δ-tocopherols standards were supplied in *n*-hexane source. The retention time was 9.28, 14.10, 15.16, and 22.22 min, respectively, for α-, β-, γ-, and δ-tocopherols. Calibration curves prepared from peak areas and calibration equations of tocopherols obtained by linear regression analysis were used to measure the chromatographic peaks by comparing with the calibration curves. Tocopherols on unsaponified compounds from extrudates were analyzed with an HPLC model HP11 with UV spectrophotometer detection at 298 nm. Develosil 60-5 (4.6 × 250 mm) column was purchased from Nomura Chemical Co., Ltd., Japan. Mobile phase was *n*-hexane, dioxane, and ethanol (95.8:4.0:0.2) at a flow rate of 1.0 mL/min.

### Statistical Analysis

All data were analyzed using ANOVA to detect differences in mean values from triplicate runs of each treatment using Duncan's multiple range test ( $\alpha = 0.05$ ) (SAS Institute, Cary, NC).

## RESULTS AND DISCUSSION

### Proximate Analysis

The four extrudates, E0, E5, E10, and E15, contained 7.24–8.02% protein, 1.42–1.95% lipid, and 2.43–2.62% ash, respectively. Table I showed that the feed moisture significantly affected the moisture level of four types of extrudates ( $P < 0.05$ ), but there was no significant difference ( $P > 0.05$ ) in the chemical components for M15-S250, M20-S200, and M20-S250, respectively. The ratio of *E. ferox* Salisb. increased with increased protein content and decreased lipid content.

### Color Determination

Results shown in Table II indicated that the higher the feed moisture content, the brighter was the color. There was also a trend that brightness of the product decreased with increased *E. ferox* Salisb. The  $a^*$  value decreased at high moisture content (20%) but increased with an increasing of *E. ferox* Salisb. ratio. Phillips et al (1984) reported that extrudates produced with high feed moisture content obtained a high  $L^*$  value and low  $a^*$  value.

### Expansion Ratio and Bulk Density

Extrudates from 15% feed moisture content had the highest degree of expansion (Table III). Feed moisture content negatively correlated with decreased screw speed on expansion ratio for most compositions. The temperature exerts a positive influence through a second-order term (Falcone and Phillips 1988). The expansion ratio also increased with increasing feed moisture (Park et al 1993; Pan et al 1998). Here, a high screw speed (250 rpm) resulted in a higher expansion ratio in high feed moisture.

Samples in a 15% feed moisture content indicated a low bulk density and high expansion ratio. Bulk density decreased with increasing feed moisture up to a certain point and then increased with further moisture increase (Park et al 1993). High feed moisture resulted in a rubbery texture with relatively high bulk density, which is why the expanded shape of the product was not maintained after extrusion (Della Valle et al 1987). Our results also showed that high screw speed (250 rpm) resulted in a lower bulk density with high (20%) feed moisture content. In general, bulk density increased with increasing feed moisture or decreasing screw speed (Barrett and Peleg 1992; Pan et al 1998).

### Water Absorption Index (WAI)/Water Solubility Index (WSI)

Extrudates obtained from high feed moisture as well as low screw speed had the highest WAI and lowest WSI (Table III). A high screw speed indicates a short residence time of starch in the barrel and results in lower water absorption (Pan et al 1998). Also, low feed moisture content showed a very low WAI but high WSI ( $P < 0.05$ ). Jean et al (1996) reported that extrudates at low feed moisture content have higher compressive resistance and cause solubility changes in the starch. The solubility increase in extrudate means the starch granule increases the fragmentation ratio at low feed moisture during extrusion of corn meal (Gomez and Aguilera 1983; Wen et al 1990). As reported in this study, WSI increased with increasing screw speed for both feed moisture levels. Therefore, selecting a low feed moisture and high screw speed will give a better quality of brown rice product for use in breakfast cereal.

### Determination of Tocopherols

Brown rice had lower vitamin E content ( $\alpha$ -,  $\gamma$ -tocopherols: 4, and 4  $\mu\text{g/g}$ ) than *E. ferox* Salisb., which contained 1,067, 60, 522, and 74  $\mu\text{g/g}$  for  $\alpha$ -,  $\beta$ -,  $\gamma$ -, and  $\delta$ -tocopherols, respectively. The tocopherol contents in extrudates remained relatively high and increased with increasing contents of *E. ferox* Salisb. (Fig. 1), the results showed that E15 had the highest content of  $\alpha$ -,  $\beta$ -,  $\gamma$ -, and  $\delta$ -tocopherols (125, 6, 78, and 9  $\mu\text{g/g}$ ), respectively. The retained ratio of the  $\alpha$ -tocopherol of extrudates after extrusion was between 76 and 130%, and the ratio range was 70 and 90%, 95 and 135%, and 83 and 139% for  $\beta$ -,  $\gamma$ -, and  $\delta$ -tocopherols, respectively (Table IV). We concluded that very high recovery of tocopherol contents is achieved after high temperature and short time treatment. Previous studies reported that vitamin E may reduce the risk of coronary heart disease by its strong antioxidant function, especially both the  $\alpha$ - and  $\gamma$ -form of tocopherol (Halliwell and Gutteridge 1999; Kontush et al 1999). In this study, we showed that E15 has the highest content of  $\alpha$ -,  $\beta$ -,  $\gamma$ -, and  $\delta$ -tocopherols. The E15 extrudates have the highest antioxidative activity, as shown by TBA and peroxide analysis (Lin 2002).

### CONCLUSIONS

Optimal conditions have been established for extrusion processing of functional foods using brown rice and *E. ferox* Salisb. Processing conditions included a feed rate at 12 rpm and barrel temperatures at 110-100-100-80°C, respectively. Die diameter was 3.5  $\times$  0.8 mm, and screw speed was 200 or 250 rpm with feed moisture content at 15 or 20%. The samples added with *E. ferox* Salisb. showed a high vitamin E content and could be a beneficial food product for coronary heart disease patients.

**TABLE III**  
Effect of Feed Moisture and Screw Speed on Expansion Ratio, Bulk Density ( $\text{g/cm}^3$ ), Water Absorption Index (WAI), and Water Solubility Index (WAI %) of Extruded Brown Rice Flour with Added *Euryale ferox* Salisb.<sup>a-c</sup>

Feed Moisture/ Screw Speed	E0	E5	E10	E15
Expansion ratio				
M15-S200	6.05b <sup>d</sup>	6.88a	6.53b	6.06a
M15-S250	6.75a	6.73a	6.83a	6.06a
M20-S200	3.00d	2.95c	2.92d	2.82c
M20-S250	5.15c	4.84b	5.04c	4.36b
Bulk density				
M15-S200	0.058c	0.043c	0.072c	0.058c
M15-S250	0.052d	0.043c	0.043d	0.060c
M20-S200	0.383a	0.392a	0.425a	0.465a
M20-S250	0.128b	0.168b	0.150b	0.210b
WAI				
M15-S200	2.51c	2.22c	2.51c	2.36c
M15-S250	2.35c	2.28c	2.27c	2.28c
M20-S200	12.79a	12.5a	13.42a	14.37a
M20-S250	9.94b	10.52b	9.01b	8.61b
WSI				
M15-S200	68.58b	69.94b	68.22a	68.06b
M15-S250	73.02a	75.28a	68.26a	74.77a
M20-S200	17.84d	18.39d	18.31c	19.33d
M20-S250	23.22c	27.21c	25.41b	27.62c

<sup>a</sup> Means of triplicates.

<sup>b</sup> E0: 100% brown rice flour; E5: 95% brown rice flour +5% *E. ferox* Salisb.; E10: 90% brown rice flour +10% *E. ferox* Salisb.; E15: 85% brown rice flour +15% *E. ferox* Salisb.

<sup>c</sup> M15-S200: feed moisture 15%, screw speed 200 rpm; M15-S250: feed moisture 15%, screw speed 250 rpm; M20-S200: feed moisture 20%, screw speed 200 rpm; M20-S250: feed moisture 20%, screw speed 250 rpm.

<sup>d</sup> Means within the same column with different letters (a-d) or row with different letters (w-z) are significantly different ( $P < 0.05$ ).

**TABLE IV**  
Recovery Tocopherol Content of Extruded Brown Rice Flour Added with *Euryale ferox* Salisb.<sup>a</sup>

Extrudates <sup>b</sup>	Tocopherol Content ( $\mu\text{g/g}$ )			
	$\alpha$	$\beta$	$\gamma$	$\delta$
E0	5d <sup>c</sup> (130%) <sup>d</sup>	2d	6d (130%)	4d
E5	47c (82%)	3c (90%)	41c (135%)	5c (139%)
E10	84b (76%)	4b (73%)	58b (103%)	7b (99%)
E15	125a (76%)	6a (70%)	78a (95%)	9a (83%)

<sup>a</sup> Means of triplicates.

<sup>b</sup> E0: 100% brown rice flour; E5: 95% brown rice flour +5% *E. ferox* Salisb.; E10: 90% brown rice flour +10% *E. ferox* Salisb.; E15: 85% brown rice flour +15% *E. ferox* Salisb.

<sup>c</sup> Means within the same column with different letters are significantly different ( $P < 0.05$ ).

<sup>d</sup> Recovery amount (%) of extrudates in brown rice added with four ratios of *E. ferox* Salisb.

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