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# Effect of particle size and concentration of defatted rice bran supplemented in tomato salad dressing

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**Abstract**

Defatted rice bran (DRB) is a low-cost, high-fiber, antioxidant-rich byproduct of rice bran oil production that has limited application in food systems due to its undesirable impacts on sensory attributes. This research aimed to determine the feasibility of integrating defatted rice bran into tomato salad dressing without undergoing chemical or enzymatic pretreatment. The DRB particle size (38, 90, and 150 μm) and concentration (1, 5, and 9%) significantly affected the functional properties and sensory attributes of salad dressing. The high bran concentration significantly increased viscosity and emulsion stability, although it had the opposite effect on color and texture sensory characteristics ($p < 0.05$). The particle size of bran significantly affected the appearance, texture, and overall liking of the product. The response surface methodology showed that the optimal DRB particle size and concentration for supplementation in a tomato salad dressing were 75 μm and 4.80%, respectively. The DRB supplementation prolonged the oxidative stability of the product compared to its control counterpart. Results demonstrated that the particle size reduction adequately modified the DRB properties to be suitable for application as a functional ingredient, which enhanced the nutritional properties and storage stability of a salad dressing.

**Keywords:** cereal bran; dietary fiber; rice byproduct; emulsion.

**Practical Application:** Defatted rice bran (DRB) could be used to enhance the functional and nutritional properties of salad dressing. DRB could also be used as a natural antioxidant to retard the oxidative stability of an emulsion product.

## 1 Introduction

Worldwide, the global rice bran oil market was forecasted to rise from $6.67 billion in 2021 to $12.27 billion by 2028 at a compound annual growth rate (CAGR) of 9.09% in the forecast period, 2021-2028 (Fortune Business Insights Pvt. Ltd., 2022), leading to the massive volume of defatted rice bran (DRB), which is a byproduct of rice bran oil extraction. DRB has the potential to be used as a supplement in dietary products or as an ingredient in functional foods (Abdul-Hamid & Luan, 2000). DRB is an excellent source of dietary fiber (DF), proteins, as well as many bioactive compounds such as phenolic substances (Mariod et al., 2010; Yuwang et al., 2018). The DF in rice bran consists mainly of insoluble dietary fiber (IDF) such as cellulose and hemicellulose (Chinma et al., 2015), resulting in an unbalanced soluble/insoluble dietary fiber (SDF/IDF). IDF contributes to health benefits by promoting the growth of intestinal microflora, increasing fecal bulk, and decreasing intestinal transit (Foschia et al., 2013). The addition of DRB, which contains a high amount of IDF in food systems, is unfavorable due to its roughness or grittiness, thus limiting its utilization in food product development. Studies have reported that the reduction in particle size of fibers could alter the IDF into SDF and the ratio of SDF/IDF (Alam et al., 2014; Chen et al., 2020; Silventoinen et al., 2021).

Particle size reduction has the added benefit of higher phytochemical compound bioaccessibility of phenolic acids (Wu et al., 2022; Alzuwaid et al., 2021; Hemery et al., 2010), as well as changes in physicochemical and functional properties (Alam et al., 2014; Alzuwaid et al., 2021; Bonifacino et al., 2020; Cao et al., 2021; Kurek et al., 2017; Zhao et al., 2018). Rosa et al. (2013) reported that ultra-fine grinding increases the antioxidant capacity of wheat bran without any prior extraction.

Many individuals in developed societies have low daily dietary fiber intakes because of their busy lifestyles and food choices. According to the American Heart Association, women should consume between 21 and 25 g of fiber, soluble or insoluble, per day, whereas men should consume between 30 and 38 g daily (Smiley, 2017). Salad is a popular food item and is a healthy dietary food choice that often includes a variety of high-fiber plant-based ingredients such as carrots, peppers, and broccoli. Often, consumers apply a flavored dressing as a salad topping. Mordor Intelligence (2021), a consumer market research firm, reported that the worldwide salad dressing market is expected to increase at a compound annual growth rate (CAGR) of 6.13% between 2020 and 2025. Tomato salad dressing is one of the most popular salad dressings consumed in Thailand. Its formulation is basically similar to French dressing.

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The literature is scarce on the use of DRB as a dietary fiber in salad dressings. Albeit studies using defatted flour (DF) from rice bran (RB) in a variety of food products have been conducted, including frozen roti dough supplemented with rice bran (Muadiad & Sirivongpaisal, 2022), salad dressing substituted with hydrogen peroxide rice bran (Maani et al., 2017), milk analogues from protein hydrolysate extracted from defatted rice bran (Wongthaweewatana et al., 2021), and low-fat meatballs enriched with hemicellulose from rice bran (Hu & Yu, 2015). Response surface methodology (RSM) is a common method used to design and formulate new products and develop existing product properties (Bas & Boyaci, 2007). RSM is used to explore the relationships between explanatory variables and response variables. Therefore, the aims of this study were to investigate the feasibility of incorporating DRB derived from oil extraction without any chemical or enzymatic pre-treatment step into tomato salad dressing. In this study, RSM was used to obtain an optimal DRB particle size and concentration for the best functional properties and sensory attributes.

## 2 Material and methods

### *2.1 Material*

DRB was provided by a local rice bran oil company (Thailand). All the ingredients were purchased from a local supermarket, and all the chemicals used in this study were analytical grade.

### *2.2 Defatted rice bran and Tomato salad dressing preparation*

For particle uniformity, the DRB was passed through a size reduction process using a ball mill and then separated into 3 fractions using the USA standard sieves (100, 170, and 400 mesh) (Endecotts Ltd., United Kingdom) with average particle sizes of 150, 90, and 38 μm, respectively.

Salad dressing was formulated with the following ingredients: rice bran oil (34%), vinegar (20%), sugar (20%), tomato puree (15%), water (8%), salt (1.3%), pepper (1.0%), and mustard powder (0.7%). Based on our preliminary study regarding physicochemical and sensory properties, DRB was incorporated into the salad dressing at 1, 5, or 9% (w/w). The sample preparation was as follows: the minor ingredients, water, mustard powder, sugar, and pepper, were mixed with a medium-speed mixer for 2 min, followed by the addition of salt, vinegar, and tomato puree. DRB was combined and homogeneously mixed for 2 min. Lastly, the oil was gradually added dropwise into the continuous phase while agitating with an Ultra-Turrax homogenizer (Model T25; Ika-Labortechnik, Germany) at 13500 rpm for 3 min. Immediately after production, all samples were pasteurized at 80 °C for 15 min and aseptically packed in the transparent glass bottles.

### *2.3 Experimental design*

*Properties of DRB with different particle sizes were performed using the Completely Randomized Design (CRD) (International Business Machines Corporation, 2015).*

The RSM was employed to study the optimum particle size (150, 90, and 38 μm) and concentration (1, 5, and 9%) of DRB supplemented in tomato salad dressing using the Central Composite Face Centered Design (CCFD) with $\alpha = \pm 1$. The design approach contained four factorial points, four axial points, one center point, and two replicates at the center point. Each factor has three levels as codes, which are low level (-1), center level (0), and high level (+1) (Dawood & Li, 2014) (Table 1). The 11 experimental points were derived from Minitab Statistical Software Version 16 (Minitab, Inc., State College, Pennsylvania, USA).

### *2.4 Property analysis*

*Physicochemical properties*

Proximate analysis, soluble, and insoluble dietary fiber fractions were analyzed following Association of Official Analytical Chemists (2005) methods. Fiber analysis was performed by the enzymatic gravimetric method (AOAC 994.13). The water holding capacity (WHC), swelling capacity (SC), and oil holding capacity (OHC) were determined according to the method described by Wang et al. (2012).

Total phenolic content (TPC). The TPC was analyzed using the Folin-Ciocalteu colorimetric method described by Muntana & Prasong (2010).

**Table 1**. A central composite face centered design (CCFD) with code, actual experimental and response data for supplementation of defatted rice bran with different particle size and concentration in tomato salad dressing.

| Defatted rice bran | | Physical properties | | | Sensory evaluation (7-point scales) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Particle size (μm) | Concen-tration (%) | Apparent viscosity (cP) | Oil droplet size (μm) | Separation index (%) | Appearance | Consistency | Color | Taste | Texture | Overall liking |
| 90, (0) | 1, (-1) | 619.17 ± 42.12 | 64.67 ± 5.03 | 22.67 ± 4.35 | 4.85 ± 1.14 | 3.85 ± 0.99 | 5.35 ± 1.04 | 5.70 ± 1.34 | 4.95 ± 1.05 | 4.70 ± 0.57 |
| 38, (-1) | 1, (-1) | 519.17 ± 2.04 | 68.00 ± 2.00 | 27.33 ± 5.48 | 4.25 ± 1.25 | 4.20 ± 1.20 | 4.50 ± 1.00 | 5.20 ± 1.20 | 4.15 ± 1.18 | 4.40 ± 0.50 |
| 90, (0) | 5, (0) | 1423.70 ± 16.06 | 40.67 ± 1.15 | 6.33 ± 2.21 | 5.10 ± 0.85 | 5.10 ± 0.91 | 4.90 ± 0.91 | 5.40 ± 0.60 | 4.75 ± 0.72 | 4.90 ± 0.55 |
| 38, (-1) | 9, (+1) | 4957.50 ± 6.12 | 33.67 ± 6.03 | 0.00 ± 0.00 | 4.25 ± 1.16 | 3.30 ± 0.92 | 3.65 ± 1.93 | 4.45 ± 1.54 | 2.65 ± 1.27 | 3.80 ± 0.77 |
| 90, (0) | 5, (0) | 1524.20 ± 21.31 | 38.00 ± 2.88 | 4.93 ± 2.33 | 5.00 ± 1.17 | 4.90 ± 1.12 | 4.80 ± 1.28 | 5.35 ± 0.93 | 4.45 ± 1.31 | 4.77 ± 0.37 |
| 90, (0) | 5, (0) | 1384.20 ± 18.28 | 38.00 ± 1.15 | 5.13 ± 1.66 | 5.40 ± 0.75 | 5.35 ± 0.81 | 5.30 ± 1.17 | 5.65 ± 0.73 | 5.20 ± 1.10 | 5.13 ± 0.69 |
| 150, (+1) | 9, (+1) | 4813.30 ± 77.57 | 39.67 ± 6.51 | 1.53 ± 1.15 | 4.60 ± 1.27 | 4.65 ± 1.23 | 4.30 ± 1.22 | 5.30 ± 0.92 | 4.00 ± 0.86 | 4.65 ± 0.67 |
| 150, (+1) | 5, (0) | 1140.80 ± 19.34 | 46.33 ± 1.15 | 15.00 ± 2.89 | 4.80 ± 1.01 | 4.85 ± 0.93 | 4.30 ± 1.26 | 4.70 ± 1.63 | 4.20 ± 1.15 | 4.50 ± 1.00 |
| 150, (+1) | 1, (-1) | 593.33 ± 16.33 | 95.00 ± 2.00 | 28.00 ± 4.31 | 4.70 ± 1.08 | 4.20 ± 1.36 | 5.05 ± 0.89 | 5.45 ± 1.28 | 5.30 ± 0.92 | 4.75 ± 0.72 |
| 90, (0) | 9, (+1) | 4815.00 ± 7.75 | 31.00 ± 3.61 | 0.00 ± 0.00 | 4.90 ± 0.91 | 4.25 ± 0.97 | 4.40 ± 0.99 | 5.65 ± 0.88 | 4.50 ± 0.95 | 4.80 ± 0.70 |
| 38, (-1) | 5, (0) | 1745.80 ± 14.97 | 51.00 ± 6.56 | 18.67 ± 3.80 | 4.15 ± 0.93 | 4.35 ± 1.18 | 4.15 ± 0.93 | 4.75 ± 1.16 | 3.65 ± 0.81 | 4.25 ± 0.55 |

DPPH (1,1-diphenyl-2-picrylhydrazyl) radical scavenging capacity. The ability of extracts from DRB to scavenge the DPPH radical was analyzed with the colorimetric method described by Brand-Williams et al. (1995).

*Apparent viscosity*

The apparent viscosity of salad dressing was determined using a Brookfield Digital viscometer (Model RVDVI+ Brookfield ENG Labs Inc., MA., USA) equipped with a spindle 27 at 50 rpm for 2 min. The measurement was conducted at 25 °C.

*Color*

The color of the sample was monitored by a Hunter Lab colorimeter (Hunter Associate Laboratory, USA). The CIE Lab color scale was used to assess the L* (black to white), a* (red to green), and b* (yellow to blue) parameters.

*Oil droplet size*

The oil droplet size of the emulsion was captured by an optical microscope (CX21FS1, Olympus, Tokyo, Japan) with a built-in digital camera (DP 70, Olympus, Tokyo, Japan) under 40X magnification. The emulsions were diluted 50 times with sodium dodecyl sulfate (SDS) to a final concentration of 0.5%, and at least 10 samples from each replication (3 replications) were examined for this property (Montenegro Villamarín, 2019).

*Separation index*

A phase separation used to monitor the physical stability of an emulsion in salad dressing was performed by measuring the height of the cream layer (Hs) and the total height of the emulsion (Ht) using a caliper (Zang et al. 2019). The emulsion separation index (%) was calculated from Equation 1.

$$Separation\ index(\%)=\left[\ Hs\ /\ Ht\ \right]\times 100 \tag{1}$$

*Oxidative stability*

Thiobarbituric acid-reactive substances (TBARS), as described by Maqsood & Benjakul (2010), were used to test the oxidative stability of a selected tomato salad dressing supplemented with the optimum particle size and concentration.

### 2.5 The framework of sensory evaluation

The sensory evaluation was performed by 30 semi-trained panelists (20-50 years old). Panelists were students and staff members in a sensory evaluation laboratory at King Mongkut's University of Technology North Bangkok who were familiar with sensory evaluation. Tomato salad dressings (approximately 40 g) (Chatsisvili et al., 2012) were served in a randomized order with lettuce and water, and panelists were asked to rate the likeness of the samples on appearance, consistency, color, taste, texture, and overall liking by using a 7-point hedonic scale (7 = strongly like, 1 = strongly dislike). Before sensory evaluation, the meaning of attributes was explained to the panelists to avoid any misinterpretations. Panelists were also asked to read the instructions and answer the questionnaire.

### 2.6 Statistical analysis

All experiments for the properties of DRB were carried out in triplicate and statistically analyzed using IBM SPSS statistics for Windows, version 23 (International Business Machines Corporation, 2015). The Fisher's least significant difference (LSD) was applied for the mean comparison at the 95% confidence level.

The response variables are used to optimize the optimum particle size and concentration, including physical properties and sensory evaluation. Each CCFD treatment was carried out in 3 replicates, and the results were expressed as mean values ± standard deviation. Significant second-order polynomial models with adjusted determination coefficients ($R^2$) of at least 0.80 or *greater* are required to ensure a satisfactory fit of the response surface models to the actual data. The p values of the lack of fit were used to evaluate the accordance of mathematical models, and the values were not significant ($p \geq 0.05$). All models selected were statistically significant ($p < 0.05$), indicating a significant relationship between bran particle size and concentration on the properties of salad dressing.

The optimum treatment was validated and compared with the predicted outcome model. The difference ($\Delta Y$) calculated using Equation 2, which was less than 10%, was acceptable (Minitab, Inc., 2016), and was used for property prediction. Significant tests of the regression model, individual model coefficients, and the p values of lack of fit were carried out with ANOVA at the 95% confidence level.

$$\Delta Y=\frac{\left|Yexperiment\text{-}Ypredicted\right|}{Yexperiment}\times 100 \tag{2}$$

The oxidative stability of the salad dressing supplemented with the optimum DRB during storage at 35 °C for 4 weeks was compared to the control counterpart sample (tomato salad dressing without DRB supplementation) using the t-test analysis at the 95% confidence level.

## 3 Results and discussion

### 3.1 Properties of defatted rice bran

The physicochemical and functional properties of DRB with different particle sizes used as raw materials are presented in Table 2. The results showed that the size of bran particles had a significant impact on bran characteristics. As particle size decreased, protein content, ratio of SDF to IDF, total phenolic content, and antioxidant capabilities all increased. The ratio of SDF to IDF of bran samples was almost doubled (from 0.44 to 0.74) as the particle size was reduced from 150 to 38 µm. The results of this study revealed that particle size reduction could improve the nutritional and functional properties of DRB. The mechanical treatment dramatically caused the structure breakdown (data not shown) of DRB, increased the surface area, as well as loosened bran functional components, thus improving the extractability of the nutritional and phytochemical substances. Moreover, the

**Table 2**. Properties of defatted rice bran with different particle size.

| Physico-chemical and functional properties | Particle size (μm) | | |
|---|---|---|---|
| | 150 | 90 | 38 |
| Moisture (%, wb)[ns] | 13.50 ± 0.56 | 13.70 ± 0.32 | 13.38 ± 0.46 |
| Protein (%, wb) | 19.59 ± 0.53[a] | 21.46 ± 1.04[b] | 22.77 ± 1.89[b] |
| Total dietary fiber (%, wb) | 25.17 ± 0.88 [b] | 23.88 ± 0.26[a] | 24.61 ± 1.44[a] |
| Soluble dietary fiber (% SDF, wb) | 7.73 ± 0.66[a] | 7.92 ± 1.35[a] | 10.44 ± 0.83[b] |
| Insoluble dietary fiber (% IDF, wb) | 17.44 ± 0.29[b] | 15.96 ± 1.19[a] | 14.17 ± 0.88[a] |
| Ratio of SDF to IDF | 0.44: 1 | 0.49: 1 | 0.74: 1 |
| Total phenolic content (mg GAE/g) | 254.65 ± 17.82[a] | 282.22 ± 15.17[b] | 318.03 ± 19.80[c] |
| DPPH radical scavenging capacity (%) | 18.29 ± 0.36[a] | 23.38 ± 0.09[b] | 26.04 ± 0.52[c] |
| Water holding capacity (g/g dried weight) | 2.43 ± 0.32[a] | 3.13 ± 0.10[b] | 3.57 ± 0.07[b] |
| Swelling capacity (mL/g dried weight) | 3.20 ± 0.20[a] | 4.00 ± 0.20[b] | 4.47 ± 0.11[c] |
| Oil holding capacity (g/g dried weight)[ns] | 2.97 ± 0.50 | 2.54 ± 0.22 | 2.05 ± 0.12 |
| Apparent viscosity (cP) | 80.77 ± 3.29[a] | 85.16 ± 1.14[b] | 90.90 ± 0.20[c] |
| L* | 72.28 ± 0.23[a] | 75.70 ± 0.17[b] | 78.34 ± 0.24[c] |
| a* | 2.86 ± 0.08[b] | 2.59 ± 0.09[b] | 1.19 ± 0.07[a] |
| b* | 19.48 ± 0.51[c] | 16.83 ± 0.19[b] | 15.09 ± 0.26[a] |

Note: Values are mean ± standard deviation of three replicates. Values in each row with different lowercase superscripts differ significantly ($p < 0.05$). [ns]The samples were not significantly different ($p \geq 0.05$).

WHC and SC of DRB significantly changed with the reduction of particle size. According to Raghavendra et al. (2006), the grinding process changed the structure of the fiber from a honeycomb to a flat ribbon type structure, thus increasing the surface area of the fiber for water and fat absorption. The hydration rate depends on many factors, such as chemical structure, molecular weight, morphology, and particle size of the fiber (Cui et al., 2011). As a result, the nutritional and functional properties of bran, such as its hydration, including apparent viscosity, increased as particle size decreased. Our findings agree with the previous studies reported by Silventoinen et al. (2021), Alzuwaid et al. (2021), and Cao et al. (2021). Additionally, the reduction in particle size of DRB affected its color property. The lightness (L*) values significantly increased with a corresponding reduction in particle size while the degree of redness and yellowness (a* and b*, respectively) decreased due to the destruction of pigment during the ball milling process (Onipe et al., 2017).

### *3.2 Effects of particle size and concentration of DRB supplemented in tomato salad dressing*

*Functional properties of salad dressing*

Apparent viscosity

The concentration of bran supplemented in salad dressing strongly impacted the apparent viscosity of the product. The higher bran concentration significantly increased the apparent viscosity of the product (Tables 1 and 3 and Figure 1a). DRB contains some polysaccharides and oligosaccharides (Qi et al., 2016), which provide a gel-like structure when heated. Consequently, the higher the level of DRB, the more viscous samples would be observed. Our results are consistent with other previous findings. Qi et al. (2016) observed that the higher quantity of

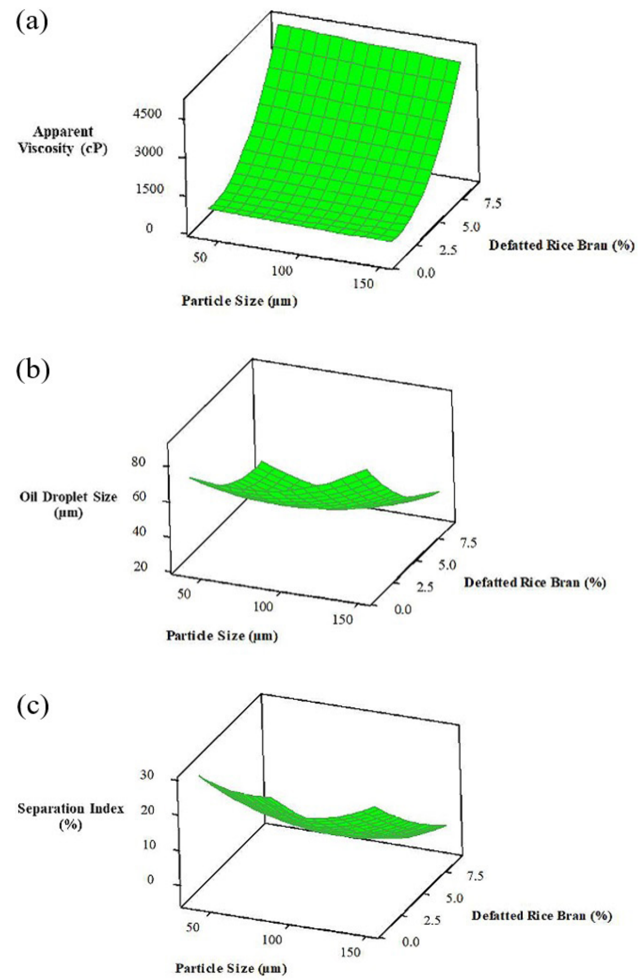


**Figure 1**. Response surface plots for the effect of particle size reduction and the concentration of defatted rice bran (DRB) on the apparent viscosity (a), oil droplet size (b), and separation index of tomato salad dressing (c).

viscous polysaccharides corresponds to a greater percentage of arabinose and galactose, which might result in a more viscous sample. Chatsisvili et al. (2012) reported that the addition of orange pulp fiber was attributed to the substantial increase in the continuous phase viscosity of a low-in-oil dressing-type o/w emulsion.

Oil droplet size

In the present study, the oil droplet size tended to decrease along with the decrease in bran particle size, whereas the bran concentration increased (Tables 1 and 3 and Figure 1b). However, the concentration was the only factor that had a statistically significant impact on the oil droplet size of the product ($p < 0.05$). Oil droplet size is significant to the stability of an emulsion. According to Risch & Reineccius (1988), a small and uniform droplet size of emulsion could improve the emulsion stability. The DRB fiber may stabilize the emulsion by adsorbing at the oil-water interface and forming a steric barrier that provides electrostatic repulsion and retards creaming and sedimentation (Gestranius et al., 2017; Yang et al., 2017). Additionally, the polysaccharide such as cellulose presented in

**Table 3**. p-values from ANOVA analysis and coefficient of determination ($R^2$) results of response data for physical properties and sensory evaluation of tomato salad dressing supplemented with different defatted rice bran particle size and concentration.

| Sources of Variation | Physical properties | | | Sensory evaluation (7-point scales) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Apparent viscosity | Oil droplet size | Separation index | Appearance | Consistency | Color | Taste | Texture | Overall liking |
| Model | 0.000* | 0.004* | 0.004* | 0.044* | 0.033* | 0.022* | 0.034* | 0.034* | 0.045* |
| Linear | 0.000* | 0.001* | 0.001* | 0.049 | $0.126^{ns}$ | 0.014* | $0.118^{ns}$ | 0.016* | $0.078^{ns}$ |
| Particle size | $0.148^{ns}$ | $0.128^{ns}$ | $0.880^{ns}$ | 0.039* | $0.052^{ns}$ | $0.077^{ns}$ | $0.112^{ns}$ | 0.026* | 0.040* |
| Concentration | 0.000* | 0.001* | 0.000* | $0.928^{ns}$ | $0.948^{ns}$ | 0.009* | $0.142^{ns}$ | 0.021* | $0.306^{ns}$ |
| Square | 0.000* | 0.031* | 0.054* | 0.023* | 0.019* | 0.030* | 0.014* | 0.067* | 0.044* |
| Interaction | $0.528^{ns}$ | $0.167^{ns}$ | $0.914^{ns}$ | $0.824^{ns}$ | $0.072^{ns}$ | $0.849^{ns}$ | $0.235^{ns}$ | $0.811^{ns}$ | $0.297^{ns}$ |
| Lack of fit | $0.173^{ns}$ | $0.116^{ns}$ | $0.180^{ns}$ | $0.922^{ns}$ | $0.521^{ns}$ | $0.809^{ns}$ | $0.341^{ns}$ | $0.534^{ns}$ | $0.605^{ns}$ |
| $R^2$ | 0.9960 | 0.9423 | 0.9406 | 0.8345 | 0.8612 | 0.8829 | 0.8606 | 0.8601 | 0.8130 |

*Significance at 95% confident level; $^{ns}$Non significance at 95% confident level.

DRB can produce a soft gel like structure with the capacity to absorb water (Maani et al., 2017), thus increasing the viscosity of the continuous phase. The viscosity increase may retard oil droplet mobility and collision, thereby preventing coalescence of the emulsion. As a result, DRB supplementation with an appropriate particle size and concentration positively promotes the stability of salad dressing. Similarly, Chatsisvili et al. (2012) found that an emulsion incorporated with orange pulp fiber had a significantly smaller droplet size compared to the control.

### Separation index

The separation index from the CCFD treatments was determined to assess the effect of DRB supplementation on emulsion stability against creaming caused by gravitational forces. A similar trend that affected the oil droplet size was observed. However, the effect of bran concentration on the separation index was more pronounced than that of particle size reduction (Tables 1 and 3 and Figure 1c). There was no separation observed in samples incorporated with 9% of either 90 or 38 μm brans. In contrast, the highest separation index value was observed in salad dressing supplemented with 150 μm for 1% DRB. An increased concentration of DRB in the continuous phase resulted in an increase in apparent viscosity, thus preventing the movement of oil droplets. Similar results were reported by Bonifacino et al. (2020) and Li et al. (2018). Additionally, Li et al. (2018) reported that the stability and apparent viscosity of the emulsion were enhanced with an increase in regenerated cellulose concentration.

## *Sensory attributes*

### Appearance and consistency

The particle size of DRB significantly affected the appearance of salad dressing ($p < 0.05$) (Tables 1 and 3 and Figure 2a) The highest score for its appearance was evaluated against a salad dressing enriched with 90 μm DRB for 5%. The smaller the DRB particle size and the highest DRB concentration tended to decrease consumer acceptance. This may be due to an increase in hydration and viscosity of the product as particle size decreased (Table 2), resulting in an unfavorable appearance. However, both the particle size and concentration of DRB supplemented in salad dressing did not significantly affect product consistency ($p \geq 0.05$) (Tables 1 and 3 and Figure 2b). Noticeably, the average apparent viscosity of the sample supplemented with 90 μm bran at 5% was approximately 1,444.03 cP, which is similar to that of commercial samples, thus resulting in a similar consistency to commercial salad dressing. Consequently, this sample tended to receive higher scores compared to other treatments. Similar results were observed by Tseng & Zhao (2013).

### Color, taste, and texture

The concentration of DRB greatly impacted the color of the salad dressing compared to its particle size ($p < 0.05$). Scores ranked by the panelists tended to be lower when the concentration of DRB increased (Tables 1 and 3 and Figure 2c). The redness of tomato salad dressing was lessened as the concentration of DRB increased because of the bran lightness. Therefore, the more DRB supplementation, the lower the score for the color attribute. Similarly, Anil (2012) reported that a high level of rice bran supplementation (especially 20%) decreased the sensory color scores and reduced the surface smoothness of pides.

The taste evaluation showed that supplementation with DRB had no significant effect on product taste (Tables 1 and 3 and Figure 2d). This might be due to the bland flavor of DRB. Sharif et al. (2009) reported that DRB can be used to substitute wheat flour for up to 10 to 20% of cookies without adversely affecting quality attributes.

On the contrary, the texture of products was affected by both DRB particle size and concentration (Tables 1 and 3 and Figure 2e). An increase in rice bran supplementation may contribute to the grittiness or rough texture because of the IDF fraction of DRB. Our results are consistent with those reported by Maani et al. (2017). Additionally, our results revealed that the very fine particles (38 μm) negatively affected product texture, which may be due to an intensified alteration of the hydration property of rice bran fiber (Table 2).

### Overall liking

The overall liking is used to measure panelists' overall hedonic response to the sample product. For this study, the sensory modalities of appearance, consistency, color, taste, and texture were reflected in the evaluation of overall liking. Results showed

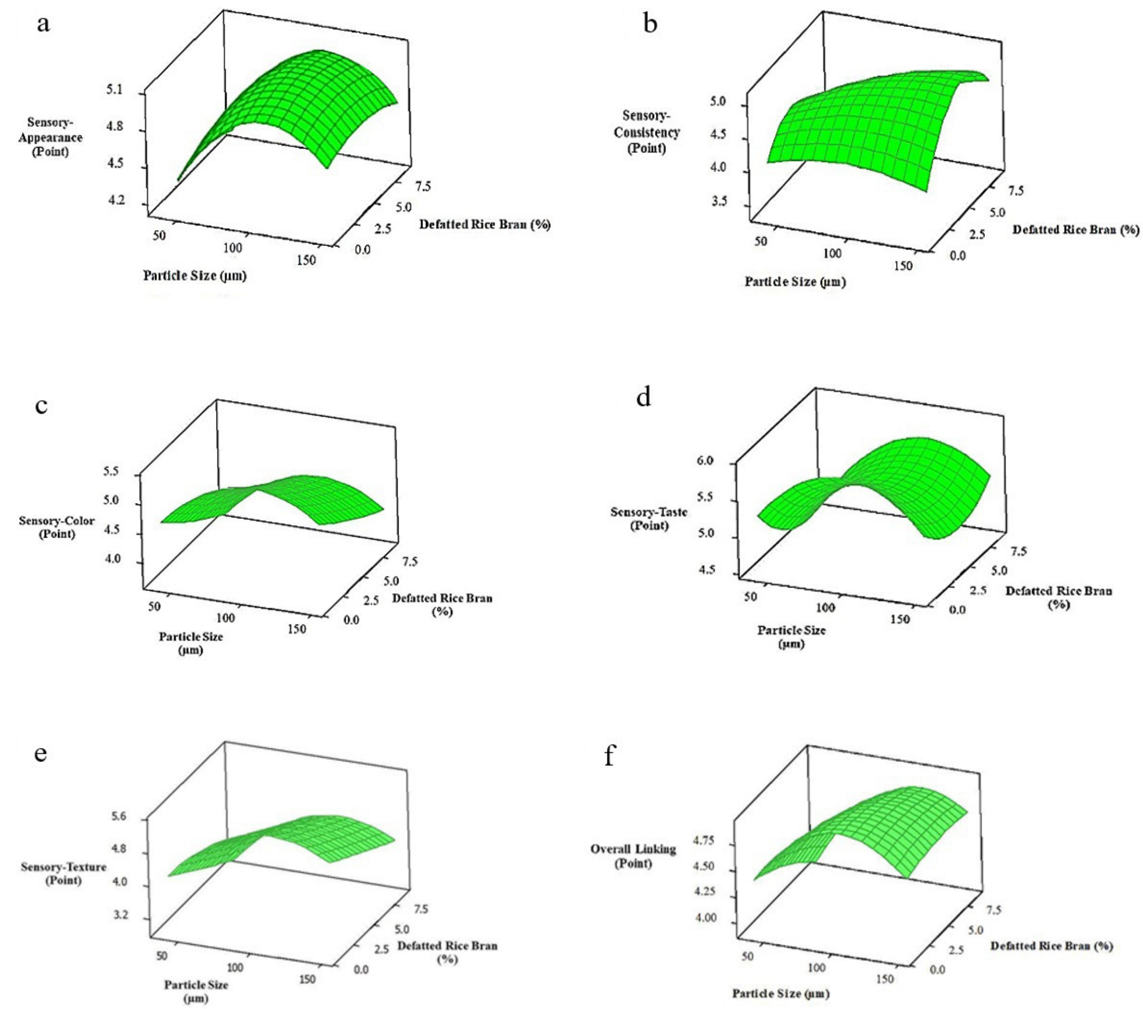


**Figure 2**. Response surface plots for the effect of particle size reduction and the concentration of defatted rice bran (DRB) on the appearance (a), consistency (b), color (c), taste (d), texture (e), and overall liking (f) of tomato salad dressing supplemented with DRB, evaluated using a 7-point hedonic scale.

that the salad dressing incorporating the smallest bran particle size in combination with high concentration was rated with the lowest score compared to the other samples. (Figure 2f). The plausible explanation might be the unusually high consistency and rough texture of the product. This implies that the apparent viscosity, consistency, and texture of a product have a significant impact on the perceived acceptance of salad dressing. Similar results were observed by Maani et al. (2017) and Hu & Yu (2015).

### *3.3 Optimization and validation of the predicted model*

The optimum particle size and concentration of DRB supplemented in tomato salad dressing were determined to meet the desirable criteria based on both functional and sensory properties that are in the same range as commercial tomato salad dressing and a separation index after storage for 4 weeks of less than 11%. The result showed that the optimum particle size of DRB was 200–255 mesh (approximately 62–75 µm) and the concentration ranged between 4.0 and 4.8%. Thus, the 75 µm particle size with a maximum level of 4.8% DRB was selected to study the validation of the predicted model compared to experimental results. Results showed that the maximum percentage of experimental uncertainty or error ($\Delta Y$, Equation 2) was below 10% (Minitab, Inc., 2016) (data not shown). Therefore, it was confirmed that the response model reflected the optimization process.

### *3.4 The oxidative stability of the salad dressing supplemented with defatted rice bran*

Salad dressing is an oil-in-water emulsion with a high fat content that is easily oxidized during processing and storage. Our results revealed that supplementation with 4.8% DRB with a particle size of 75 µm could retard lipid oxidation compared to a control sample (Figure 3). The DRB with 75 µm particle size used in this study is composed of 22.77% protein, an SDF/IDF ratio of 0.58, 318.03 ± 19.80 mg GAE/g (dry weight) total phenolics, and 26.04 ± 0.52% DPPH free-radical scavenging. Consequently, a sample incorporated with DRB demonstrated higher oxidative stability during storage compared to its control counterpart. According to Devi & Arumughan (2007), DRB contains considerable amounts of phytochemical compounds

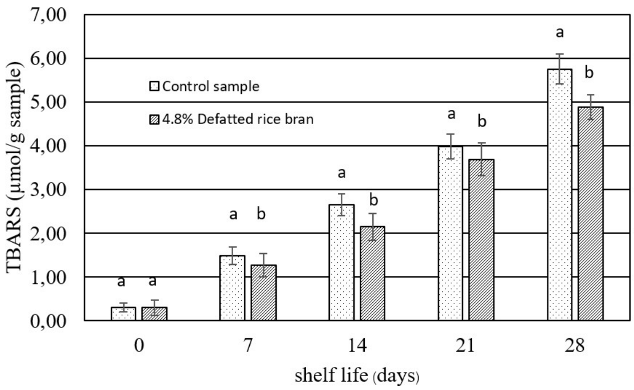


**Figure 3**. The thiobarbituric acid-reactive substances (TBARS) in tomato salad dressing supplemented with 4.8% defatted rice bran at an average particle size of 75 µm compared to a control sample during storage at 35 °C for 4 weeks. Different letters in superscript on the bars indicate a significant difference between samples at the same period of storage ($p < 0.05$).

that might be employed as alternatives to synthetic antioxidants in food products. Similarly, Aksoy et al. (2022) reported that the phenolic extracts from cold-pressed grape and pomegranate seed oil byproducts could be used as a natural antioxidant to reduce the oxidation rate in salad dressing.

## 4 Conclusions

Our study revealed that the particle size and concentration of DRB affected the physico-chemical and sensory properties of salad dressing. The particle size of DRB supplementation affected the appearance, texture, and overall liking of the product while having no effect on its color or taste. The supplementation concentration affected the viscosity and emulsion stability. In addition to nutritional enhancement, the results from this study suggested that the supplementation of optimum particle size (75 µm) and concentration (4.8%) prolonged oxidative stability, thus extending product shelf life. This innovative finding thereby contributes to an increase in the value of an important byproduct of rice bran oil extraction.

## Conflict of interest

The authors declare that they have no conflict of interest in the publication.

## Availability of data and material

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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