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Balancing quality and safety: Optimising drying and sodium metabisulphite use in low-fat desiccated coconut

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Abstract: Indonesia, as a leading coconut producer, generates a substantial amount of coconut pulp from coconut milk extraction, which can be further processed into low-fat desiccated coconut. However, the drying process induces browning, reducing its whiteness and overall quality. Sodium metabisulphite is commonly used to prevent browning, but excessive use raises health concerns. In this study, the optimisation of the drying temperature and sodium metabisulphite concentration was conducted to minimise the browning while maintaining the quality of low-fat desiccated coconut. Using Response Surface Methodology (RSM) with a Central Composite Design (CCD), responses such as the browning index (*BI*), whiteness index (*WI*), moisture content, yield, free fatty acids (*FFAs*), ash, fat, protein, total phenolic content (*TPC*), and crude fibre were examined. The results showed that both the drying temperature and sodium metabisulphite concentration significantly influenced the physicochemical properties. The optimal conditions were identified at 62.505 °C and 380.059 ppm sodium metabisulphite, resulting in a whiteness index of 87.219, browning index of 5.1025, yield of 43.125%, moisture content of 2.3%, and free fatty acid content of 4.45%. These findings highlight an effective strategy for reducing the additive dependency while maintaining the physicochemical quality of low-fat desiccated coconut.

Keywords: browning; desiccated coconut; drying; response surface methodology; sodium metabisulphite

Indonesia, one of the world's leading coconut producing countries, has an annual coconut production of around 17.19 million metric tonnes (FAOSTAT 2022). For local communities, the coconut is an inseparable part of life because all parts of the coconut can be used to meet the economic,

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social, and cultural needs (Ahuja et al. 2014). From coconut milk to coconut oil, it is generally used for daily consumption and also for export market opportunities (Suprehatin and Al Naufal 2021). Among all of them, coconut milk is a high-value product that is often used in traditional Indonesian cuisine, such as rendang, which has coconut milk as its main ingredient (Rini et al. 2016). However, coconut milk extraction has by-products. This by-product still contains valuable nutrients, rich in insoluble dietary fibre ranging from 27.32% to 35.08% and can be used for further processing by drying to be processed into desiccated coconut, a dried product commonly used in bakery and confectionery industries due to its texture, flavour, and nutritional value. Studies have shown that coconut milk residue contains approximately 23.2% crude fibre, significantly higher than the fresh coconut kernel, making it a potential source for fibre-enriched food products (Ng et al. 2010; Yalegama et al. 2013).

Producing desiccated coconut involves several stages, including peeling, grating, pressing to extract the coconut milk, treating it with anti-browning agents, blanching, and drying (Effendy et al. 2023). This stage of drying is very important because it ensures the long-term product preservation by removing the moisture content. However, this process often causes natural browning due to heat exposure (Ginting et al. 2015). Browning can occur due to both enzymatic and non-enzymatic reactions, with the Maillard reaction being a primary cause of non-enzymatic browning during heating (Manzocco et al. 2000).

To avoid browning, sodium metabisulphite ($Na_2S_2O_5$) is most often used to inhibit oxidative reactions (Divine and Rankin 2013). However, the use of sodium metabisulphite is increasingly being regulated due to health concerns. Sulphite compounds have been associated with adverse allergic reactions, particularly in asthmatic individuals (Raghul 2023). Many countries have established food safety standards that limit the amount of sulphites allowed in food products. The U.S. Food and Drug Administration (FDA) requires that any food product containing sulphites must have a clear label indicating their presence (Zang and Kabadi 2023). Eliminating sodium metabisulphite could lead to the rapid discolouration and quality degradation. Therefore, alternative natural anti-browning agents, such as ascorbic acid, citric acid, and plant extracts, have been explored (Hamdan et al. 2022). Based on previous studies, the use of natural anti-browning agents may result in undesirable sensory or off-flavour changes, which may affect consumer acceptance (Loizzo et al. 2012). Citric acid is an effective anti-browning agent, but its use can impart a sour taste or aroma to the product, which may be undesirable in certain applications (Salazar-Montoya et al. 2024).

Previous studies have primarily focused on optimising the drying parameters for desiccated coconut, examining the effects of the drying time, temperature, microbiological quality, and methods on the product's quality attributes (Tanihatu et al. 2017; Paputungan and Monoarfa 2023), but research is still limited on how to minimise the sodium metabisulphite content while ensuring product stability. This study addresses this gap by optimising the drying conditions to reduce the additive usage without compromising important product attributes. Optimising the conditions for quality improvement and additive reduction was performed by Response Surface Methodology (RSM). This method is an effective tool to optimise this process that is useful for modelling and analysing problems where multiple variables influence the response. RSM not only defines the effects of the independent variables, but also generates a mathematical model, develops, improves, and optimises processes, and evaluates the influence of variables and their interactions (Pompeu et al. 2009; Montgomery 2012; Hidayat et al. 2020). Unlike full factorial design, which requires testing all the possible combinations, RSM reduces the number of experimental runs while still providing accurate optimisation (Veza et al. 2023). This research seeks to align the need for effective browning prevention with the need to minimise the application of potentially harmful chemicals, thereby ensuring consumer safety and product quality.

MATERIAL AND METHODS

Materials and sample preparation

The materials used in this study included a mature local hybrid coconut cultivar aged 11–12 months sourced from Cibadak District, Sukabumi Regency, Indonesia (coordinates: –6.8939°S, 106.7855°E), sodium metabisulphite (Merck, Germany), and distilled water. The analytical materials comprised methanol (Merck), ethanol (Merck), hex-

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ane (Merck), a phenolphthalein indicator (Merck), H_2SO_4, NaOH, HCl, and Whatman No. 4 filter paper.

The sample preparation involves sorting mature coconuts with firm flesh and a low water content, coconuts aged 11–12 months were selected due to their mature kernel characteristics, a higher fat content, and reduced water content, which are ideal for coconut milk extraction and by-product utilisation such as desiccated coconut (Tulashie et al. 2022). Followed by peeling to remove the husk, shell, and testa. The coconuts are grated and then squeezed to extract the coconut milk, leaving low-fat grated coconut as a by-product. This by-product is treated with a sodium metabisulphite solution, optimised via Response Surface Methodology (RSM). This solution is sprayed evenly onto 150 g of samples in each treatment group (Feng et al. 2022). The treated coconut is then steam-blanched for 10 min using a steamer to deactivate the enzymes, reduce the bacterial counts, and maintain the colour. Xiao et al. (2017) reported that steaming enhances the whiteness. Subsequently, the desiccated coconut is dried in a blower oven for 3 h (Putra and Setiawati 2021). The drying process is conducted under various temperature treatments, as determined by the combinations provided by the Response Surface Methodology (RSM).

Optimisation using response surface methodology (RSM)

The research used RSM with a Central Composite Design (CCD) and was optimised using Design Expert software (version 13). The study focused on the drying temperature and sodium metabisulphite concentration (Table 1). A drying temperature range of 60 °C to 80 °C was chosen based on the work of Pratiwi et al. (2020) and Hidayat et al. (2023), who identified these temperatures as producing the best moisture content, fat content, and yield in the coconut processing. The concentration of the sodium metabisulphite was selected in the range of 0 ppm to 1 200 ppm. This is based on research conducted by Nastiti et al. (2014), which showed that the range of sodium metabisulphite significantly affects the product characteristics such as the lightness and nutritional content. The responses in this research include the yield, whiteness index, browning index, moisture content, ash content, fat content, protein content, crude fibre content, total phenolic content, and free fatty acid. The stages in determining the number of treatment combinations in this study were 13 runs, which were obtained from a randomised experimental design by the Design Experts software.

Analytical methods

Yield. The yield was calculated as the ratio of the weight of desiccated coconut to the weight of the raw grated coconut. The yield was determined by weighing the materials before drying and after drying (Tanihatu et al. 2017).

$$\text{Yield}(\%) = \frac{W_2}{W_1} \times 100\% \quad (1)$$

where: W_1 – the initial weight before drying (g); W_2 – the final weight after drying (g).

Whiteness index (WI). The colour testing was conducted using a chromameter with the CIE $L^*a^*b^*$ method. The *WI* combines the brightness and the yellow-blue axis to reflect the degree of whiteness (Zambrano-Zaragoza et al. 2014).

$$WI = 100 - \sqrt{\left(100 - L^*\right)^2 + a^{*2} + b^{*2}} \quad (2)$$

Browning index (BI). The desiccated coconut browning index (*BI*) was measured using the CIE $L^*a^*b^*$ scale. Each treatment was assessed to calculate the *BI*, which serves as an indicator of brown colour changes (Zambrano-Zaragoza et al. 2014).

$$BI = \frac{\left[100(x - 0.31)\right]}{0.172} \quad (3)$$

$$x = \frac{\left(a^* + 1.75L^*\right)}{\left(5.646L^* + a^* - 3.012b^*\right)} \quad (4)$$

Moisture content (MC). The moisture content (*MC*) analysis carried out using the thermogravimetric method (AOAC 2005). The analysis began by oven-drying the crucibles at 110 °C for 15 minutes. Then, 2 g of the sample was placed in the dried crucible and oven-dried at 110 °C for 24 hours. The sample was cooled in a desiccator and weighed until a constant weight was achieved (Hidayat et al. 2023).

$$\text{Moisture content}(\%) = \frac{(a + b) - c}{b} \times 100\% \quad (5)$$

where: a – the weight of the empty crucible (g); b – the weight of the sample (g); c – the weight of the sample

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Table 1. Variables of the experimental design

Independent variables	Unit	–1	0	1
Drying temperature	°C	60	70	80
$Na_2S_2O_5$ concentration	ppm	0	600	1 200

and crucible after drying (g).

Ash content. The ash content analysis was carried out by the gravimetric method. This method started by oven-drying the crucibles at 110 °C for 30 minutes. Then, 2 g of the sample was placed in the dried crucible and incinerated in a furnace at 550 °C for 6 hours. The crucible with ash was cooled in a desiccator and weighed (AOAC 2005).

$$\text{Ash content}(\%) = \frac{W_{ac} - W_c}{W_a} \times 100\% \quad (6)$$

where: W_c – the weight of the crucible (g); W_{ac} – the weight of the crucible and ash (g); W_a – the weight of the sample before ashing (g).

Fat content. The fat content was determined according to the procedure described by Kurniawan and Rahim (2022). A pre-weighed fat flask was placed in an oven at 110 °C for 30 minutes. The sample (1 g) was wrapped in filter paper and placed in a Soxhlet extraction apparatus connected to a fat flask. Hexane was used as the solvent for 6 h of reflux. The fat extract was dried in an oven at 110 °C for 4 h, cooled in a desiccator, and weighed.

$$\text{Fat content}(\%) = \frac{W_{f2} - W_{f1}}{W_f} \times 100\% \quad (7)$$

where: W_{f2} – the weight of the fat flask before extraction (g); W_{f1} – the weight of the fat flask after extraction (g); W_f – the weight of the sample (g).

Crude fibre content. The crude fibre analysis was performed by extracting 1 g of the sample's fat using a Soxhlet apparatus with petroleum ether. The defatted sample was then boiled with 1.25% H_2SO_4 and 3.25% NaOH, filtered through a pre-weighed filter paper, washed, dried, and ashed. The weight differences were used to calculate crude fibre content (Pratiwi and Sugitha 2020).

$$\text{Crude fibre content}(\%) = \frac{W_{c2} - W_{c1}}{W_c} \times 100\% \quad (8)$$

where: W_{c2} – the weight of the filter and residue after drying (g); W_{c1} – the weight of the filter and residue after ashing (g); W_c – the weight of the sample before ashing (g).

Protein content. The protein content was measured using the Kjeldahl method, where 0.3 g of the sample was digested in a 100 mL Kjeldahl flask with 1 g of a selenium mixture and 10 mL of concentrated H_2SO_4. The digest was neutralised with distilled water, followed by distillation and titration with 0.05 N HCl until a pink endpoint was observed (Hidayat et al. 2023).

$$\text{Protein}(\%) = \frac{V\,\text{HCL} \times N\ \text{HCl} \times 1.4}{W_p \times 1000} \times 100\% \quad (9)$$

where: N – the normality of HCl; V – the volume of the HCl used (mL); W_p – the weight of the sample (g).

Total phenolic content (TPC). The *TPC* was analysed by extracting 4 g of the low-fat desiccated coconut sample with 20 mL of methanol. The extract was shaken for 3 h, filtered, and evaporated. The phenolic content was measured using the Folin-Ciocalteu reagent, with the absorbance read at 765 nm, and expressed as mg gallic acid equivalents (*GAE*) per 100 g of sample (Phonphoem et al. 2022).

$$TPC\left(\text{mg } GAE \cdot 100\, g^{-1}\right) = \frac{C \times V}{W_t} \quad (10)$$

where: C – the concentration of gallic acid equivalent obtained from the calibration curve (mg·mL); V – the volume of the extract (mL); W_t – the weight of the sample (g).

Free fatty acids (FFAs). The *FFA* levels were determined by titrating a 2 g sample in 30 mL neutralised 95% ethanol with 1 *N* NaOH and phenolphthalein indicator until a pink endpoint was achieved (Yuvita et al. 2022).

$$FFA(\%) = \frac{V\,\text{NaOH} \times N\ \text{NaOH} \times \text{fatty acid}}{W_{fa} \times 1\,000} \times 100\% \quad (11)$$

where: V – the volume of the NaOH used (mL); N – the normality of NaOH; W_{fa} – the weight of the sample (g).

Statistical analysis

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The data were analysed using an analysis of variance (ANOVA) at a 95% confidence level to determine the significance of the factors. The statistical analysis was performed using Design Expert (version 13) software. An analysis of variance (ANOVA) was used to evaluate the significance of the results. A significant *P*-value (less than the acceptable risk level) indicates a meaningful effect. A non-significant lack of fit indicates that the model adequately represents the experimental data (Njoku and Otisi 2023). Optimisation involved prioritising each factor and response variable. The best solutions from Design Expert 13 were verified by comparing the predicted responses with the actual experimental outcomes. The verification data were further analysed using a one-sample *t*-test to confirm the accuracy of the predictions. The one-sample *t*-test aims to determine whether the mean response of a sample is significantly different from the target value, which is important for validating experimental results (de Oliveira et al. 2019).

RESULTS AND DISCUSSION

A total of 13 samples were tested with different temperatures and sodium metabisulphite concentration treatments (Table 2) and analysed to obtain the models as in Table 3. The model can be used to determine the optimal temperature and sodium metabisulphite levels for the desired product quality.

In Table 3, based on the statistical analysis (ANOVA), the linear models could represent the experimental data well. All the responses were analysed with these models, except for the whiteness index, ash content, and total phenolic content, which a quadratic model better represented. A model is considered adequate when it is statistically significant (*P*-value < 0.05) and exhibits a non-significant lack of fit (*P*-value > 0.05), indicating the model's suitability for the response data. According to the results, only five responses meet these criteria: the yield, *WI*, *BI*, moisture content, and *FFA*. Therefore, these responses are utilised to optimise the temperature and metabisulphite addition in the drying condition.

Yield. A linear model was selected based on the variance analysis of the yield response. The yield response is significant, with a *P*-value of 0.0025, less than 5%. The lack of fit value is 0.8443, indicating non-significance, suggesting that the model

Table 2. Results of the experimental design treatments

Factor 1	Factor 2										
A: Temp. (°C)	B: $Na_2S_2O_5$ (ppm)	Yield (%)	*WI*	*BI*	*MC* (%)	Ash (%)	Fat (%)	Protein (%)	Crude fibre (%)	*TPC* (mg *GAE*·100 g^{-1} coconut)	*FFA* (%)
70	0	47.40	85.30 ± 0.62	6.10 ± 0.09	1.96 ± 0.00	1.85 ± 0.03	38.30 ± 0.29	8.20 ± 0.04	38.10 ± 0.10	13.12 ± 0.12	2.48 ± 0.01
70	600	40.40	87.30 ± 0.02	6.50 ± 0.08	1.44 ± 0.03	1.85 ± 0.04	44.60 ± 0.30	8.18 ± 0.10	40.10 ± 0.15	10.72 ± 0.38	4.96 ± 0.01
80	600	43.40	86.90 ± 0.13	6.30 ± 0.56	1.37 ± 0.81	1.89 ± 0.09	41.10 ± 0.80	8.09 ± 0.36	39.30 ± 0.49	11.63 ± 0.81	4.90 ± 0.69
70	600	44.80	87.60 ± 0.13	5.20 ± 0.01	1.70 ± 0.10	1.88 ± 0.06	43.60 ± 0.37	8.01 ± 0.02	40.80 ± 0.83	9.84 ± 0.22	3.97± 0.70
70	600	44.40	87.70 ± 0.03	5.40 ± 0.00	1.68 ± 0.06	1.79 ± 0.01	37.80 ± 0.40	7.82 ± 0.23	42.10 ± 0.62	12.35 ± 0.22	3.96 ± 0.01
70	1 200	42.10	88.20 ± 0.01	5.50 ± 0.00	1.20 ± 0.08	1.92 ± 0.05	45.40 ± 0.46	8.08 ± 0.00	39.50 ± 0.25	12.50 ± 0.80	5.45 ± 0.01
80	0	47.60	84.40 ± 0.07	6.90 ± 0.01	1.85 ± 0.13	1.92 ± 0.06	45.70 ± 0.68	7.75 ± 0.02	41.10 ± 0.70	9.94 ± 0.34	3.46 ± 0.01
60	600	44.20	86.90 ± 0.11	5.80 ± 0.01	2.02 ± 0.02	1.77 ± 0.04	48.30 ± 0.17	8.06 ± 0.11	37.10 ± 0.13	6.44 ± 2.63	3.96 ± 0.01
60	0	47.80	84.80 ± 0.04	6.99 ± 0.19	2.12 ± 0.00	1.93 ± 0.01	49.10 ± 0.11	8.07 ± 0.02	38.60 ± 6.95	10.04 ± 0.22	3.71 ± 0.35
70	600	44.20	87.40 ± 0.03	5.80 ± 0.06	1.89 ± 0.00	1.96 ± 0.23	45.20 ± 0.36	8.66 ± 0.08	40.50 ± 0.51	10.80 ± 0.16	3.96 ± 0.01
60	1 200	43.20	88.10 ± 0.04	5.57 ± 0.00	2.01 ± 0.00	1.73 ± 0.64	46.80 ± 0.30	8.06 ± 0.41	36.10 ± 0.60	7.86 ± 0.21	4.78 ± 0.35
80	1 200	40.60	88.20 ± 0.02	5.52 ± 0.00	1.27 ± 0.03	1.63 ± 0.32	39.10 ± 0.13	7.63 ± 0.08	41.20 ± 0.42	7.82 ± 1.44	5.44 ± 0.00
70	600	42.50	87.10 ± 0.03	6.60 ± 0.56	1.89 ± 0.02	1.30 ± 0.13	42.30 ± 0.45	8.18 ± 0.14	38.30 ± 0.16	10.55 ± 0.27	4.47 ± 0.01

BI – browning index; *FFA* – free fatty acid; *MC* – moisture content; Temp. – temperature; *TPC* – total phenolic content; *WI* – whiteness index

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Table 3. Model analysis

Response	Model	Model equation	*P*-value	
			significance	lack of fit
Yield	linear	$Y = 44.05 - 0.6(A) - 0.282(B)$	0.0025	0.8443
WI	quadratic	$Y = 87.4 - 0.05(A) + 1.67(B) + 0.125(AB) - 0.45(A^2) - 0.6(B^2)$	0.0011	0.6384
BI	linear	$Y = 6.01 + 0.06(A) - 0.5667(B)$	0.0463	0.9142
Moisture content	linear	$Y = 1.72 - 0.2767(A) - 0.2417(B)$	0.0021	0.5519
Ash content	quadratic	$Y = 1.78 + 0.0017(A) - 0.071(B) - 0.0225(AB) - 0.0016(A^2) + 0.0534(B^2)$	0.9661	0.8303
Fat content	linear	$Y = 43.64 - 3.05(A) - 0.3(B)$	0.1212	0.3919
Protein content	linear	$Y = 8.06 - 0.12(A) - 0.0417(B)$	0.5015	0.8136
Crude fibre content	linear	$Y = 39.45 + 1.63(A) - 0.1667(B)$	0.0553	0.4658
TPC	quadratic	$Y = 11.14 + 0.8417(A) - 0.82(B) + 0.015(AB) - 0.282(A^2) + 0.9548(B^2)$	0.1141	0.0784
FFA	linear	$Y = 4.27 + 0.225(A) + 1.0(B)$	0.0010	0.4768

A – drying temperature; *B* – sodium metabisulphite concentration; *BI* – browning index; *FFA* – free fatty acid; *TPC* – total phenolic content; *WI* – whiteness index

fits well with the design and can be optimised. The yield values ranged from 40.40% to 47.80% across all the experimental treatments. Similar results were also reported by Tanihatu et al. (2017) in the production of desiccated coconut at three drying time conditions.

Figure 1A illustrates that the yield decreases with the increased sodium metabisulphite concentration and, to a lesser extent, with higher drying temperatures. The yield, defined as the weight loss during drying, is influenced by the moisture content (Mujumdar 2014). Higher sodium metabisulphite concentrations reduce the moisture content due to tissue damage caused by the sulphite process, which creates perforations that speed up drying. This rapid moisture loss directly lowers the product yield, highlighting a proportional relationship between the moisture content and yield (Prabasini et al. 2013). This is in line with the findings of (Chandra et al. 2016), who observed that increasing the sodium metabisulphite concentration (up to 3 000 ppm) can cause greater drying shrinkage due to the increased moisture removal, although differences in the amount of ingredients and drying conditions can also contribute to the variability.

Whiteness index (*WI*). A quadratic model is suitable for analysing the whiteness index in low-fat desiccated coconut, showing significance with

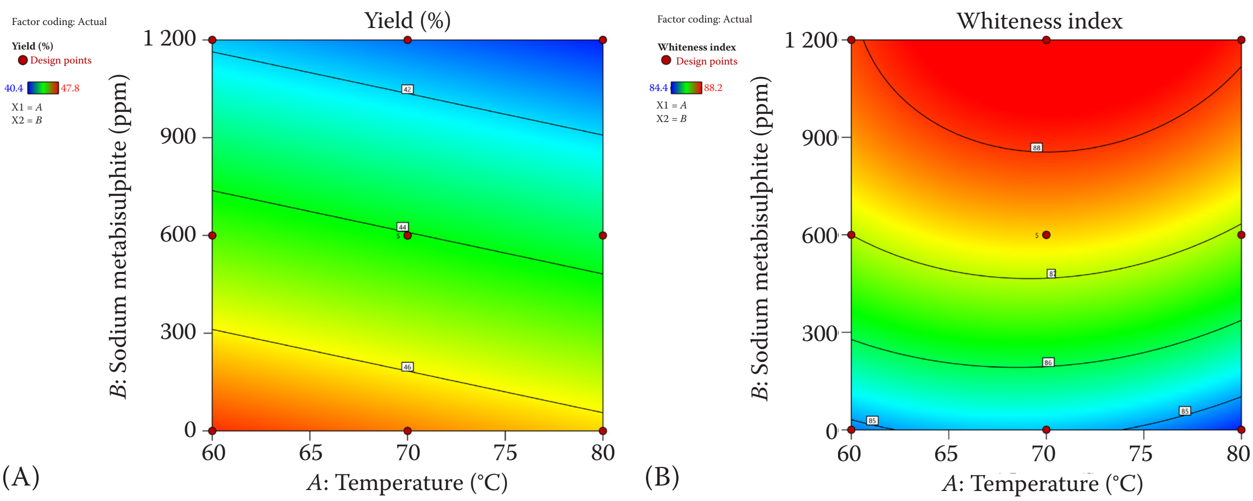

Figure 1. Plot contour of the yield (A), and whiteness index (B) responses

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a *P*-value of 0.0011 and a non-significant lack-of-fit value of 0.6384, confirming a good fit with the experimental design. Both the drying temperature and sodium metabisulphite concentration significantly impact the whiteness index, making the model effective for optimisation. Figure 1B indicates that increasing the sodium metabisulphite concentration enhances the whiteness index, as the colour gradient shifts from blue to red. The whiteness index values ranged from 84.40 to 88.20 (Table 2) across all the experimental treatments.

The concentration of sodium metabisulphite positively affects the whiteness index. Sodium metabisulphite acts as a reducing agent that neutralises the reactive oxygen species and inhibits the polyphenol oxidase activity, thereby preventing enzymatic and non-enzymatic browning, particularly in food with a high polyphenol content (Rahayu and Hudi 2021). The maximum whiteness index was obtained at a sodium metabisulphite concentration of 1 200 ppm (88.20), while 600 ppm also provided a comparable range of 86.90 to 87.70. This result suggests a lower concentration can still achieve nearly the same whitening effect as the highest level tested.

Meanwhile, the drying temperature had a less pronounced impact. The highest whiteness index occurred around a drying temperature of 70 °C, with lower values at 60 °C and 80 °C. Higher temperatures were negatively correlated with the lightness (*L**), reducing the whiteness index due to increased Maillard reaction products. This temperature-dependent reaction between the amino acids and reducing sugars promotes darker pigments, changing the colour attributes (Huang et al. 2012; Heim and Krebs 2018). The results suggest that lower concentrations of sodium metabisulphite can still achieve desirable whiteness levels, supporting the potential for reduced additive use in industrial coconut processing. Excessive use of sodium metabisulphite can cause undesirable sulphur odour and potential regulatory issues, thus limiting its application in food products (Zang and Kabadi 2023).

Browning index (*BI*). The linear model selected for evaluating the browning index response in low-fat desiccated coconut is statistically significant with a *P*-value of 0.0463, indicating reliability at a 95% confidence level. Additionally, the lack of fit value of 0.9142 is non-significant, making the model suitable for use. The whiteness index values ranged from 5.20 to 6.99 (Table 2) across all the experimental treatments.

The results show that increasing the sodium metabisulphite concentration effectively reduces the browning index due to its anti-browning properties. Sulphites act as strong nucleophiles and prevent non-enzymatic browning by reducing and scavenging the free radicals (Divine and Rankin 2013). Unlike the sulphite concentration, the drying temperature had a minimal effect on the browning index, likely due to the strong inhibitory action of sulphite. Abdelhaq and Labuza (1987) showed that browning during apricot drying can be effectively inhibited by SO_2 treatment at 800 ppm; thus, the effect of the drying temperature is negligible. Meanwhile, this study found that even a lower sodium metabisulphite concentration of 600 ppm was sufficient to consistently maintain a low browning index, regardless of the temperature. This implies the more efficient use of sulphite while achieving

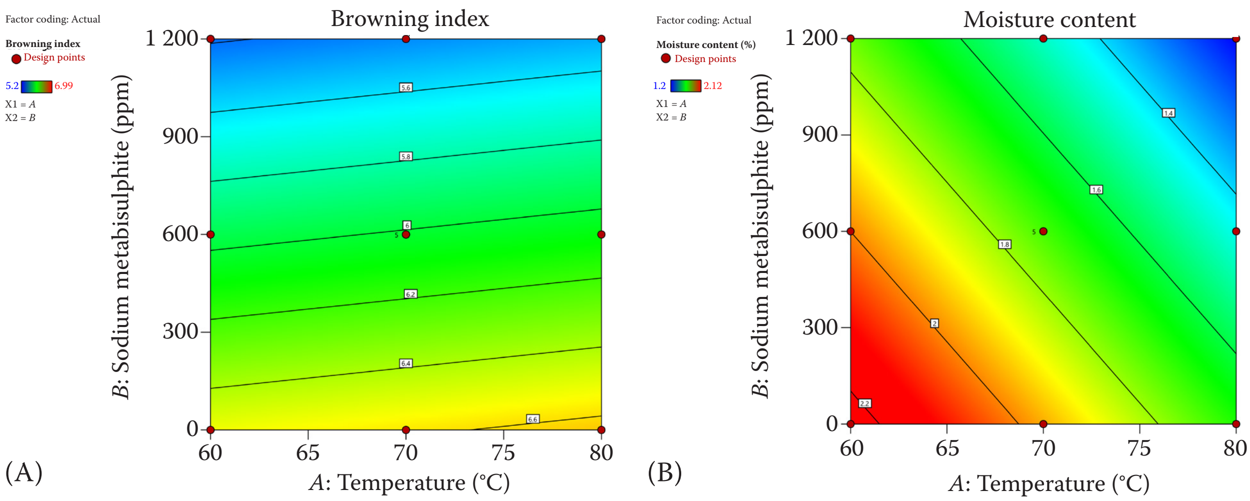

Figure 2. Plot contour of the browning index (A), and moisture content (B) responses

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similar browning control. Figure 2A supports this conclusion, showing that concentrations starting from 600 ppm resulted in low browning index values at all temperatures. Rahayu and Hudi (2021) similarly found that sodium metabisulphite improved the lightness and reduced the yellowness in banana flour, aligning with this study's findings on desiccated coconut. Overall, these findings highlight the potential to optimise the use of sulphites at lower concentrations to achieve effective browning control in dried products.

Moisture content. The recommended linear model shows significant results with a *P*-value of 0.0021 (Table 2), indicating a minimal chance of error at a 95% confidence level. The lack of fit value for the moisture content response is 0.5519 (Table 3), confirming the significant impact of the treatments used. This model can optimise the production process of desiccated coconut.

The contour plot in Figure 2B indicates that the moisture content decreases as the drying temperature increases. Blue to green areas signify the lowest moisture content, while red areas indicate the highest. According to the model equation, increasing the sodium metabisulphite concentration and drying temperature reduce the moisture content. The low moisture content increases the desiccated coconut product's shelf life and durability. Based on the Codex standard, the moisture content must be below 4% (Codex 1991). High temperatures and the addition of sodium metabisulphite can be used for the drying process to achieve these specifications. Higher temperatures lead to quicker moisture loss, and drying rates vary at different temperature levels. This phenomenon is due to the increased energy in water molecules at higher temperatures, enabling faster evaporation. Additionally, the sodium metabisulphite treatment significantly affects the moisture reduction. The sulphiting process applied during the soaking of grated coconut can damage cell structures, causing micro-perforations that facilitate internal moisture migration. Sodium metabisulphite also reacts with water to form sodium disulphide compounds, aiding in moisture binding and removal (Br Sembiring et al. 2020).

These findings are consistent with the results of Kayran and Doymaz (2021), who studied the drying kinetics of apricots. In their research, sulphites pre-treated apricot samples exhibited significantly shorter drying times compared to untreated controls across all temperature levels (50–80 °C). The pre-treatment reduced the resistance to the moisture movement, thereby accelerating the drying rate. Notably, the treated samples dried between 11.43% and 19.56% faster, indicating the effective role of sulphite in improving the drying efficiency.

Free fatty acids (*FFAs*). The recommended model for analysing the *FFA* response is a linear model. This model yields significant results, with a *P*-value of 0.0010, indicating a very low probability of model error at a 95% confidence level. The lack of fit value for the free fatty acid response is 0.4768, showing that the lack of fit is insignificant. Therefore, this model aligns well with the experimental design and is applicable for optimising the production process of desiccated coconut. The Figure 3 contour plot shows that higher temperature and sodium metabisulphite concentration increase the product's free fatty acid levels. This is crucial for optimising desiccated coconut production. The lowest free fatty acid values are in the blue area, while the highest are in the red area.

The drying temperature plays a critical role in determining the *FFA* levels in food products, as higher temperatures promote lipid degradation, leading to increased *FFA* formation (Gawrysiak-Witulska et al. 2015; Tape et al. 2023). Elevated *FFA* levels compromise the product quality, reduce the stability, and shorten the shelf life. Additionally, they lower the oxidative stability of oils, making them more prone to spoilage. A high *FFA* content also poses health concerns, as it can result in the formation of toxic and potentially carcinogenic compounds. Sodium metabisulphite further influences the *FFA* levels by enhancing lipid peroxidation (Ercan et al. 2010) and interacting with unsaturated fatty acids,

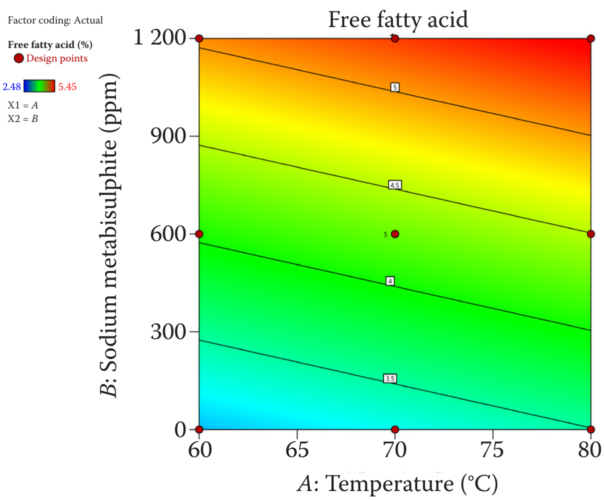

Figure 3. Plot contour of the free fatty acid responses

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increasing their polarity (Bai et al. 2016). This process generates free radicals, accelerating the lipid degradation and disrupting the fatty acid metabolism. These combined effects underscore the importance of optimising the drying temperature and sodium metabisulphite concentration to mitigate the *FFA* formation and ensure food safety and quality.

High levels of *FFA*s in food products can significantly impact their quality, flavour, and safety. Excessive *FFA*s can lead to undesirable sensory attributes, such as off-flavours and rancidity, which are detrimental to consumer acceptance. Specifically, high *FFA*s can produce unpleasant flavours, particularly short-chain fatty acids, which can impart soapy or rancid tastes (Leonard et al. 2023).

Optimisation. The optimisation process uses mathematical models for key responses: the whiteness index (*WI*), browning index (*BI*), yield, moisture content, and free fatty acids (*FFAs*). Table 4 outlines the optimisation design for desiccated coconut. The drying temperature was set as "is-in-range" to identify the best treatment for minimising browning. The sodium metabisulphite concentration was minimised to determine the optimal amount under minimal conditions. The browning index was set to minimise with a priority level of 5, while the whiteness index was maximised at the same importance level. The yield was also maximised to achieve the best result, and the *FFA* was minimised to ensure it meets applicable standards.

The results of the optimum condition solution recommendations based on Design Experts can be seen in Table 5. The determination of optimum conditions is based on the highest desirability value. Each response was evaluated using an individual desirability function, which assigns values from 0 (undesirable) to 1 (most desirable), and these were integrated into a total desirability function to identify the best overall system solution (Baş and Boyacı 2007). The optimal point selected is a temperature of 62.505 °C with the addition of 380.059 ppm so-

Table 4. Optimisation criteria

Name	Goal	Lower limit	Upper limit	Importance
A: Drying temperature (°C)	is in range	60	80	4
B: $Na_2S_2O_5$ concentration (ppm)	minimise	0	1 200	5
WI	maximise	84.4	88.2	5
BI	minimise	5.2	6.99	5
Yield (%)	maximise	40.4	47.8	4
Moisture content (%)	is in range	1.2	2.12	4
FFA (%)	is in range	2.48	5.45	4

A – drying temperature; *B* – sodium metabisulphite concentration; *BI* – browning index; *FFA* – free fatty acid; *WI* – whiteness index

Table 5. Optimal solution

Temperature (°C)	Na_2S_2O (ppm)	*WI*	*BI*	Yield (%)	Moisture content (%)	*FFA* (%)	Desirability
62.505	380.059	86.530	6.176	45.525	1.846	3.734	0.583

BI – browning index; *FFA* – free fatty acid; *WI* – whiteness index

Table 6. Verification result

Response	Actual	Prediction	95% Prediction interval (*PI*)		*P*-value
			PI low	*PI* high	
WI	87.219	86.530	86.695	87.672	0.014
BI	5.103	6.176	5.094	6.843	0.365
Yield (%)	43.125	45.525	41.825	47.169	0.661
Moisture contente (%)	2.300	1.846	1.582	2.280	0.151
FFA (%)	4.445	3.734	3.255	4.945	0.387

BI – browning index; *FFA* – free fatty acid; *WI* – whiteness index

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dium metabisulphite. The desirability value based on this solution is 0.583. The desirability value is influenced by the complexity of the components, the range used, the number of components, and the response. A higher level of importance makes it more difficult for the optimum formula to have high desirability (Baş and Boyacı 2007; Engelen 2015).

Model verification. The verification process, utilising a one-sample *t*-test, revealed insignificant discrepancies between the predicted and actual values across various parameters (Table 6). The one-sample *t*-test is commonly used to compare predicted and observed means in process optimisation studies, providing statistical evidence regarding the accuracy of the model (Montgomery 2012). Most responses align well with the predictions and fall within acceptable ranges. The significant *P*-value for the whiteness index suggests a potential area for model refinement. The moisture content also requires attention despite the non-significant *P*-value, as the actual value exceeds the specified range.

The predicted mean for the whiteness index was 87.183, and the observed value was 87.219. The *P*-value was 0.014, indicating a significant *P*-value (typically $P < 0.05$), which indicates a meaningful deviation between the predicted and actual responses, often suggesting a model misfit or the presence of uncontrolled variables (Myers et al. 2016). This result confirms the effectiveness of the optimisation in maximising the whiteness index, meeting the goal of maintaining a high level of whiteness. The predicted mean for the browning index was 5.969, and the observed value was 5.103. There is no significant difference with a *P*-value of 0.365, indicating that the browning index was minimised effectively beyond the predicted value. This result aligns well with reduced browning while also minimising the use of sodium metabisulphite.

The predicted mean for the yield was 44.497, and the observed value was 43.125. The *P*-value was 0.661, showing no significant difference. Although the actual yield is slightly lower than the prediction, it remains within an acceptable range (95% *PI* low of 41.825 and high of 47.169), suggesting that the optimisation was generally successful in maximising the yield. The predicted mean for the moisture content was 1.931, and the observed value was 2.300. The *P*-value was 0.151, indicating no significant difference. However, the actual moisture content exceeded the predicted range (95% *PI* low of 1.582 and high of 2.280). This discrepancy might be due to the variability in the drying conditions or to measurement inaccuracies (Brennan and Grandison 2011). The moisture retention can be influenced by several factors, such as the ambient humidity, uniformity of drying, and equipment precision, which might not have been fully controlled during the experiment. The predicted mean for free fatty acids was 4.100, and the observed value was 4.445. There is no significant difference with a *P*-value of 0.387, suggesting that the goal for the free fatty acid content was effectively met, with the actual value falling within the acceptable range (95% *PI* low of 3.255 and high of 4.945).

The results of this optimisation support the dependence of the model determined in estimating the characteristics of the quality of desiccated coconut, especially under conditions optimised by the reduced level of additives. The high whiteness index and reduced browning index achieved under these conditions suggest that the role of sodium metabisulphite as a preservative can be partially replaced by process optimisation. This aligns with the study's goal of balancing the quality and safety in desiccated coconut production. In the context of large-scale food manufacturing, where chemical additives are often overused for the appearance and shelf-life preservation, this approach offers a feasible alternative for reducing the additive dependency (Garcia-Fuentes et al. 2015). The findings demonstrate the potential for cleaner-label coconut products without significantly compromising quality, which responds to increasing consumer concerns and regulatory pressures regarding sulphite use (Guzik et al. 2022).

CONCLUSION

This study provides new contributions to understanding the effects of the drying temperature and sodium metabisulphite concentration on the quality parameters of low-fat desiccated coconut. The results showed that sulphite concentration could be significantly reduced to 380.059 ppm without affecting the whiteness level, browning index, yield, and moisture content. These findings enhance the knowledge of the mechanism of action of sodium metabisulphite in controlling enzymatic and non-enzymatic browning processes, indicating that lower concentrations are successful under appropriate dehydration conditions. This study underlines the

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need to balance between the drying condition and chemical treatments to maintain product stability. These findings offer potential applications in reducing sulphite usage in the food industry while maintaining product quality and addressing consumer health concerns. Future studies should explore the possibility of examining alternative drying methods and/or natural anti-browning agents.

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