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Critical Factor Screening in Vacuum Foam Drying of Black Pepper Oleoresin Using Fractional Factorial Design

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ABSTRACT

This research investigated the critical factors in vacuum foam drying of black pepper oleoresin using a fractional factorial design. In total, five process variables were investigated: oleoresin-to-xanthan gum ratio, Tween 80 concentration, drying and mixing temperatures, drying time, and their overall impact on powder moisture, piperine, and particle size. Results from the analysis of moisture content and particle size showed that Tween 80 concentration had a significant influence, positively correlating with moisture retention, reduced particle size, and piperine retention. Yield was mainly determined by the oleoresin-to-xanthan gum ratio and bioactive loading, suggesting a trade-off between piperine concentration and mass recovery. The combination of mixing temperature and drying time had a strong effect on maintaining the piperine stability. The optimal Tween 80 concentration for desirable properties was 2.0%. In this way, an optimal temperature-time interaction could be achieved using response surface methodology and was proposed for future research. This research demonstrated the bioactive retention and stability of the powder during storage, as well as the preparation of high-quality nutraceutical powders.

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INTRODUCTION

Economically, none of the spices comes close to black pepper, especially its oleoresin, which contains piperine, monoterpenes, and sesquiterpenes (Meghwal & Goswami, 2013; Olalere et al., 2019). It has unrivaled marketing potential and potent pharmacological antioxidant, anti-inflammatory, and antimicrobial activity (Teixeira et al., 2013). The antioxidant properties of black pepper oleoresin are partly attributed to its flavonoid content. Takooree et al. (2019) and Srinivasan (2007) note that black pepper (Piper nigrum L.) oleoresin contains a multitude of flavonoids, which are important contributors to the oleoresin's therapeutic and antioxidant properties. These flavonoids possess a C6-C3-C6 polyphenolic structure that enables them to perform significant antioxidant functions through hydrogen atom donation and metal chelation mechanisms. The compounds are present in both glycosidic and free aglycone forms, with the bound forms demonstrating higher correlation with total antioxidant activity (Redha, 2010). Compared with whole black pepper powder, black pepper oleoresin provides enhanced bioavailability of flavonoid compounds, contributing to cardiovascular protection through inhibition of low-density lipoprotein oxidation (Ahmad et al., 2012). Furthermore, flavonoids in black pepper oleoresin, including quercetin and kaempferol derivatives, exhibit notable antiproliferative activity against various cancer cell lines by modulating oxidative stress pathways and cellular signaling mechanisms (Srinivasan, 2020). These bioactive properties underscore the pharmaceutical and nutraceutical potential of black pepper oleoresin as a natural source of health-promoting compounds.

However, oleoresin is viscous and semi-liquid, making it problematic to incorporate into food due to its handling and storage challenges. The issues with oleoresin can be resolved by converting oleoresin to a powder that is both versatile and has a longer shelf-life (Shaikh et al., 2006). The technique of vacuum foam drying has recently become available and is particularly well-suited to this kind of work because it can dry at temperatures below 70 °C without damaging heat-sensitive bioactive materials (Hardy & Jideani, 2017). This technology uses mechanical foam-generating agitation in a vacuum to obtain a stable foam, which, because of its increased surface area, allows moisture to evaporate. As noted, moisture content reduction can be done without compromising bioactive components. For example, Sramek et al. (2015) studied vacuum foam drying of tomato paste and reported that the method provided carotenoid retention comparable to that of freeze-dried products. Various features for drying success, such as formulation and process, are essential and should be carefully considered, including Tween 80 surfactants, which decrease interfacial tension and stabilize foam structure.

Meanwhile, carriers such as xanthan gum hydrocolloids modify viscosity and contribute to matrix formation. (Kubbutat et al., 2021; Kothekar et al., 2007) There have been considerable investigations on the encapsulation of black-pepper oleoresin via spray drying and freeze drying (Don et al., 2024; Shaikh et al., 2006), but the thorough examination of vacuum foam drying for such applications remains largely unaddressed. Other works have used spray drying at high processing temperatures (150-180°C), which may hinder volatile compound retention. Moreover, to the best of the author's knowledge, there is no study in the literature on the impact of vacuum foam drying on the quality of black pepper oleoresin powder.

To determine relevant factors, Mason et al. (2003) and Nahum-Shani et al. (2018) suggest using a fractional factorial design, which is an optimal, less resource-intensive, and more efficient approach than a complete factorial design. Hence, this research intends to inform the screening of relevant factors affecting the quality of black pepper oleoresin powder produced by vacuum foam drying. The five factors tested in this study were: (1) the oleoresin to xanthan gum ratio, (2) concentration of Tween 80, (3) drying temperature, (4) temperature of mixing, and (5) time of drying. Some of the quality attributes tested were powder yield, moisture content, total piperine, and particle size.

METHODOLOGY

Materials

Local provider supplied black pepper (Piper nigrum L.) from West Kalimantan, Indonesia. For oleoresin extraction, 96% technical-grade ethanol was used, while analytical-grade absolute ethanol was used to prepare the chromatography sample. Tween 80 (food grade) and xanthan gum (food grade) were used as formulation agents. For the quantitative analysis, a piperine standard (Sigma-Aldrich) was used.

Statistical Analysis

The main effect of process variables on oleoresin powder attributes was assessed using a fractional factorial design (Minimum Run Resolution IV). The variables were the oleoresin-to-xanthan gum ratio (1:50-1:10), Tween 80 concentration (0.5-2.0% w/v), drying temperature (50-70 °C), mixing temperature (25-50 °C), and drying duration (3-6 h). Using Design-Expert 13.0, 12 experiment runs were analyzed using ANOVA with $\alpha = 0.05$.

Oleoresin Extraction

A multi-stage reflux extraction method was used to isolate the black pepper oleoresin. First, 10 g of ground black pepper (60-mesh) was added to a flask fitted with a reflux condenser, along with 50 mL of 96% ethanol. This extraction was done at 60 °C and a solid-to-solvent ratio of 1:5 (w/v) for 60 minutes. This extraction was repeated 3 times for a total solvent ratio of 1:15. The extracted solution was filtered, and the combined extracts were concentrated with a rotary vacuum evaporator at 50 °C until dry.

Foam Preparation and Vacuum Drying

The methodology for preparing each specific type of foam correlated to the data in Table 1 of the Experimental Design Matrix. Oleoresin was dispersed in 150 mL of distilled water and subjected to 10,000 rpm homogenization before the addition of Tween 80 and xanthan gum, each added separately at defined entrance temperatures, mixing temperatures, and mixing times. The foam was spread on stainless steel drying trays and then dried in a vacuum oven at a pressure of -0.095 MPa. The dried foam product was ground and then passed through a 40-mesh sieve. A finer, uniform-sized powder was obtained.

Powder Characterization

Yield

Calculated as the percentage of final powder weight relative to the initial total solids, as described by Hasrini et al. (2017).

Moisture Content

Determined via the oven drying method at 70°C until a constant weight was achieved (Goula & Adamopoulos, 2010).

Total Piperine Content

Quantified using Gas Chromatography-Mass Spectrometry (GC-MS) following the method of Kapoor et al. (2009). Samples were dissolved in absolute ethanol and sonicated before analysis, with separation performed on a capillary column using a programmed temperature gradient from 60°C to 300°C.

Particle Size

The median particle diameter (D50) was measured using a laser diffraction particle size analyser in dry measurement mode, according to Koyama and Kitamura (2014).

Table 1. Experimental Factors of Resolution IV Minimum Run Fractional Factorial Design

Sample	O: XG	Tween 80 (%)	Drying Temp. (°C)	Mixing Temp. (°C)	Drying Time (h)
1	(-1) 1:50	(1) 2.0	(-1) 50	(-1) 25	(1) 6
2	(1) 1:10	(1) 2.0	(-1) 50	(1) 50	(1) 6
3	(1) 1:10	(1) 2.0	(-1) 50	(-1) 25	(-1) 3
4	(1) 1:10	(-1) 0.5	(1) 70	(1) 50	(-1) 3
5	(1) 1:10	(-1) 0.5	(-1) 50	(-1) 25	(1) 6
6	(-1) 1:50	(-1) 0.5	(1) 70	(1) 50	(1) 6
7	(-1) 1:50	(1) 2.0	(-1) 50	(1) 50	(-1) 3
8	(-1) 1:50	(1) 2.0	(1) 70	(1) 50	(1) 6
9	(-1) 1:50	(-1) 0.5	(1) 70	(-1) 25	(-1) 3
10	(-1) 1:50	(-1) 0.5	(-1) 50	(1) 50	(1) 6
11	(1) 1:10	(1) 2.0	(1) 70	(-1) 25	(-1) 3
12	(1) 1:10	(-1) 0.5	(1) 70	(-1) 25	(1) 6

Note: (-1) = low level; (1) = high level; O: XG = Oleoresin: Xanthan Gum Ratio; Drying Temp. = Drying Temperature; Mixing Temp. = Mixing Temperature

RESULTS AND DISCUSSION

Overview of Experimental Results

The yield, moisture content, total piperine content, and particle diameter of black pepper oleoresin powder obtained from vacuum foam drying across 12 experimental runs are presented in Table 2. The powder yield ranged from 80.13% to 97.69%; the moisture content varied from 7.22% to 11.76% (wet basis); the total piperine content ranged from 0.49% to 14.79%; and the particle diameter ranged from 795 µm to 943 µm. These considerable variations reflect the influence of different factor combinations employed in the fractional factorial design, indicating that the selected factors and their levels were appropriate for detecting effects on powder quality attributes.

Table 2. Yield, Moisture Content, Total Piperine Content, and Particle Diameter of Black Pepper Oleoresin Powder

Sample	Ratio O: XG	Tween 80 (%)	Drying Temp. (°C)	Mixing Temp. (°C)	Drying Time (h)	Yield (%)	Moisture Content (%)	Piperine Content (%)	Particle Dia. (µm)
1	1:50	2.0	50	25	6	89.74	7.56	2.16	839
2	1:10	2.0	50	50	6	84.97	7.46	14.40	804
3	1:10	2.0	50	25	6	84.59	7.22	6.25	798
4	1:10	0.5	70	50	3	86.48	9.41	7.86	805
5	1:10	0.5	50	25	3	89.02	11.49	4.76	943
6	1:50	0.5	70	50	3	90.43	10.66	0.72	869
7	1:50	2.0	50	50	3	86.35	9.14	1.57	798
8	1:50	2.0	70	50	6	89.32	8.95	14.79	901
9	1:50	0.5	70	25	3	94.03	11.76	2.03	884
10	1:50	0.5	50	50	6	97.69	11.04	0.49	879
11	1:10	2.0	70	25	3	84.95	8.14	10.66	795
12	1:10	0.5	70	25	6	80.13	9.81	1.83	867

Note: Ratio O: XG = Oleoresin: Xanthan Gum Ratio; Drying Temp. = Drying Temperature; Mixing Temp. = Mixing Temperature; Particle Dia. = Particle Diameter

Oleoresin powder, which was formulated with an oleoresin-to-xanthan gum ratio of 1:50, 0.5% Tween 80, 50°C drying temperature, 50°C mixing temperature, and 6 hours drying duration (Sample 10), exhibited the highest yield (97.69%). However, this sample also showed the lowest piperine content (0.49%), suggesting that conditions favoring high yield may not necessarily preserve bioactive compounds. This inverse relationship indicates a trade-off between mass recovery and bioactive retention that must be considered in process optimisation. Conversely, Sample 8 (formulated with an oleoresin to xanthan gum ratio of 1:50, 2.0% Tween 80, 70°C drying temperature, 50°C mixing temperature, and 6 hours drying duration) demonstrated the highest piperine retention (14.79%) while maintaining an acceptable yield of 89.32%, representing a more balanced outcome for producing functional oleoresin powder.

The moisture content values obtained (7.22-11.76%) are within acceptable ranges for dried food powders, though some samples exceeded the recommended maximum of 10% for optimal storage stability. Samples prepared with a higher Tween 80 concentration (2.0%) consistently exhibited lower moisture content, with Sample 3 achieving the lowest value (7.22%). The particle diameter showed relatively narrow variation (795-943 µm), indicating that the vacuum foam drying process produced reasonably uniform particle sizes across different treatment combinations. The data in Table 2 provide a comprehensive overview of how the five experimental factors and their combinations influenced the four quality parameters of black pepper oleoresin powder.

Factor Screening Analysis

To systematically identify the critical factors affecting each quality parameter, Normal probability plots, Pareto charts, and Analysis of Variance (ANOVA) were employed as diagnostic tools. The Normal probability plot displays the standardised effects against their expected normal values; deviations from the straight line indicate potential significance. The Pareto chart ranks the absolute values of standardised effects in descending order, with effects exceeding the Bonferroni limit considered statistically significant. The ANOVA provides quantitative confirmation via F-tests and p-values at the $\alpha = 0.05$ significance level. Table 3 presents a comprehensive recapitulation of the screening results for all four response variables.

Table 3. Recapitulation of Normal Plot, Pareto Chart, and ANOVA Results for Factor Screening

Response Variable	Normal Plot Indication	Pareto Chart Result	Significant Factor (ANOVA)	p-value	F-value	Effect Direction
Yield (%)	A, B, and C deviated from the normal line	Only A exceeded the Bonferroni limit	A (Ratio O: XG)	0.0090*	11.72	1:50 → Higher
Moisture Content (%)	A and B deviated from the normal line	Only B exceeded the Bonferroni limit	B (Tween 80)	0.0025*	24.85	2.0% → Lower
Total Piperine Content (%)	A, B, C, D, DE deviated from the normal line	B, A, DE exceeded the Bonferroni limit	A (Ratio O: XG)	0.0164*	12.60	1:10 → Higher
			B (Tween 80)	0.0097*	16.55	2.0% → Higher
			DE (Interaction)	0.0242*	10.19	Complex
Particle Diameter (μm)	B deviated from the normal line	Only B exceeded the Bonferroni limit	B (Tween 80)	0.0400*	5.75	2.0% → Smaller

*Note: * indicates significant at a = 0.05; A = Oleoresin: Xanthan Gum Ratio; B = Tween 80 Concentration; C = Drying Temperature; D = Mixing Temperature; E = Drying Duration; DE = Interaction between D and E*

Powder Yield

The powder yield represents the mass recovery efficiency of the vacuum foam drying process. As shown in Table 3, the Normal probability plot indicated that factors A (oleoresin: xanthan gum ratio), B (Tween 80 concentration), and C (drying temperature) deviated from a normal line, suggesting potential significance. However, the Pareto chart confirmed that only factor A exceeded the Bonferroni limit. The ANOVA results showed that the oleoresin-to-xanthan gum ratio was the only factor that significantly influenced powder yield (p =

0.0090, F = 11.72), while the other factors had no significant effects within the tested ranges.

The significant effect of the xanthan gum ratio on yield can be attributed to several mechanisms. Xanthan gum serves as a carrier material, forming the structural matrix of the dried powder. A higher oleoresin-to-xanthan gum ratio (1:50) provides more matrix material to encapsulate and retain the oleoresin components during drying, thereby increasing the overall yield. Additionally, xanthan gum contributes to foam stability through its viscoelastic properties, thereby preventing foam collapse and material loss during vacuum drying (Kubbutat et al., 2021). The hydrocolloid network formed by xanthan gum also facilitates uniform moisture removal, reducing localized overheating and associated material degradation. These findings are consistent with those of Sramek et al. (2015), who reported that carrier material concentration significantly influenced powder recovery in vacuum-foam-dried tomato paste.

Moisture Content Moisture content is a critical quality parameter that affects the storage stability, flowability, and reconstitution properties of dried powder products. The screening analysis revealed that the Normal probability plot showed that factors A and B deviated from the normal line. However, the Pareto chart clearly demonstrated that only factor B (Tween 80 concentration) exceeded the significance threshold. The ANOVA confirmed that Tween 80 concentration was the sole significant factor affecting moisture content (p = 0.0025, F = 24.85), representing the highest F-value among all significant effects identified in this study.

The mechanism underlying this observation relates to the surface-active properties of Tween 80. As a non-ionic surfactant, Tween 80 reduces the interfacial tension between water and air phases in the foam structure (Kothekar et al., 2007). This reduction in surface tension promotes the formation of smaller, more uniform foam bubbles with greater surface area, thereby enhancing moisture-evaporation efficiency during vacuum drying. Furthermore, Tween 80 facilitates the formation of thinner lamella films around air bubbles, thereby reducing the diffusion path length for water molecules and accelerating drying kinetics. Higher Tween 80 concentrations (2.0%) resulted in lower moisture content than lower concentrations (0.5%), consistent with the findings of Hardy and Jideani (2017) and Qadri et al. (2020).

Total Piperine Content Total piperine content is the most important quality parameter for black pepper oleoresin powder, as piperine is the principal bioactive alkaloid responsible for the characteristic pungency and pharmacological properties. The screening analysis for piperine content revealed the most complex pattern among all response variables. The Normal probability plot showed that multiple factors (A, B, C, D, and interaction DE) deviated from the normal line, and the Pareto chart confirmed that factors A, B, and interaction DE exceeded the significance threshold. The ANOVA identified three significant effects: oleoresin to xanthan gum ratio (p = 0.0164, F = 12.60), Tween 80 concentration (p = 0.0097, F = 16.55), and the interaction between mixing temperature and drying duration (p = 0.0242, F = 10.19).

The carrier matrix's encapsulation efficiency can explain the significant effect of the oleoresin-to-xanthan gum ratio on piperine retention. A higher proportion of oleoresin (ratio 1:10) results in greater piperine loading per unit mass of powder. The dominant influence of Tween 80 concentration on piperine retention is particularly noteworthy. Higher Tween 80 concentrations (2.0%) consistently resulted in better piperine preservation, attributed to its emulsifying and protective properties, which facilitate the formation of stable oil-in-water emulsions and protective interfacial layers around oleoresin droplets. The significant interaction effect between mixing temperature and drying duration (DE) suggests that the optimal combination of these parameters is critical for piperine retention, as explained by the temperature- and time-dependent nature of piperine degradation kinetics. These findings are supported by Shaikh et al. (2006) and Don et al. (2024).

Particle Diameter Particle size is an important physical characteristic that influences the flowability, dispersibility, and reconstitution properties of powder products. The screening analysis showed that the Normal probability plot indicated factor B deviating from the normal line, and the Pareto chart confirmed that only factor B exceeded the Bonferroni limit. The ANOVA results verified that Tween 80 concentration significantly influenced particle diameter ($p = 0.0400$, $F = 5.75$), with higher concentrations resulting in smaller particle sizes.

Tween 80 reduces surface tension at the air-water interface, promoting the formation of smaller, more numerous foam bubbles (Kothekar et al., 2007). During vacuum drying, these smaller bubbles maintain their integrity, producing powder particles with correspondingly smaller dimensions. The surfactant also enhances foam stability by forming viscoelastic films at bubble interfaces, preventing coalescence and maintaining a uniform bubble-size distribution throughout the drying process. Furthermore, higher Tween 80 concentrations improve the emulsification of oleoresin within the aqueous phase, resulting in smaller oleoresin droplets that become incorporated into the dried matrix as smaller particles, consistent with observations by Zbicinski and Rabaeva (2009).

CONCLUSIONS AND RECOMMENDATIONS

This study identified Tween 80 concentration as the critical determinant of moisture and particle size in vacuum-foam-dried black pepper oleoresin, while the oleoresin-to-xanthan gum ratio governed yield. Significantly, piperine retention depended on the interaction between mixing temperature and drying duration. As the first systematic screening of this method, the findings recommend 2.0% Tween 80 and simultaneous optimisation of temperature-time parameters.

Practically, this technique provides a viable low-temperature alternative to spray drying for heat-sensitive nutraceuticals. An optimal formulation requires balancing carrier ratios to either yield (1:50) or loading (1:10). Future research should employ response surface methodology to refine these conditions and assess storage stability.

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REFERENCES

Ahmad, N., Fazal, H., Abbasi, B. H., Farooq, S., Ali, M., & Khan, M. A. (2012). Biological role of Piper nigrum L. (Black pepper): A review. Asian Pacific Journal of Tropical Biomedicine, 2(3), S1945-S1953.

Goula, A. M., & Adamopoulos, K. G. (2010). A new technique for spray drying orange juice concentrate. *Innovative Food Science & Emerging Technologies*, *11*(2), 342–351. https://doi.org/10.1016/j.ifset.2009.12.001

Hardy, Z., & Jideani, V. A. (2017). Foam-mat drying technology: A review. *Critical Reviews in Food Science and Nutrition*, *57*(12), 2560–2572.

Hasrini, R. F., Zakaria, F. R., Adawiyah, D. R., & Suparto, I. H. (2017). Mikroenkapsulasi minyak sawit mentah dengan penyalut maltodekstrin dan isolat protein kedelai. *Jurnal Teknologi dan Industri Pangan*, *28*(1), 10–19.

Kapoor, I. P. S., Singh, B., Singh, G., De Heluani, C. S., De Lampasona, M. P., & Catalan, C. A. N. (2009). Chemistry and in vitro antioxidant activity of volatile oil and oleoresins of black pepper (*Piper nigrum*). *Journal of Agricultural and Food Chemistry*, *57*(12), 5358–5364.

Kothekar, S. C., Ware, A. M., Waghmare, J. T., & Momin, S. A. (2007). Comparative analysis of the properties of Tween-20, Tween-60, Tween-80, Arlacel-60, and Arlacel-80. *Journal of Dispersion Science and Technology*, *28*(3), 477–484. https://doi.org/10.1080/01932690601108045

Koyama, M., & Kitamura, Y. (2014). Development of a new method for producing micron-sized powder by vacuum foam drying. *Journal of Food Engineering*, *143*, 34–40. https://doi.org/10.1016/j.jfoodeng.2014.06.027

Kubbutat, P., Leitão, L., & Kulozik, U. (2021). Stability of foams in vacuum drying processes: Effects of interactions between sugars, proteins, and surfactants on foam stability and dried foam properties. *Foods*, *10*(8), 1876. https://doi.org/10.3390/foods10081876

Mason, R. L., Gunst, R. F., & Hess, J. L. (2003). *Statistical design and analysis of experiments* (8th ed.). Wiley.

Meghwal, M., & Goswami, T. K. (2013). *Piper nigrum* and piperine: An update. *Phytotherapy Research*, *27*(8), 1121–1130. https://doi.org/10.1002/ptr.4851

Nahum-Shani, I., Dziak, J. J., & Collins, L. M. (2018). Multilevel factorial designs with experiment-induced clustering. *Psychological Methods*, *23*(3), 458–479.

Olalere, O. A., Abdurahman, N. H., Yunus, R. B. M., Alara, O. R., & Ahmad, M. M. (2019). Mineral element determination and phenolic compounds profiling of oleoresin extracts using an accurate mass LC-MS-QTOF and ICP-MS. *Journal of King Saud University - Science*, *31*(4), 859–863.

Prabhakar, P. K., & Kishore, A. (2023). Foam mat drying: Recent advances on foam dynamics, mechanistic modeling, and hybrid drying approach. *Critical Reviews in Food Science and Nutrition*, *63*(26), 8275–8291.

Qadri, O. S., Srivastava, A. K., & Yousuf, B. (2020). Trends in foam mat drying of foods: Special emphasis on hybrid foam mat drying technology. *Critical Reviews in Food Science and Nutrition*, *60*(10), 1667–1676.

Raharitsifa, N., & Ratti, C. (2010). Foam-mat freeze-drying of apple juice, part 1: Experimental data and ANN simulations. *Journal of Food Process Engineering*, *33*(s1), 268–283. https://doi.org/10.1111/j.1745-4530.2009.00400.x

Redha, A. (2010). Flavonoid: Struktur, sifat antioksidatif dan peranannya dalam sistem biologis. Jurnal Belian, 9(2), 196-202

Srinivasan, K. (2007). Black pepper and its pungent principle, piperine: A review of diverse physiological effects. Critical Reviews in Food Science and Nutrition, 47(8), 735-748. https://doi.org/10.1080/10408390601062054

Srinivasan, K. (2020). Biological activities of red pepper (Capsicum annuum) and black pepper (Piper nigrum) L.: An update. Critical Reviews in Food Science and Nutrition, 62(18), 4862-4891.

Shaikh, J., Bhosale, R., & Singhal, R. (2006). Microencapsulation of black pepper oleoresin. *Food Chemistry*, *94*(1), 105–110.

Sramek, M., Schweiggert, R. M., & Carle, R. (2015). Preparation of high-grade powders from tomato paste using a vacuum foam drying method. *Journal of Food Science*, *80*(8), E1658–E1666. https://doi.org/10.1111/1750-3841.12965

Takooree, H., Aumeeruddy, M. Z., Rengasamy, K. R. R., Venugopala, K. N., Jeewon, R., Zengin, G., & Mahomoodally, M. F. (2019). A systematic review on black pepper (Piper nigrum L.): From folk uses to pharmacological applications. Critical Reviews in Food Science and Nutrition, 59(sup1), S210-S243. https://doi.org/10.1080/10408398.2019.1565489

Teixeira, B., Marques, A., Ramos, C., Neng, N. R., Nogueira, J. M., Saraiva, J. A., & Nunes, M. L. (2013). Chemical composition and antibacterial and antioxidant properties of commercial essential oils. *Industrial Crops and Products*, *43*, 587–595. https://doi.org/10.1016/j.indcrop.2012.07.069

Zbiciński, I., & Rabaeva, J. (2009). Drying of foamed biological materials: Opportunities and challenges. *Drying Technology*, *27*(10), 1018–1027.