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Original Research Article

Development of Durian Seed Powder as a Cocoa Flavour Substitute through Microbial Fermentation

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Abstract: The seeds of *Durio zibethinus*, or durian seeds, being an underutilised waste product have been shown to have the potential of producing a chocolate aroma when they have undergone fermentation treatment. However, to date, producing a good cocoa substitute from durian seeds has not been given much attention due to issues with the taste and method of production. This study was conducted to determine a viable method for producing a flavour substitute for cocoa powder through the fermentation of durian seeds, and subsequently, to characterise the produced substance. Durian seed powder (DSP) was prepared by fermenting the seeds with fruit pulps in a 14-day fermentation, after which the seeds were dried under different time durations, and then roasted to a moisture content of 5% before grinding. Characterisation of DSP showed a composition of moisture, ash, crude fat, and carbohydrate that was dissimilar to cocoa, but with the crude protein content close to that of cocoa (11.18%). Appearance-wise, colorimetric analysis showed that longer roasting time of the seeds resulted in a closer appearance to commercial cocoa powder. The average theobromine content was found to be 14.496 mg/ml, which is within the expected range in cocoa powder. On sensory evaluation, 25 randomly selected panellists' taste-tested the sample powder mixed with varying degrees of sugar and cocoa powder. The results showed that DSP has the potential to substitute for cocoa powder to a certain extent. Finally, a SuperPro Designer simulation was performed to gauge the economic viability of DSP production, where the estimated cycle time of at least 16 days per batch was indicated.

Keywords: *Durio zibethinus*; durian seeds; fermentation; cocoa flavour; cocoa substitute

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1. Introduction

Durio zibethinus, or just simply "durian", is a fruit that is native to Southeast Asia that is widely consumed annually, generating large amounts of organic waste, in the form of seeds that make 20% to 25% of the weight of the whole fruit. The pulp of the durian fruit is widely celebrated for its rich, creamy texture and intense, distinctive aroma, which has contributed to its popularity in Southeast Asia and beyond (Ali *et al.*, 2020). In contrast, the seeds of the durian fruit, which make up a significant portion of the fruit's biomass, have traditionally been overlooked and often discarded as waste by consumers and processors alike (Md Sani *et al.*, 2022). Currently durian seeds are used in limited applications, such as animal feed or fertilizer (Sancho *et al.*, 2015), chips (Sofiyanita & Nurhayati, 2018), flour (Baraheng & Karrila, 2019) and gum (Permatasari *et al.*, 2021).

Durian tree bears a close genetic ancestry with *Theobroma cacao*, which is the cacao fruit tree, as it was found to be the closest ancestor to the durian tree in the Malvaceae family (Teh *et al.*, 2017). This genetic relationship suggests that the durian seed may possess inherent characteristics that could be exploited to develop it as a viable alternative to traditional cocoa-based ingredients, potentially opening new opportunities for its utilization in the food and beverage industry. Up until this article was written, there have been limited studies exploring the potential of durian seeds as a replacement for cocoa in food products (Wijayahena & Jayaweera, 2020). Nevertheless, Natania & Wijaya (2022) demonstrated the potential of durian seeds as coffee substitute, as it was found to produce up to 69% of similarity of aroma profile to Arabica and Robusta coffee beans.

Efforts for finding chocolate flavour substitute is crucial due to the increasing global demand for chocolate-based products, coupled with the constrained supply of cocoa beans in the face of various challenges, such as climate change, pests, and diseases, which have impacted cocoa production in recent years (Schroth *et al.*, 2016; Krauss & Barrientos, 2021). In Malaysia, the cocoa production has declined from its peak in the 1990s, leading to a greater reliance on imports to meet the domestic demand for cocoa-based products (Khoo *et al.*, 2016). Although Malaysia is no longer a cocoa producer, the consumption of cocoa-based products remains high, necessitating the exploration of alternative sources to supplement the supply of cocoa (Mohamed Arshad & Ibragimov, 2015). Numerous attempts have been made to create viable flavour substitutes, either through artificially synthesized chemicals, such as synthetic chocolate flavourings made from vanillin and benzaldehyde (Irving, 1954) or from edible plants such as chicory roots and carob pods (Fadel *et al.*, 2006), hazelnut skins (Şahin & Özata, 2022), jackfruit seeds (Ravindran *et al.*, 2020; Spada *et al.*, 2017) and durian seeds

(Wijayahena & Jayaweera, 2020). The latter has drawn increasing attention due to its potential to mimic the unique flavour profile of cocoa, while also offering a sustainable and cost-effective alternative to traditional cocoa sources (Vilela, 2018).

In order to reproduce the cocoa flavour in durian seeds, the process of flavour formation in cocoa processing has to be recreated with minor adjustments. The general flavour profile of cocoa can be attributed to specific aromatic compounds such as 2-methylpropanal, 3(or 2)-methylbutanal, phenylacetaldehyde, 2-ethyl-2(or 3),5-dimethylpyrazine, 2-acetyl-1-pyrroline, 2,3-dimethylpyrazine, trimethylpyrazine, tetramethylpyrazine, 3,5(or 2)-diethyl-2(or 5)-methylpyrazine, 3-methylbutanoic acid and 4-hydroxy-2,5-dimethyl-3(2H)-furanone. These compounds are amongst the most significant contributing chemicals in the sensory perception of the cocoa flavour (Velásquez-Reyes *et al.*, 2023). The aromatic of cocoa beans is produced through a series of physicochemical transformations that the kernels undergo during the fermentation, drying, and roasting stages.

The post-harvest handling of cocoa begins with the harvest, in which the ripe pods were picked and split open to extract the seeds along with the pulp. The seeds, still coated in the cacao pulp, were then fermented anaerobically in an enclosed environment, usually in a crate covered with banana leaves or gunny sack. The seeds were then left to ferment for half a week. The coverings would then be removed, and for the remainder of the week, the seeds would be stirred for aeration once a day as aerobic fermentation commences (Afoakwa, 2010).

The most important process in the production is by far the fermentation phase, where flavour precursors are formed through the formation of reducing sugars, free amino acids and peptides from the degradation of the cocoa nibs' storage components (Kadow *et al.*, 2015). This process is divided into the anaerobic and aerobic phases, whereby the former requires the activity of indigenous yeast (*Saccahromyces cerevisiae*) and lactic acid bacteria (*Limosilactobacillus fermentum*), while the latter relies on acetic acid bacteria (*Acetobacter pasteurianus*). The main purpose of the fermentation process for the cocoa beans is three-fold: to remove the pulp around the cocoa seed, reduce the content of undesirable compounds, and to increase the concentrations or induce the formation of aroma precursors (Castro-Alayo *et al.*, 2019).

In the anaerobic fermentation, the microbes secrete alcohol, lactic acid and pectinase, causing the fruit pulp to liquefy as the seeds become acidified and swell. As the fermentation transitions to the aerobic phase, the acetic acid bacteria oxidise the alcohol produced by the yeast to form acetic acid, which adds to the acidification of the seeds and activates the degradation of the storage proteins in the seeds, forming the required flavour precursors. The seeds also begin undergoing enzymatic browning in this phase, reducing the astringency as polyphenols become oxidized, a process that continues to happen when the seeds enter the drying phase. The beans are then kibbled to remove the shells and roasted between temperatures from 120 ºC to 140 ºC (Engeseth & Ac Pangan, 2018), making the contents of the seeds undergo the Maillard reaction, which converts the precursor compounds into the signature aromatic compounds of roasted cocoa nibs.

Prior investigations aimed at developing effective cocoa or chocolate flavor substitutes have yielded variable outcomes. Among the more successful and commonly utilized substitutes is carob pod, which is made into carob seed powder, and is widely accessible unfermented carob powder is predominantly utilized as a partial substitute for cocoa, rather than a complete replacement, particularly in baked goods formulations (Ikram *et al.*, 2023; Rodríguez-Solana *et al.*, 2021).

The potential of jackfruit seeds has been a recent subject of interest in the search for cocoa substitution, as these seeds exhibit similar biochemical characteristics and flavor attributes to cocoa beans when subjected to appropriate processing techniques, such as fermentation. This is further supported by the seed having a relatively high level of carbohydrate (69.39%) and protein (13.67%) (Sy Mohamad *et al.*, 2019). The jackfruit seed is characterized by its complex and pronounced aroma, suggesting that it possesses a rich phytochemical profile and contains a variety of aromatic precursor compounds even prior to undergoing fermentation (Brahma & Ray, 2023).

The cocoa fermentation process has been adapted and applied to jackfruit seeds to investigate their viability as a cocoa substitute (Spada *et al.*, 2017). The whole fresh jackfruit seeds with its pulp were fermented in a bucket covered with banana leaves for 8 days. The bucket was closed up for the first 3 days, similar to the way fresh cocoa pods are processed. Based on the characterisation findings of the resulting volatile compounds generated from the study, the method appears to be successful in replicating the cocoa aroma profile (Spada *et al.*, 2020). Sensory evaluation of diet chocolate products incorporating jackfruit seed-derived cocoa substitute revealed that the use of the substitute did not impact the sensory properties of the chocolate (Ravindran *et al.*, 2020).

The findings and techniques developed through the research on jackfruit seeds provided a foundation for the exploration of durian seeds as a cocoa substitute, informing the subsequent research on processing durian seeds employing similar techniques (Wijayahena & Jayaweera, 2020), including the fermentation of durian seeds with jackfruit pulp. The resulting powder produced was found to be similar to the cocoa aroma profile in terms of the volatile compounds detected and appear to be acceptable as a cocoa substitute based on odour sensory testing analysis. As few studies have been performed to refine the method for processing of durian seeds, further work is necessary to fully explore any methodological issues that might arise and the need for modifications to the procedure to address those issues.

To address these challenges, this study aims to explore the untapped potential of durian seeds as a cocoa flavour substitute through multifaceted approach combining microbial fermentation, chemical characterization, and sensorial assessment to contribute to the development of a novel, sustainable, and economically viable cocoa flavour substitute derived from durian seeds. Successful utilisation of durian seeds for flavour generation will be of benefit to the food industry and the environment, as it will provide an alternative to conventional cocoa, while also reducing food waste and creating value-added products from an underutilised agricultural by-product.

2. Methodology

2.1. Preparation of Samples

The method used for preparing durian seed powder (DSP) was based on the method as described by Wijayahena and Jayaweera (2020) with a slight alteration. Whereas previous studies have utilized solely jackfruit pulp as the substrate for the fermentation of both jackfruit and durian seeds, incorporating durian pulp in the methodology would be economically advantageous, as durian seeds inherently contain remnants of durian pulp. The selection of durian pulp as the substrate for fermentation is justified by the prevalence of "tempoyak", a commonly consumed fermented food product in Malaysia that is produced by fermenting durian pulp. Durian pulp fermentation is mainly produced via anaerobic fermentation by three microbe types, *S. cerevisiae*, *L. fermentum* and *A. pasteurianus*, at mesophilic temperatures between 27 ^{o}C to 34 ^{o}C. Prior research has demonstrated that yeasts, lactic acid bacteria, and acetic acid bacteria are key players in the fermentation process, suggesting a strong potential for leveraging this microbial activity to facilitate the fermentation of durian seeds for the current study.

Each sample was given a code based on the type of durian varieties the seeds were taken from (the first 2 alphabets), the type of substrates the seeds were fermented with (the second alphabet, where “D” is durian pulp and “J” is jackfruit pulp), and the fermentation run in which the sample was processed under (the number at the end), as the samples were fermented at different times, even though they had the same duration.

The seeds were split into two groups for different drying and roasting times. The first half of the seeds, KPJ1, KPD1, XOJ1, XOD1, were dried for 48 hours at 60 °C, which was double of what Wijayahena and Jayaweera (2020) used, as upon cutting the kernels open, it was found that the kernels were still moist in the centre. The remaining samples, KPD2, KWD4, UOD4, UOJ5, and including the control UO03, were only dried for 24 hours at 60 °C, as described by Wijayahena and Jayaweera (2020), before roasting.

Table 1. Preparation method for samples.

Fermentation Duration	Sample Code	Seed/Substrate Types	Drying Time	Roasting Time
14 days	KPJ1	Kampung durian + overripe jackfruit pulp	Dried for 48 hours at 60 °C	1 hour 30 minutes
	KPD1	Kampung durian + kampung durian flesh		
	XOJ1	XO durian + overripe jackfruit pulp		
	XOD1	XO durian + XO durian pulp,		
15 days	KPD2	Kampung durian full pod, seed with flesh in tact	Dried for 24 hours at 60 °C	2 hours 20 minutes
14 days	UO03 (Control)	Unknown variety durian seeds, no substrate		
14 days	KWD4	Durian kahwin + durian kahwin flesh	Dried for 24 hours at 60 °C	2 hours 20 minutes
	UOD4	Unknown variant durian seeds + durian kahwin flesh		
14 days	UOJ5	Unknown durian seeds + jackfruit flesh	Dried for 24 hours at 60 °C	2 hours 20 minutes
	JFJ5	Jackfruit whole pod, seed with flesh in tact		

Note: XO, durian kahwin and kampung durian are common names of local durian varieties.

Durian and jackfruit pulps were used in different batches for two reasons. The first was to discern if durian seeds can be fermented with non-jackfruit pulps, as previous studies done by Wijayahena and Jayaweera (2020), had only used jackfruit pulp in the fermentation process. The second reason was to compare the ability of different fruits to reproduce the cocoa aroma in the DSP.

The fermentation was performed by mixing the cleaned and fresh durian seeds with either durian or jackfruit pulp in seed-to-pulp weight ratio of about 2:1 and enclosing the seeds in a disposable plastic container. The mixture was left to ferment anaerobically in an incubator (Incucell, Germany) under temperatures between 28 ºC and 32 ºC with the lid closed for 7 days. The lid of the incubator was then opened to facilitate aerobic fermentation for the subsequent 7 days, during which the mixtures were manually stirred once per day. After the fermentation period, any remaining pulp remnants were removed, and the seeds were patted dry with paper towels.

The first four samples of seeds were dried for 24 hours, dehulled manually with a knife, then dried for an additional 24 hours. The remaining samples of seeds were dried for only 24 hours prior to dehulling. All seven of samples of the dried seed kernels, regardless of drying time, were then roasted in an oven (Memmert, Germany) at 180 ºC to achieve a moisture content less than 5%. The roasting time for the seeds with 48 hours of drying took 90 minutes, while the seeds dried for 24 hours took 140 minutes.

The roasted seed kernels were then ground in a hammer mill to obtain a coarse powder. As a control, one batch (UO03) of durian seeds were left to ferment in the same conditions without the presence of either jackfruit or durian pulp, and one batch of jackfruit seeds were fermented with jackfruit pulp for comparison. Both samples were processed similarly. The seed and fruit pulp combinations as well as their respective drying and roasting methods for each sample are presented in Table 1.

Table 2. Composition of sample mixtures

SAMPLE MIX	COMPOSITION BY WEIGHT
A0	100% DSP
A1	50% DSP, 50% sugar
A2	37.5% DSP, 12.5% cocoa, 50% sugar
A3	25% DSP, 25% cocoa, 50% sugar
A4	12.5% DSP, 37.5% cocoa, 50% sugar
A5	50% cocoa, 50% sugar

Note: DSP = Durian seed powder

2.2. Proximate Analysis and Colorimetry

The proximate analysis for the samples was performed based on the procedures as described by Penner and Nielsen (2017) in accordance with the AOAC International standard methods of analysis to determine moisture, ash, crude fat, crude protein and carbohydrates (with crude fibre inclusive). The analysis of every sample was performed in duplicate. Colorimetric difference of each DSP sample was measured with handheld colorimeter (Graigar, China).

2.3. Theobromine Content Analysis

The theobromine content was determined using UV-Vis spectrophotometry at 272 nm with a spectrophotometer (Thermo Fisher Scientific, USA) following the method as described by Li *et al.* (1990) using extracts made via solvent percolation from the DSP. The Extracts were prepared and clarified according to the method described by Nguyen and Nguyen (2017).

2.4. Sensory Testing

The DSP taken from one batch was mixed with fine white table sugar (MSM, Malaysia) and commercial cocoa powder (Beryl's, Malaysia) according to the proportions shown in the Table 2. Untrained and randomly selected participants were then instructed to evaluate each mixture based on appearance, aroma, flavour and the overall likeness to cocoa of each dry powder mixes by filling in a Google form after tasting about a coffee-stirrer's worth of each mixture.

2.5. Economic Simulation

A SuperPro Designer (v10, Intelligen Inc.) Simulation was conducted to gauge the overall cycle time of the entire process, without taking into account operating, material or capital costs.

3. Results and Discussions

3.1. Effects of Different Preparation Methods

The fermentation process of the seeds was found to be feasible with both jackfruit and durian pulp, as the samples KPJ1, KPD1, XOJ1, XOD1, KWD4, UOD4, UOJ5 and JFJ5 produced a chocolate-like aroma after drying and roasting. However, two exceptions were noted—the KPD2 sample was observed to be over-fermented, and the UO03 sample was fermented without the addition of a substrate. Hence, further analyses of these two samples were not included in the present study. The origin of the durian seeds used in the samples did not appear to significantly impact the quality of the chocolate-like aroma produced, with roasting time and seed-to-pulp ratio having a more pronounced influence on the resulting aroma intensity. However, it is noted that an olfactometer or gas chromatography test would have allowed for a more comprehensive and quantitative assessment of the aromatic profiles of the different samples.

Figure 1. DSP samples obtained using different preparation methods

The samples KPD1, KPJ1, XOD1, and XOJ1 were subjected to a more prolonged drying process, with 24 hours of drying at 60 °C, followed by an additional 24 hours of drying after dehulling, resulting in a total drying time of 48 hours. The extended drying time reduced the roasting time to 90 minutes. Thus, duration needed to reach the targeted moisture content was achieved faster, producing a powder with a paler colour (refer to Figure 1) and weaker aroma compared to the samples KWD4, UOD4, and UOJ5, which were dried for only 24 hours as whole seeds and then roasted for 140 minutes after dehulling. The latter group showed a more pronounced chocolate-like aroma and a darker colour, suggesting that the extended drying and roasting processes may have been detrimental to the development of the desired flavour profile.

3.2. Proximate Analysis and Colorimetry

The results of the proximate analysis for the DSP as well as commercial cocoa powder are shown in Table 3. The data for sample UOJ5 was excluded due to incomplete findings.

Table 3. Proximate analysis of DSP and cocoa powder (in percentage).

Sample	Moisture	Ash	Crude Fat	Crude Protein	Carbohydrates And Crude Fibre
KPD1	6.62	3.83	0.65	10.73	78.18
KPJ1	8.355	3.57	0.35	10.26	77.47
XOD1	7.23	3.33	0.92	10.33	78.20
XOJ1	8.04	2.78	1.08	9.56	78.55
UOD4	9.32	3.94	0.95	13.49	72.31

Sample	Moisture	Ash	Crude Fat	Crude Protein	Carbohydrates And Crude Fibre
KWD4	9.35	3.87	1.13	12.71	72.94
CO00 (reference)	7.68	18.67	13.50	15.59	44.56

Note: KPD1, KPJ1, XOD1, and XOJ1 were dried for 48 hours; UOD4 and KWD4 were dried for 24 hours

The results of the proximate analysis for the DSP as well as commercial cocoa powder are as shown in Table 3. As shown in Table 3, all values from all samples exhibited similar values. Though in this study, a few varieties of durian were used, the findings suggest that the proximate composition of DSP remained relatively consistent across the different durian varieties examined. Higher moisture content was observed at both samples KWP 4 and UOD4 due to the shorter drying period treatment (24 hours) as compared to KPD1, KPJ1, XOD1, and XOJ1 that had undergone 48 hours of drying. However, lower values of ash content (2.78–3.94%) of the DSP samples were observed as compared with Faridah *et al.* (2021) who reported ash content of 4.06–4.68% for durian seed flours. This difference could be attributed to the variation in the processing conditions where Faridah *et al.* (2021) adopted sodium hydroxide treatment during the sample preparation.

Interestingly, the protein content of the DSP samples was found to be almost 2-fold higher (9.56–13.49%) than Faridah *et al.* (2021) and Hartati *et al.* (2023). Similarity of values between Faridah *et al.* (2021) and Hartati *et al.* (2023) for protein content in durian seed flour is likely due to the adoption of similar samples and processing procedures. High protein content observed in the current study may be attributed to the microbial fermentation process, which could have enhanced the extraction and solubilization of proteins from the durian seeds prior to the drying step (Tan *et al.*, 2021). Dissimilarities of all DSP values with the commercial cocoa powder are expected, given the inherent differences in the botanical origin, chemical composition, and processing methods. Commercial cocoa powder showed higher values for all analyses except for moisture (7.68%) and carbohydrate and crude fibre (44.56%) content compared to the DSP samples. The DSP demonstrated a relatively high content of carbohydrates, which is known to play a crucial role in the development of the characteristic cocoa flavour through various chemical reactions, such as Maillard reactions and caramelization, during thermal processing (Voon *et al.*, 2007). The comparable protein content between DSP and commercial cocoa powder suggests that the DSP may possess a similar potential to generate the distinctive cocoa aroma and flavour notes through enzymatic and non-enzymatic reactions during processing (Voon *et al.*, 2007). Notably, the DSP samples with higher protein content, specifically KWD4 and UOD4, exhibited a more pronounced chocolate aroma.

The colorimetric measurement for each sample, as well as the deviation of each sample from the cocoa powder reference are shown in Table 4.

Table 4. Colorimetry data of DSP and cocoa powder.

Sample	**L* (Tone)**	**a* (RG standard)**	**b* (YB standard)**	**E*ab**	**Roasting time, minutes**
KPD1	100	49.2925	20.7825	17.51	90
KPJ1	100	47.21	16.3525	14.84	90
XOD1	100	43.1525	14.85	14.28	90
XOJ1	100	55.01	19.575	19.06	90
UOD4	96.36	41.95	10.94	10.27	140
KWD4	95.78	40.155	10.0575	10.43	140
UOJ5	91.53	41.5	10.3075	6.11	140
CO00 (reference)	86.6075	45.1175	10.3075	-	-

All samples with shorter drying times and longer roasting times (UOD4, KWD4, UOJ5) exhibited lower L* (lightness) values, indicative of a darker appearance. Interestingly, the DSP samples, particularly KPD1, KPJ1, XOD1, and XOJ1 which had undergone 48h drying, showed a higher L* value. Similar observation was found on a* values, and b* values, suggesting that samples with shorter drying times and longer roasting times have closer appearance to the commercial cocoa powder. The darker appearance, as well as the reddish-brown hue, observed in the DSP samples subjected to more intense thermal processing are attributable to the Maillard reactions and caramelization reactions that occur during prolonged heating, leading to the formation of melanoidins and other coloured compounds (Danehy, 1986). Achieving a closer visual resemblance of DSP to commercial cocoa powder is crucial to facilitate its successful adoption as a cocoa substitute for public consumption.

3.3. Theobromine Content

The theobromine content of the DSP samples and commercial cocoa powder are presented in Table 5. Theobromine is a key bioactive compound found in cocoa that contributes to its characteristic bitter taste profile (Aunillah *et al.*, 2021). Notably, the theobromine content of the DSP samples was significantly lower compared to the commercial cocoa powder.

Table 5. Absorbance values and theobromine content

SAMPLE	ABSORBANCE, nm	CONCENTRATION, mg/ml
KPD1	0.230	15.768
KPJ1	0.206	14.653
XOD1	0.247	16.552
XOJ1	0.175	13.234
UOD4	0.135	11.400
KWD4	0.151	12.109
UOJ5	0.273	17.759
CO00	0.302	19.095

This finding suggests that the DSP may exhibit a less pronounced bitterness compared to cocoa, which could be advantageous in certain food applications where a milder flavour profile is desirable. It is worth to mention that measurement of theobromine content by spectrophotometry can be compromised due to the presence of other analytes in the extracts (Mukherjee *et al.*, 2021). Therefore, the use of high-performance liquid chromatography for the determination of theobromine is recommended to obtain a more accurate quantification (Kreiser & Martin, 1980).

3.4. Sensory Evaluation

The study further assessed the sensory characteristics of the mixtures of DSP with cocoa powder and sugar (refer Table 2) through a comprehensive sensory evaluation. Twenty-five volunteers were recruited and given the samples to evaluate for various attributes, including colour, aroma strength, aroma quality, flavour, aftertaste, likeness to cocoa and overall preference on a scale from 1 to 5. The average scores for the evaluation are represented in Figure 2. The results revealed that highest scores were obtained by A4 and A5, formulations with higher cocoa powder of 37.5% and 50%, respectively. However, least acceptance was observed for A0 and A1, 100% DSP and 50% DSP, respectively. This observation suggests high reliance to cocoa powder and poor substitution of DSP to commercial cocoa powder. Interestingly, a degree of acceptability of A2 and A3 formulations with 37.5% DSP:12.5% cocoa powder: 50% sugar and 25% DSP:25% cocoa powder:50% sugar, respectively, indicating potential for further optimisation of the DSP-cocoa powder blends to improve sensory characteristics.

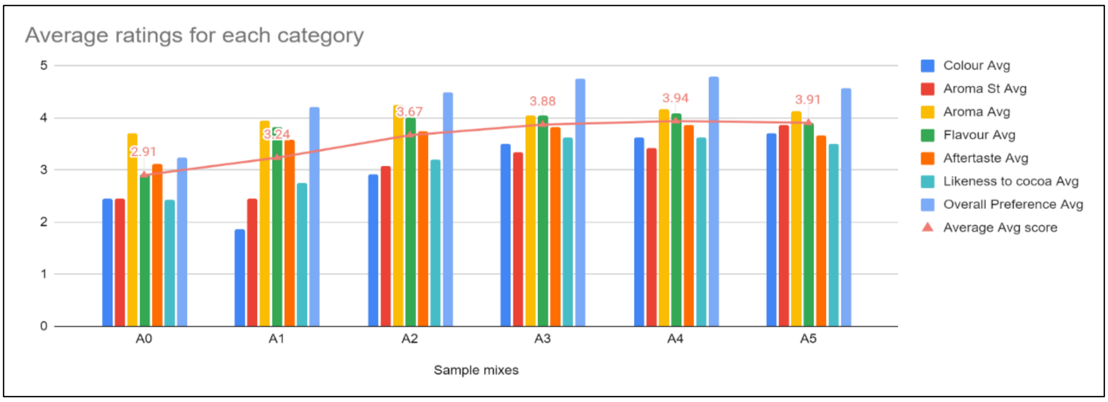

Figure 2. Average ratings of the sample mixes for each evaluation category

Standard deviations (SD) of respondents' rating on the acceptance of the sample mixtures are shown in Figure 3. The SD values represent unity or diversity of the volunteers' perception on the different attributes assessed. Higher SD values were observed with A4 (12.5% DSP:37.5% cocoa:50% sugar) and A5 (50% cocoa:50% sugar), indicating disagreements and mixed perception among volunteers. Higher cocoa percentage in the mixtures likely contributed to the bitter and astringent notes, which may not be universally appreciated. The samples with lower SD values such as A1 (50% DSP:50% sugar) and A2 (37.5%DSP:12.5% cocoa:50% sugar) represent a more uniform acceptance among the volunteers, suggesting a more balanced sensory profile. A3 (25% DSP:25% cocoa: 50% sugar) showed a mid-level SD values, implying a relatively consistent level of acceptability among the volunteers compared to the higher cocoa percentage formulations.

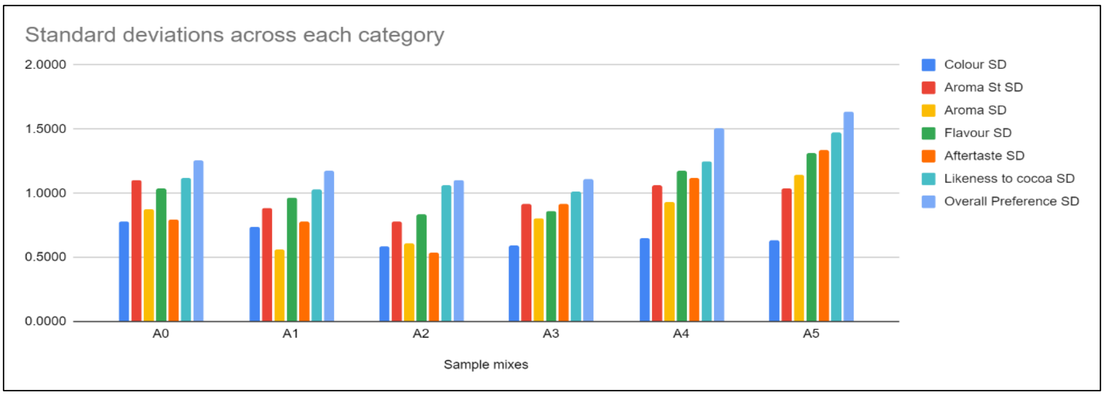

Figure 3. Average ratings of the sample mixes for each evaluation category

The overall preference of volunteers on the sample mixtures is summarized in Figure 4. About 36% and 24% of volunteers preferred the A5 and A4, respectively, reflecting the strong liking for the higher cocoa powder content. Interestingly, about 16% of the volunteers favoured the A1 formulation, which contained a 50% DSP and 50% sugar blend. Acceptance of DSP can also be manifested on volunteers when 12% of volunteers favoured A3 formulation, which contained 25% DSP, 25% cocoa and 50% sugar. The least acceptance was observed with A0 (100% DSP) indicating the reliance of sugars and cocoa to the mixtures.

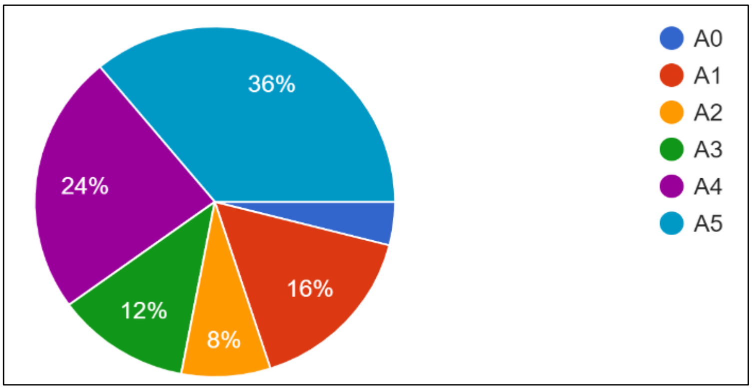

Figure 4. Participants' preferred choice of DSP, sugar and cocoa powder mixtures

Overall, the sensory results support the potential of DSP as a partial cocoa substitute where the ideal formulation would consist similar amount of DSP and cocoa powder. For future studies, it is recommended to explore the incorporation of additional ingredients or process modifications to further optimize the sensory profile and consumer acceptance of the DSP-based cocoa substitutes.

3.5. Economic Simulation

The SuperPro Designer simulation utilized the mass loss data collected from processing sample KWD4, which had the highest wet weight to dry weight ratio, resulting in a yield of 23.53% from 340 grams of durian seeds. The simulation model was scaled up to a production capacity of 3.4 metric tons, with the resulting process flowsheet illustrated in Figure 5. The scaled-up production process integrated fundamental processing steps, including fermentation vessel, seed pretreatment, drying, dehulling, roasting and grinding, with the objective of achieving an approximate annual output of 800 metric tons of DSP.

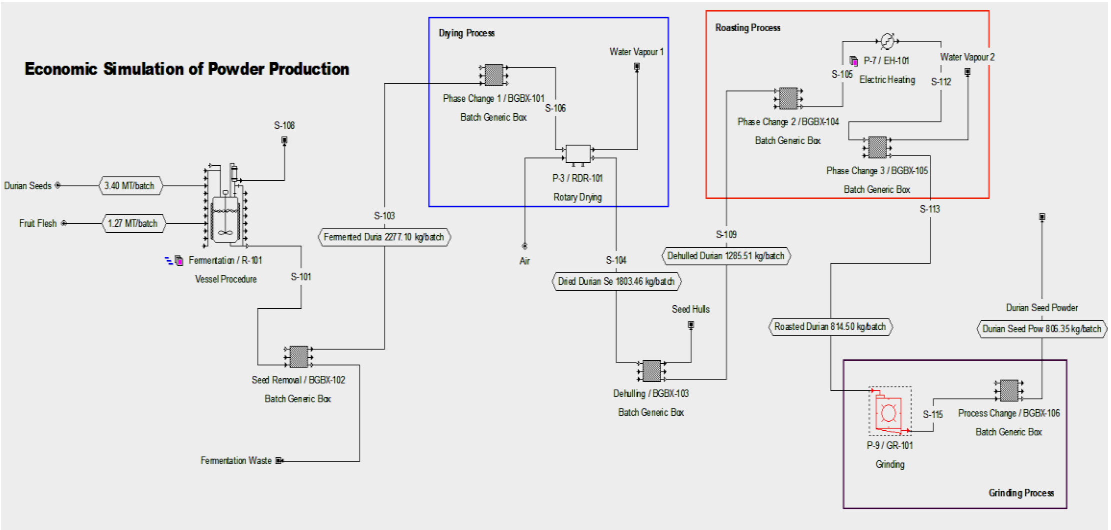

Figure 5. SuperPro Designer simulation flowsheet for DSP production

The simulation yielded a total cycle time of 15.90 days, with the fermentation process taking 14 days per batch as the longest component. Without a staggered reactor setup, the annual production would be limited to approximately 23 batches, as the fermentation stage remains the primary bottleneck in the process. To address this limitation, the implementation of a multi-reactor configuration could potentially improve the overall productivity by allowing for parallel processing and a higher annual output. Implementing a multi-reactor configuration with 6 additional units resulted in a significant increase in annual production capacity, reaching 155 batches and yielding 126.2 metric tons of product. Further expanding the multi-reactor setup to 13 additional units led to an even more substantial increase, with 310 batches produced annually and a total output of 252.5 metric tons.

Given that durians are a seasonal fruit, harvested for approximately 4 to 6 months per year, implementing a staggered reactor configuration with 6 additional units would likely yield a more realistic annual production output for a commercial producer. This simulation demonstrates that with a well-designed and managed fermentation process, large quantities of DSP can be produced efficiently and cost-effectively, as durian seeds are essentially a waste product with minimal intrinsic value. However, the manual processing steps in this proposed method remain laborious and time-consuming, and thus warrant further optimization to enhance the overall process efficiency.

4. Conclusions

The present study explores the potential of DSP as a viable substitute for cocoa powder, thereby offering a novel approach to valorising what is commonly perceived as a waste product. The findings contribute to a more comprehensive understanding of the DSP production process, its characterization, and the feasibility of employing it as a cocoa substitute. Further research, particularly focused on the commercial-scale production of DSP, would likely enhance the utilization of durian seeds as a value-added product, which could potentially alleviate the demand pressures on the cocoa powder market.

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