IDENTIFYING SUITABLE FOOD-GRADE WASTE MATERIALS AS ECO-FRIENDLY FABRIC: A CURRICULUM FRAMEWORK FOR SUSTAINABLE FASHION DESIGN

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Abstract: The identification of suitable food-grade waste materials for eco-friendly fabric production represents a critical but underexplored domain in Malaysian fashion design education. The present study examines three primary categories of food-grade waste with the highest indicative potential for textile application in Malaysia: pineapple leaf fibre (approximately 30%), banana fibre (approximately 20%), and citrus or fruit-derived fibre (approximately 17%), as derived through SPSS frequency analysis of structured survey responses, subsequently weighted against secondary data from Malaysian agricultural waste reports and peer-reviewed textile research. Adopting a quantitative cross-sectional design supported by documentary analysis, the study administered a structured 22-item five-point Likert questionnaire to 100 respondents drawn from fashion design students, educators, and industry practitioners, with instrument reliability confirmed through Cronbach's Alpha ($\alpha = 0.71$). Drawing on findings related to material properties, waste availability, and respondent-perceived design suitability, this paper proposes the Eco-Material Selection Framework for Fashion Design Curriculum (EMSF-FDC) as a conceptual three-layered model integrating material profiling, curriculum alignment, and design output evaluation. The proposed framework is positioned as an initial conceptual contribution requiring subsequent expert validation and pilot implementation in classroom settings before its pedagogical effectiveness can be empirically established. This study contributes to the discourse on sustainable fashion education by offering a structured and transparent starting point for eco-material selection within the Malaysian curriculum context, while explicitly acknowledging the perception-based foundation of the underlying survey data and the conceptual status of the framework.

Keywords: Food-grade waste, eco-friendly fabric, banana fibre, pineapple leaf fibre, fashion design curriculum, EMSF-FDC, sustainable textile education, Malaysia.

INTRODUCTION

The global fashion industry consumes vast quantities of natural and synthetic fibres, placing significant pressure on agricultural land, water resources, and petrochemical supplies (Niinimaki et al., 2020). In Malaysia, the fashion and textile sector is among the more resource-intensive industries, generating waste across both production and consumption stages of the supply chain. Against this backdrop, researchers and educators have increasingly turned to food-grade waste materials as viable and sustainable alternatives to conventional textiles. Food-grade fibres derived from organic waste sources such as banana stems, pineapple leaves, and fruit rinds offer biodegradability, renewability, and a reduced environmental footprint than petroleum-based synthetic alternatives (Blackburn, 2005; Sadravi et al., 2020).

Fashion design education carries a unique responsibility in facilitating this transition. By equipping students with the knowledge and skills to identify, evaluate, and utilise food-grade materials, fashion design programmes can cultivate a generation of designers who prioritise ecological responsibility alongside aesthetic excellence (Fletcher, 2008; Gwilt, 2014). However, the integration of eco-material identification into formal design curricula remains inconsistent and lacks structured, evidence-based frameworks to guide educators and students. The present research responds to this gap by investigating which food-grade waste categories are most suitable for application as eco-friendly fabric and by proposing a curriculum-oriented selection framework grounded in empirical survey findings and supporting documentary evidence.

This paper is grounded in the second research objective of a broader study on food-grade material apparel: What types of food-grade waste can be applied as the material for eco-friendly clothing? Through a survey of 100

respondents and documentary analysis of international and local eco-material case studies, the study identifies and ranks the most promising food-grade fibre categories and proposes a conceptual framework for their integration into fashion design curricula in Malaysia.

This study contributes a structured eco-material selection framework, the EMSF-FDC, tailored for the Malaysian fashion design curriculum context. The framework responds to the documented absence of systematic material selection models in sustainable design education at the local level. Findings are particularly relevant to Malaysian higher education institutions seeking to integrate eco-material literacy as a structured competency within their fashion design programmes, in alignment with SDG 4 (Quality Education) and SDG 12 (Responsible Consumption and Production). The contribution is positioned as conceptual at this stage; empirical validation through expert review and pilot implementation is a necessary next step.

The relevance of structured pedagogical frameworks in creative education is well established in the literature. Hassan et al. (2022) demonstrated that purposefully designed teaching tools enhance learner engagement and design competency development, a principle that informs the EMSF-FDC proposed in this paper. Similarly, Wardi et al. (2025a) showed that creative design students benefit from curricula that balance autonomous exploration with structured instructional scaffolding, an approach reflected in the layered structure of the present framework.

LITERATURE REVIEW

Food-grade Fibre Sources and Their Properties

Several food-derived materials have emerged as viable candidates for eco-friendly textile production. Banana fibre, extracted from the pseudostem of the Musa genus plant, is characterised by high tensile strength, moisture absorption, and natural lustre. Banana plants are widely cultivated across Southeast Asia, and their stems are typically discarded after fruit harvest, generating a significant available waste biomass. Kozlowski (2012) confirmed that plant-based natural fibres such as banana represent promising alternatives to conventional synthetics given their mechanical strength and biodegradable properties.

Pineapple leaf fibre (PALF), derived from the leaves of Ananas comosus, is among the most extensively studied food-grade fibres for textile application (Sadravi et al., 2020). PALF is fine, white, and lustrous, with surface and drape properties comparable to silk. The commercial product Pinatex, developed by Ananas Anam, has demonstrated the marketability of PALF-based fabric in the international fashion industry. In Malaysia, pineapple cultivation concentrated in Johor and Sarawak provides a readily accessible agricultural waste stream for domestic eco-textile production.

Citrus and fruit-derived fibres represent a third category of food-grade material with textile application potential. Orange fibre, developed by the Italian company Orange Fiber, utilises cellulose extracted from citrus juice by-products to produce a silky fabric used in limited-edition collections by international fashion brands. The relative novelty of this material in Malaysia creates opportunities for innovation and research within local fashion design programmes, particularly in experimental design and material innovation units.

Material Selection as a Design Education Competency

Material selection is a foundational competency in fashion design education, encompassing knowledge of fibre properties, fabric behaviour, production compatibility, and environmental impact (Ashby, 2013). Traditional design curricula have focused predominantly on conventional textiles such as cotton, polyester, and nylon, offering limited exposure to alternative or experimental eco-materials. There is growing scholarly consensus that expanding material literacy to include sustainable alternatives enhances students' capacity for ecological design thinking and prepares them for a rapidly evolving professional landscape (Fletcher, 2008; Gwilt, 2014).

Research in design education has consistently highlighted the centrality of tactile and sensory engagement in developing material literacy. Hassan et al. (2024a) found that learners engage more deeply with material knowledge when sensory modalities are actively stimulated during the learning process. Their findings suggest that direct physical interaction with food-grade fibres, including hands-on testing of banana fibre yarns and PALF swatches, can deepen student understanding of eco-material properties and their design implications.

Wardi et al. (2025b) further demonstrated that team-based learning environments in textile design education produce stronger creative outcomes and deepen material understanding through peer evaluation and collaborative prototyping. In the context of eco-material selection, collaborative studio projects that require students to evaluate, blend, and prototype food-grade fabric alternatives can bridge theoretical material knowledge and practical design application.

Consumer and Educator Preferences in Eco-Material Fashion

Survey data from the present research indicate that cotton-like characteristics are the most preferred tactile quality among respondents at 69 per cent, followed by polyester-like properties at 16 per cent and lycra at 14 per cent. This preference pattern reflects the dominance of conventional material familiarity in shaping consumer and student expectations, and highlights the challenge of introducing food-grade alternatives in a fashion education and market environment accustomed to established textile standards.

Findings also indicate that blouse and dress silhouettes are the most frequently purchased and preferred clothing categories, at 38 per cent and 36 per cent respectively. This consumer preference data is relevant for curriculum planning, as it directs eco-material design projects toward basic garment constructions that align with both respondent expectations and the structural capabilities of food-grade fabrics, namely blouses, dresses, and skirts that do not require complex construction techniques beyond the technical range of food-grade fibres.

Research Gap and Critical Comparison of Existing Frameworks

Although the literature reviewed above establishes the technical viability of food-grade fibres and the pedagogical relevance of material literacy, a critical comparison of existing eco-material selection frameworks reveals a persistent gap at the intersection of sustainable material science and design education curriculum design in the Malaysian context.

Industry-oriented frameworks such as the Higg Materials Sustainability Index (Higg MSI) and the Cradle-to-Cradle (C2C) Certified standard provide robust environmental impact metrics for textile materials, yet they are calibrated for industrial decision-making rather than for classroom pedagogy. These frameworks do not articulate how material selection knowledge should be sequenced across design studio units, nor do they specify pedagogical entry points that match student competency levels in undergraduate fashion design programmes (Fletcher, 2008; Niinimaki et al., 2020). Consequently, while industry frameworks support compliance and procurement decisions, they offer limited direction for educators developing eco-material learning outcomes.

Scholarly contributions on sustainable fashion education, including those of Fletcher (2008) and Gwilt (2014), articulate broad pedagogical principles for embedding sustainability into design teaching, but stop short of proposing structured selection tools tied to specific waste streams available within a national or regional context. Equally, Malaysian-focused studies on agricultural waste utilisation (Global Environment Centre, 2017; National Solid Waste Management Department Malaysia, 2016) document the availability of organic waste resources, but do not connect these material flows to fashion design curriculum content or studio practice.

The unique position of the present study therefore lies in three areas. First, it foregrounds locally available food-grade waste streams, namely PALF, banana fibre, and citrus-derived fibre, which are abundant in Malaysian agriculture but underutilised in textile education. Second, it proposes a layered framework that explicitly links material profiling to curriculum alignment and design output, addressing the pedagogical sequencing gap left by industry-oriented indices. Third, it grounds this framework in primary survey data from Malaysian respondents, providing a contextualised evidence base rather than transposising frameworks developed in Western or industrial settings. The resulting EMSF-FDC is therefore positioned not as a competitor to industry sustainability metrics, but as a pedagogical bridge between material science evidence, agricultural waste availability, and fashion design teaching practice.

METHODOLOGY

Research Design

This study adopts a quantitative cross-sectional design, supported by documentary analysis of existing eco-material textile products, case studies, and published research. The cross-sectional approach captures respondent

perceptions and material evaluations at a single point in time, enabling systematic comparison across respondent groups. The integration of survey and documentary analysis provides triangulation of findings, strengthening the evidence base for the proposed EMSF-FDC framework.

Figure 1
Research Design Flow

Step	Phase	Description
1	Research Problem Identification	Gap in systematic eco-material selection models within Malaysian fashion design education
2	Literature Review	Food-grade fibre properties, eco-fashion education, sustainable textile curriculum integration; critical comparison with existing frameworks (Higg MSI, C2C, Fletcher, Gwilt)
3	Instrument Development	22-item five-point Likert questionnaire; pilot tested with 15 respondents; reliability confirmed (Cronbach's Alpha $\alpha = 0.71$)
4	Data Collection	100 respondents (purposive sampling); quantitative survey + documentary analysis of eco-material prototypes
5	Data Analysis	SPSS v.26 frequency analysis on each item; conversion of Likert responses into weighted suitability scores; integration with secondary agricultural waste data through composite weighting (see Section 3.5)
6	Framework Development	EMSF-FDC, a conceptual three-layer model: Material Profile, Curriculum Alignment, Design Output
7	Validation Roadmap	Critical discussion of framework limitations; expert review and classroom pilot identified as required next-stage validation activities (see Sections 6.3 and 7.2)

Sampling

A purposive sampling technique was employed, targeting respondents with knowledge in fashion design and textile-related fields. Respondents were drawn from fashion design students, educators, and industry practitioners in Malaysian higher education institutions. This approach was selected to ensure that material evaluations and curriculum preference data were grounded in informed design and textile knowledge, producing contextually meaningful findings for curriculum development purposes. A total of 100 respondents participated in the study. The implications of this sample size for the generalisability of findings are addressed explicitly in Sections 6.3 and 7.2.

Pilot Study

A pilot study involving 15 respondents was conducted before full-scale data collection to evaluate the clarity of survey items and the relevance of documentary analysis criteria. Minor revisions were made to three questionnaire items following pilot feedback, particularly those addressing respondent familiarity with eco-material production processes. The pilot study confirmed the overall suitability of the instrument for the target respondent population.

Instrument and Reliability

The survey instrument comprised 22 items assessed on a five-point Likert scale (1 = strongly disagree, 5 = strongly agree), addressing respondent material preferences, clothing consumption behaviour, and awareness of food-grade fabric alternatives. The reliability of the survey instrument was assessed using Cronbach's Alpha, achieving a value above 0.70 ($\alpha = 0.71$), indicating acceptable internal consistency for exploratory education research (Taber, 2018). This confirms that the instrument measures its intended constructs reliably across the respondent sample.

Data Analysis Procedure and Quantification of Material Rankings

To address concerns regarding methodological transparency, this section sets out in detail the procedure used to derive the indicative percentage rankings for the three primary food-grade waste categories (PALF ≈ 30%, banana ≈ 20%, citrus ≈ 17%). The procedure was implemented in IBM SPSS Statistics v.26 and proceeded through four sequential stages.

Stage 1: Item-level frequency analysis. For each of the 22 questionnaire items, descriptive frequency tables were generated in SPSS, recording the number and percentage of respondents selecting each Likert point. Items relevant to the present analysis were the four items measuring respondent perception of textile suitability for each food-grade fibre category (PALF, banana, citrus, hybrid blend), and the two items measuring perceived availability of these material sources within the Malaysian context.

Stage 2: Conversion of Likert responses into weighted suitability scores. For each material category, a weighted suitability score was calculated by combining the percentage of respondents who selected "Agree" (4) and "Strongly Agree" (5) on the relevant items. Scores of 4 were weighted at 0.5 and scores of 5 at 1.0, producing a single composite endorsement value per material on a 0–1.0 scale. This conversion procedure follows established practice for converting ordinal Likert data into normalised endorsement metrics in education and design research (Taber, 2018).

Stage 3: Integration with secondary data through composite weighting. To produce a final indicative ranking that reflects both perceived suitability and real-world availability, the perception-based endorsement value (Stage 2) was integrated with secondary data on Malaysian agricultural waste availability sourced from the National Solid Waste Management Department Malaysia (2016) and the Global Environment Centre (2017), and from international peer-reviewed textile research on the technical viability of each fibre (Kozlowski, 2012; Sadravi et al., 2020). A composite weighting of 60% perception data and 40% secondary data was applied, reflecting the study's primary methodological emphasis on respondent-informed curriculum design while retaining grounding in documented agricultural and material science evidence. The resulting composite score for each material was scaled to a percentage value to facilitate intuitive interpretation by curriculum developers.

Stage 4: Ranking and interpretation. The four resulting composite scores were ranked in descending order, producing the indicative percentages reported throughout this paper (PALF ≈ 30%, banana ≈ 20%, citrus ≈ 17%, hybrid blends as variable, context-dependent values). These percentages should be interpreted as indicative comparative rankings reflecting both respondent perception and supporting secondary evidence, rather than as precise statistical estimates of national fibre availability or absolute textile suitability. This distinction is emphasised both in the findings narrative (Section 4) and in the limitations discussion (Sections 6.3 and 7.2). The transparent disclosure of this composite weighting procedure responds directly to the methodological accountability standards expected in peer-reviewed curriculum and design education research.

Documentary Analysis

A documentary review of food-grade textile prototypes, international eco-fashion brand literature, and design education case studies was conducted as a secondary method. Prototypes assessed included garments produced from banana fibre, pineapple leaf fibre, and citrus-derived materials, evaluated against criteria including tensile strength, digital printability, dyeing compatibility, and wash durability. Findings from the documentary analysis were triangulated with survey data to inform the development of the EMSF-FDC framework.

Framework Development and Validation Approach

The EMSF-FDC framework was developed by synthesising three evidence streams: the weighted survey rankings described in Section 3.5, the documentary analysis described in Section 3.6, and the thematic insights drawn from the literature review (Section 2). The framework is therefore positioned as a conceptual contribution derived from triangulated data, rather than as an empirically tested pedagogical instrument.

The present study did not include a formal expert validation stage involving structured rating panels or a Content Validity Index (CVI) procedure, nor did it include classroom implementation testing with lecturers and students. These omissions are recognised as a methodological boundary of the present contribution. To address this transparently, two strategies are adopted. First, Section 6.3 critically discussed the framework's conceptual status, articulating the specific aspects that require empirical validation before pedagogical effectiveness can be claimed. Second, Section 7 (Conclusion) sets out a concrete validation roadmap, identifying the expert review procedure and classroom pilot design that should constitute the next stage of research on the EMSF-FDC. This explicit acknowledgement is intended to align the paper's claims with the empirical evidence currently available, in line with the standards of accountable scholarship in curriculum and design education research.

RESULTS

Ranking of Food-grade Waste Materials

Application of the four-stage data analysis procedure described in Section 3.5 produced a clear comparative ranking of food-grade waste materials by their composite indicative score. Pineapple leaf fibre (PALF) recorded the highest composite score, equivalent to approximately 30 per cent on the scaled comparative metric. Banana fibre followed at approximately 20 per cent, and citrus or fruit-derived fibre at approximately 17 per cent. Hybrid blends combining food-grade fibres with synthetic materials produced variable composite scores depending on blend ratio and intended garment application, and are therefore reported as a context-dependent category rather than a single ranked value.

Within the survey component, the four items measuring perceived textile suitability of PALF returned combined Agree/Strongly Agree response rates ranging from 64 to 78 per cent across items, while equivalent items for banana fibre returned rates ranging from 51 to 63 per cent, and citrus fibre items from 42 to 55 per cent. Within the secondary data component, Malaysian agricultural waste documentation confirmed pineapple cultivation in Johor and Sarawak as the largest readily accessible food-grade fibre stream, with banana cultivation distributed across multiple states providing the second largest stream. Citrus and other fruit-derived sources were comparatively less consolidated within domestic waste streams, but were strongly represented in international peer-reviewed textile research as a viable experimental fibre category.

Table 1

Composite Indicative Ranking of Food-grade Waste Materials by Availability and Textile Suitability

Category	Composite Indicative Score (%)	Key Textile Properties	Curriculum Application
Pineapple Leaf Fibre (PALF)	≈30%	Fine, lustrous, silk-like drape; high tensile strength; excellent digital printability	Pattern drafting, weave studies, print media design
Banana Fibre	≈20%	Strong, moisture-absorbent; suitable for yarn spinning and polyester blending	Fibre science, garment construction, blend fabric units
Citrus / Fruit-Derived Fibre	≈17%	Cellulosic, smooth surface, silky finish; compatible with natural dyeing	Experimental design, innovation and research projects
Hybrid Blends (Food-grade + Synthetic)	Variable	Combined structural and print-ready surface; improved wash durability	Studio production, portfolio collections, industry-linked projects

Note. Composite indicative scores combine respondent perception data (60% weighting) and secondary agricultural waste / peer-reviewed textile research (40% weighting), as detailed in Section 3.5. Values are indicative comparative rankings and not precise statistical estimates.

Material Attributes and Design Compatibility

Frequency analysis of respondent preference items showed that cotton-like tactile characteristics were the most preferred fabric quality at 69 per cent, followed by polyester-like properties at 16 per cent and lycra-like properties at 14 per cent. Within the documentary analysis component, banana-polyester blends were observed to closely approximate the hand-feel of cotton when subjected to mechanical finishing treatments. Digital printing on blended food-grade fabrics received the highest acceptability ratings within the relevant survey items, with abstract and pastel-toned surface patterns achieving the strongest positive evaluation responses.

Within the garment category items, blouse and dress silhouettes were reported as the most frequently purchased and preferred clothing categories, at 38 per cent and 36 per cent respectively. These results are presented in Section 4 as descriptive findings; their pedagogical and curricular implications are discussed in Section 5.

DISCUSSION

Implications of Material Rankings for Curriculum Design

The dominance of PALF in the composite ranking has direct implications for the sequencing of eco-material content within fashion design programmes. Read in light of Hassan et al. (2022), who demonstrated that purposefully designed teaching tools enhance learner engagement, and Wardi et al. (2025a), who identified the value of structured scaffolding for Generation Z creative learners, the high composite score of PALF positions this fibre as a pedagogically appropriate entry point for introductory eco-material units. PALF combines high respondent endorsement, well-documented technical viability in international research (Sadravi et al., 2020), and confirmed agricultural availability within Malaysia, three conditions that together support its use as the first material profiled in a structured curriculum sequence.

Banana fibre, with its lower but still substantial composite score and complementary structural properties, fits better with intermediate units focused on yarn spinning, blending, and garment construction. This sequencing is consistent with the team-based learning principles discussed by Wardi et al. (2025b), which emphasise progressive skill development through collaborative prototyping. Citrus and fruit-derived fibre, with its lower composite score but strong international research representation, is best positioned within experimental design and innovation units where the pedagogical objective is exploration rather than production reliability.

Bridging Conventional Material Familiarity and Eco-Material Adoption

The strong respondent preference for cotton-like tactile characteristics (69 per cent) is not merely a descriptive finding; it represents a pedagogical challenge that any eco-material curriculum must address explicitly. Fletcher (2008) and Gwilt (2014) have argued that sustainable fashion education frequently encounters resistance not at the level of environmental values but at the level of sensory and aesthetic expectation. The finding that banana-polyester blends approximate the cotton hand-feel when mechanically finished provides a pragmatic curricular response to this challenge: rather than positioning eco-materials as a wholesale replacement for familiar fabrics, the curriculum can introduce them through hybrid blends that preserve sensory continuity while progressively introducing sustainable content.

This bridging strategy aligns with the visual-spatial and sensory engagement findings of Hassan et al. (2024a, 2024b), which underscore that deep learning in creative disciplines depends on multimodal sensory engagement. The integration of digital printing on blended food-grade fabrics, which received the strongest positive responses in this study, offers a further bridging opportunity by linking new material literacy to existing competencies in surface design that students typically acquire through conventional textile units.

Positioning EMSF-FDC Against Existing Frameworks

The discussion above clarifies the distinct contribution of EMSF-FDC relative to the frameworks reviewed in Section 2.4. Industry sustainability indices such as Higg MSI provide quantitative environmental impact data but do not specify how this knowledge should enter the design studio. Pedagogical sustainability literature articulates broad principles but does not connect them to specific local waste streams. EMSF-FDC occupies the intermediate space between these contributions by translating ranked material data into curriculum-aligned learning activities. The findings of the present study should therefore be interpreted as supporting the conceptual feasibility of EMSF-FDC, not as confirming its pedagogical effectiveness, which remains a question for subsequent empirical investigation as set out in Sections 6.3 and 7.

THE ECO-MATERIAL SELECTION FRAMEWORK FOR FASHION DESIGN CURRICULUM (EMSF-FDC)

Framework Overview

The EMSF-FDC framework was developed based on triangulated findings from the quantitative survey (Section 3.5), documentary analysis of eco-material prototypes (Section 3.6), and the critical literature synthesis (Section 2.4). The framework is presented as a conceptual three-layer model intended to function simultaneously as a pedagogical guide for educators delivering eco-material content and as a material decision-making tool for students and curriculum developers selecting sustainable fabric alternatives for design projects. It is structured across three interdependent layers: Material Profile, Curriculum Alignment, and Design Output.

Figure 2
Eco-Material Selection Framework for Fashion Design Curriculum (EMSF-FDC)

ECO-MATERIAL SELECTION FRAMEWORK FOR FASHION DESIGN CURRICULUM (EMSF-FDC)

Conceptual model derived from survey, documentary analysis, and eco-material case studies. Pedagogical and decision-making guide.

LAYER 1: MATERIAL PROFILE	LAYER 2: CURRICULUM ALIGNMENT	LAYER 3: DESIGN OUTPUT
Pineapple (PALF) ≈30%	Eco-Material Literacy	Printed Apparel
Banana Fibre ≈20%	Sustainability Studies	Wearable Eco-Fashion
Citrus / Fruit Fibre ≈17%	Fibre Science Units	Sustainable Collections
Waste source identification	Design Studio Units	Mini Skirt
Fibre extraction methods	Research Methods	Crop Top
Material property testing	Portfolio Development	Blouse
Design limitation analysis	SDG12-aligned Assessment	Shift Dress
		Hybrid Blend Garments
Durability, comfort	Assessment criteria aligned with	Market-positioned between
Tactile quality	SDG4 and SDG12	contemporary design and quality
Wash performance	Industry-standard evaluation	Eco-brand identity
Digital printability	Peer and jury review	

Dual Function: PEDAGOGICAL GUIDE (teaching tool for educators) and MATERIAL DECISION-MAKING TOOL (guide for sustainable fabric selection)

Layer Descriptions

Layer 1, the Material Profile, requires students and educators to systematically document the source, estimated availability, extraction method, fibre properties, and design limitations of each food-grade material under consideration. The dominance of PALF in the composite ranking (approximately 30 per cent) positions this fibre as the recommended starting material for Layer 1 profiling activities in Malaysian design programmes, providing a locally relevant and commercially viable entry point into eco-material learning.

Layer 2, Curriculum Alignment, maps food-grade material knowledge onto specific course outcomes, studio units, and assessment criteria within the fashion design programme. The findings discussed in Section 5 indicate that this layer is most effectively implemented through collaboration between fabric science units and studio design courses, enabling students to apply material knowledge directly within garment production contexts. Alignment with SDG 4 and SDG 12 provides an internationally recognised framework for articulating learning outcomes and programme sustainability commitments.

Layer 3, Design Output, focuses on the garments and collections produced through eco-material design projects, ensuring that studio outputs demonstrate market viability, aesthetic competence, and sustainable material application simultaneously. Hassan et al. (2024c) emphasised the importance of community-relevant and contextually grounded design outcomes for fostering authentic and sustained learner engagement. This principle is embedded in the framework's positioning of eco-material garment outputs within the competitive Malaysian fashion market, ensuring that student work carries commercial and pedagogical value.

Critical Discussion of the Framework's Conceptual Status and Limitations

Consistent with the methodological transparency commitments stated in Section 3.7, this section provides an explicit critical discussion of the EMSF-FDC framework's present conceptual status and the limitations that follow from this status.

First, the framework is grounded in respondent perception data rather than in classroom implementation data. While the survey responses, drawn from informed fashion design students, educators, and industry practitioners, provide a defensible foundation for an initial conceptual model, perception data cannot substitute for evidence of how the framework performs when used as a teaching instrument. The pedagogical effectiveness of EMSF-FDC,

including its impact on student eco-material competency, learning engagement, and design output quality, therefore remains an empirical question that this paper does not answer.

Second, the framework has not yet been subjected to formal expert validation through procedures such as a Content Validity Index (CVI), Delphi review, or structured rating panel involving fashion design educators and curriculum developers. Such expert validation would establish the face validity and content validity of the three layers, the appropriateness of the suggested studio unit alignments, and the practical feasibility of the suggested assessment criteria. The absence of this validation step is a recognised boundary of the present contribution and is not compensated for by triangulating survey, documentary, and literature evidence.

Third, the curriculum alignment proposals in Layer 2 are grounded in the broader Malaysian higher education context but have not been mapped against the specific course outcome statements of any single institution. Translating EMSF-FDC into a deployable curriculum tool will require institution-level adaptation, including alignment with each programme's existing learning outcomes, assessment regulations, and accreditation requirements.

Fourth, the framework treats the three identified materials (PALF, banana, citrus) as the primary teaching focus based on the findings of this study. Future iterations may need to incorporate additional locally available food-grade fibres as new agricultural waste streams are documented or as advances in fibre extraction technology expand the viable material pool.

These limitations are reported here as scholarly transparency rather than as residual weaknesses. They define the validation roadmap presented in Section 7 and identify clear, actionable directions for the next stage of research on EMSF-FDC.

CONCLUSION

Summary of Findings

The present research has identified pineapple leaf fibre, banana fibre, and citrus-derived fibre as the three primary food-grade waste categories with the strongest indicative potential for application in Malaysian fashion design education, based on combined survey-perception and secondary-data evidence. The dominance of PALF in the composite ranking suggests that curriculum frameworks may reasonably position this fibre as the primary eco-material candidate for introductory sustainable design units. Meanwhile, banana fibre and citrus-derived fibre serve complementary roles in intermediate and experimental studio activities.

This study contributes the EMSF-FDC as a structured eco-material selection framework tailored for Malaysian fashion design curriculum, responding to the documented gap in systematic material selection models in sustainable design education. The framework is positioned as a conceptual contribution functioning simultaneously as a pedagogical guide and as a material decision-making tool, with practical relevance for educators, curriculum developers, and institutional policymakers, contingent on subsequent empirical validation.

Limitations and Their Implications for Validity

Four specific limitations bound the validity of the present findings, each with concrete implications for how the results should be interpreted and applied.

First, the sample size of 100 respondents, while sufficient for the exploratory cross-sectional design adopted here and sampled purposively from informed populations, restricts the statistical generalisability of the rankings to the broader population of Malaysian fashion design educators and students. The composite percentages reported should therefore be read as indicative of the study sample rather than as nationally representative estimates. Replication with larger and probability-based samples is required before the rankings can be claimed to reflect the wider Malaysian fashion design education community.

Second, the ranking procedure relies on a 60/40 weighted integration of perception data and secondary data. Although this composite weighting was selected to reflect the study's primary focus on respondent-informed curriculum design (Section 3.5), the choice of weighting ratio is itself a methodological decision that influences

the resulting percentages. Sensitivity analysis using alternative weightings (for example, 50/50 or 40/60) was beyond the scope of this paper and represents a useful direction for methodological refinement in future studies.

Third, the EMSF-FDC framework is at present a conceptual model. As detailed in Section 6.3, it has not been subjected to expert validation procedures or classroom pilot implementation. Claims regarding its practical effectiveness as a teaching instrument or its impact on student competency development cannot therefore be made based on the data reported here. The pedagogical claims advanced in this paper are accordingly framed as feasibility-supported propositions rather than as empirically demonstrated outcomes.

Fourth, the study is geographically and contextually bounded to Malaysian higher education and to the food-grade waste streams currently dominant in Malaysian agriculture. Direct transposition of the framework to other national contexts, such as Indonesia, the Philippines, or Vietnam, would require local adaptation of both the material rankings and the curriculum alignment proposals.

Specific Directions for Future Research

The limitations detailed above translate into a concrete research roadmap. Four interconnected research activities are identified as priorities for the next stage of work on EMSF-FDC.

Activity 1: Expert validation through CVI or modified Delphi procedure. A panel of 8 to 12 fashion design educators, sustainable textile researchers, and industry practitioners should be convened to rate each component of the framework on relevance, clarity, and feasibility, producing a Content Validity Index value for each layer and for the framework as a whole. This activity directly addresses the conceptual-status limitation discussed in Section 6.3.

Activity 2: Classroom pilot implementation with measurable competency outcomes. The framework should be deployed in a single fashion design programme over one or two semesters, with pre-test and post-test measurement of student eco-material competency using a validated competency instrument. Comparison with a control or pre-implementation cohort would generate the first empirical evidence of pedagogical effectiveness.

Activity 3: Multi-institutional replication. Following successful single-site piloting, replication across multiple Malaysian universities offering fashion design programmes would test the framework's adaptability and produce comparative competency outcome data.

Activity 4: Industry-academia collaboration with agricultural waste producers. Direct collaboration between fashion design programmes and Malaysian pineapple, banana, and citrus producers would secure consistent fibre supply for studio teaching, generate authentic studio-to-market design pathways, and produce empirical evidence on the commercial viability of student-designed eco-material garments.

Together, these activities define a measurable validation programme for EMSF-FDC and a defensible pathway from the present conceptual contribution to an empirically grounded curriculum tool. The framework offered in this paper should therefore be understood as an evidence-informed starting point for that programme of work, rather than as its conclusion.

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