Standards for Sustainable Packaging Materials of Egyptian Black Honey Product: A Green Industry Approach

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Abstract

This study focuses on developing standards for choosing sustainable packaging materials for Egyptian black honey to support the circular economy and enhance the ability to market locally and internationally. Eco-friendly packaging materials that balance cost-effectiveness and product preservation are crucial to raising global awareness of environmental sustainability. The research aims to develop a comprehensive set of methodologies to help packaging designers choose sustainable packaging materials to improve product quality, reduce waste, and support the global marketing of Egyptian black honey. A descriptive analytical methodology was used to evaluate the characteristics of four primary packaging materials for Egyptian black honey (Glass, Tin, Tetra Pak, and PET), the environmental impact, and the design for the recycling methodologies. The researcher used comparative analysis to analyze the final results of the evaluations and comparisons. The results indicate that Tetra Pak is the first suitable option that balances between sustainability and product preservation. Then, followed by glass, which excels in protecting product quality but faces challenges due to its weight and fragility. Tin is highly recyclable but may have chemical interactions under certain conditions, while PET is versatile but less environmentally sustainable. Recommendations include adopting Tetra Pak packaging, optimizing its design for Egyptian black honey, and developing and implementing a green industry approach to reduce waste and promote the reuse and recycling of packaging materials. Stakeholders should also focus on applying international standards such as ISO 18604 and FSSC22000, raising consumer awareness, and conducting further research to refine packaging materials for export readiness.

Keywords:

Egyptian Black Honey – Sustainable Packaging Materials – Green Industry – Design for Recycling – Environmental Impacts

الملخص:

تركز هذه الورقة البحثية على تطوير معايير لاختيار مواد التعبئة المستدامة لمنتج العسل الأسود المصري، لدعم الاقتصاد الدائري المصري وبما يتوافق مع خطة التنمية المستدامة المصرية 2030 وتعزيز القدرة على تسويق منتج العسل الأسود المصري محليًا ودوليًا. وتعتبر مواد التغليف الصديقة للبيئة التي توازن بين التكلفة الفعالة والحفاظ على المنتج ضرورية لزيادة الوعي العالمي بالاستدامة البيئية. وتهدف الورقة البحثية إلى تطوير مجموعة شاملة من المنهجيات لمساعدة مصممي التغليف في اختيار خامات التغليف المستدامة لتحسين جودة منتج العسل الأسود، وتقليل فاقد المنتج النهائي، ودعم التسويق العالمي للعسل الأسود المصري. وقد تم استخدام المنهج التحليلي الوصفي لتقييم خصائص أربعة من خامات التغليف الرئيسية لمنتج العسل الأسود المصري وهم (الزجاج، الصفيح، تيترا باك، وPET)، وتأثيرها البيئي، واستخدام منهجية التصميم من أجل إعادة التدوير. وقد استخدم الباحث التحليل المقارن لتحليل النتائج النهائية للتقييمات والمقارنات. وقد تم التوصل لعدة

نتائج منها أن خامة تيترا باك توفر أفضل توازن بين الاستدامة والحفاظ على المنتج، يليها خامة الزجاج الذي يتفوق في حماية جودة المنتج ولكنه يواجه تحديات بسبب وزنه وهشاشته. أما الصفيح فهو قابل لإعادة التدوير بنسبة كبيرة ولكنه قد يتفاعل كيميائيًا مع منتج العسل الأسود تحت ظروف معينة، بينما خامة البلاستيك PET متعدد الاستخدامات ولكنها أقلهم من حيث الإستدامة البيئية. ويوصي الباحث باعتماد خامة تيترا باك لتغليف وتعبئة العسل الأسود، واجراء تحسينات في التصميم البنائي، وتطوير وتنفيذ مدخل صناعي أخضر لتقليل فاقد المنتج وتعزيز إعادة استخدام وتدوير خامات التغليف. ويجب على أصحاب المصلحة أيضًا التركيز على تطبيق المعايير الدولية مثل ISO 18604 وFSSC22000، وزيادة وعي المستهلك، وإجراء المزيد من الأبحاث لتحسين خامات التغليف المستخدمة لزيادة فرص تصدير المنتج.

الكلمات المفتاحية:
العسل الأسود المصري، خامات التغليف المستدامة ، الصناعة الخضراء، التصميم لإعادة التدوير ، التأثيرات البيئية

Introduction

To guarantee quality and market competitiveness against global environmental concerns, Egyptian black honey needs sustainable packaging. Packaging waste creates major problems in Egypt, where just 12% of municipal solid waste is recycled and 81% is discarded in open dumps (El-Halwagi, & Others, 2022). Sustainable packaging for Egyptian black honey is critical to reducing environmental impact. National policies, such as the Waste Management Law of 2020 and Egypt Vision 2030, aim to increase recycling rates to 25% by 2030 (Hemidat & Others, 2022), yet the current 3% recycling rate for plastics underscores the need for innovative packaging solutions (Back to Blue Initiative, 2022). This paper addresses these problems by creating appropriate sustainable packaging standards for Egypt's infrastructure and market needs. Egyptian black honey is a good product that requires a sustainable packaging system to maintain its quality, shelf life, and to meet the importing standards. As global awareness of environmental issues grows, the shift towards sustainable packaging has become inescapable. Sustainable packaging is a revolutionary idea using eco-friendly, resource-efficient, and socially responsible materials and processes. This means designing for minimalism will reduce the material quantities, and using manufacturing methods that will lead to saving water and reducing energy, and using renewable, recyclable, or biodegradable materials (ECI, 2023). These concepts help sustainable packaging to reduce resource use and environmental impact, thereby enhancing product marketability. This study intends to develop sustainable criteria for choosing materials for packaging Egyptian black honey to support the green sector, meet the rising consumer demand for environmentally friendly products, and investigate the possibility of exporting black honey abroad. (David Feber & others, 2023)

The Research Problem:

The absence of sustainable packaging standards for Egyptian black honey packaging materials and low consumer awareness of sustainable practices may hinder the maintenance of its quality, shelf life, and competitiveness in domestic and international markets.

Research Aim:

Develop a set of methodologies for using sustainable materials in the packaging of Egyptian black honey to support the green industry by enhancing quality maintenance, reducing waste,

conserving resources, increasing shelf life, and improving marketability domestically and globally.

The Importance of the Research:

Developing methodologies for choosing the sustainable materials used in packaging black Egyptian honey can help reduce waste, conserve resources, increase shelf life, improve handling and storage, and enhance the product's marketability domestically and globally by addressing consumer demand for environmentally conscious products.

The Research Methodology:

The researcher used the descriptive analytical approach to choose the sustainable packaging materials for Egyptian black honey by collecting and analyzing data on different packaging materials, comparing their properties, and then applying the methodologies of their environmental impacts, and designing for recycling to enhance the green industry.

1- Applying the Research Methodology

This study investigates three novel ways (depicted in Fig. 1) to establish recommendations and criteria for sustainable packaging materials tailored for Egyptian black honey. Initially, the researcher examined the fundamental characteristics of diverse materials such as glass, tin, PET, and Tetra Pak. (Ismail, 2024) Therefore, the researcher emphasized their barriers mechanical, chemical, and thermal properties to achieve an optimal equilibrium between product protection and environmental responsibility. According to Varžinskas and Milčius, sustainable packaging must be designed, produced, utilized, and disposed of according to the principles of sustainable development.

Moreover, the methodology for assessing environmental impacts evaluates the main factors, such as energy use, waste production, carbon footprint, and global warming potential. Then, applying and implementing the Design for Recycling (DFR) from the beginning, through material selection, disassembly facilitation, and contamination mitigation to guarantee that packaging aligns with sustainability and supports the green industry. Marques Sastre et al. highlight that sustainable packaging contributes to minimizing the ecological footprint of companies and saving their resources.

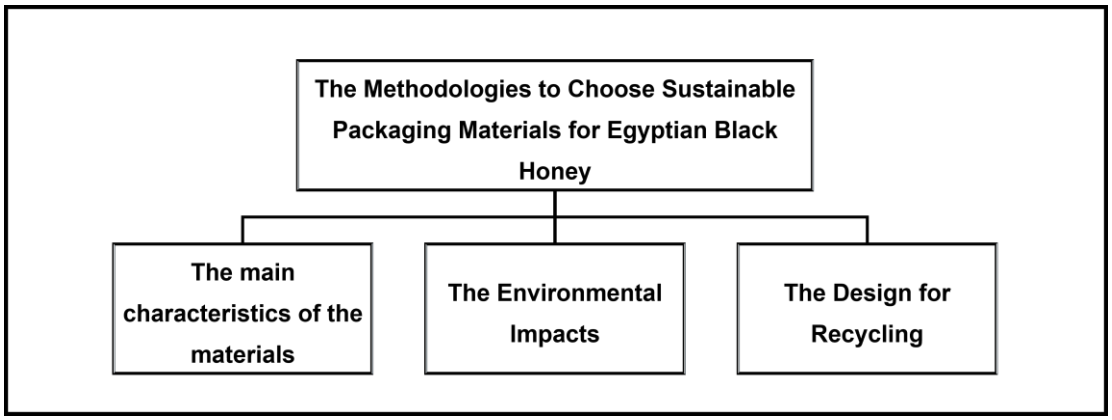

FIGURE 1: METHODOLOGIES TO CHOOSE THE SUSTAINABLE PACKAGING MATERIALS FOR EGYPTIAN BLACK HONEY

2- The main characteristics of the packaging of Egyptian black honey materials:

The main characteristics of packaging materials are important for protecting products and ensuring their quality. Therefore, understanding the physical and chemical properties is fundamental for selecting the appropriate materials to resist various environmental conditions and interactions with the product. (Jayan, H., 2018) This holistic approach to material selection improves product performance and contributes significantly to sustainability by reducing waste and improving recyclability. (Lee, 2011) Accordingly, the following basic packaging materials are used to package Egyptian black honey made from sugarcane are Tetra Pak, Glass, Tin, and PET. The researcher makes a comparison between the four materials in the main physical and chemical properties, such as Barrier, Mechanical, Chemical, Thermal, and Physical Properties.

2-1 Comparing the main characteristics of the materials used in packaging Egyptian black honey:

As shown in Table 1 highlights the comparison of Packaging Materials for Egyptian Black Honey products for evaluating key properties, including Barrier Properties, Mechanical Properties, Chemical Properties, Thermal Properties, Physical Properties, and Preservation Properties.

TABLE 1 COMPARISON OF PROPERTIES FOR GLASS, PET, TIN, AND TETRA PAK PACKAGING MATERIALS

SOURCES (NILESH CHAUDHARY, 2020), (THE FSG TEAM, 2021), (KATA GALIĆ, 2025), (GREEN WHALE, 2022), (VAHIT ILHAN, 2024), (JIMMY A. SHAH, 2021), (TETRA PAK, 2025), (RONAN FARRELL ET AL., 2023), (IDOWU D. IBRAHIM ET AL., 2022), (INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, 2007), (MARK J. KIRWAN, 2013), (KENNETH MARSH, 2007), (AINARA SANGRONIZ ET AL., 2019), (VALENTINA SIRACUSA, 2011), (KIT L. YAM, 2009), (SHAH, JIMMY A., 2021).

No.	Property/ Material	Glass	PET	Tin	Tetra Pak
1	**Barrier Properties**				
1.1	**Gas and Moisture Barrier**	Non-permeable	Moderately permeable; enhanced by coextrusion with EVOH	Non-permeable	Non-permeable
1.2	**Carbon Dioxide Barrier (Permeation, $cm^3/m^2/day$)**	0.0001	15	0.0001	0.5
1.3	**Impermeability**	Yes	No, enhanced by barrier layers	Yes	Yes
2	**Mechanical Properties**				
2.1	**Break or Tear Resistance**	Easy to break	Very strong	Impact resistant	Tear resistant but susceptible to punctures

2.2	**Durability**	High	High	High	High, due to PE layers
2.3	**Corrosion Resistance**	-	-	Corrosion resistant when coated; may corrode if uncoated.	-
3	**Chemical Properties**				
3.1	**Chemical Interaction**	Chemically inert	Occurs at high storage temperatures	May occur	Does not occur
3.2	**Non-Reactivity**	Yes	Yes	Yes	Yes
4	**Thermal Properties**				
4.1	**Thermal Stability**	High temperature resistant	Moderate; deforms above 80°C	Strong thermal stability	Strong thermal stability
4.2	**Thermal Sterilization**	Yes	Yes	Yes	Yes
5	**Physical Properties**				
5.1	**Water Absorbance (%)**	0	0.1–0.2	0	0.01 - Low; paperboard absorbs water if not sealed
5.2	**Color**	None	Colored on demand	Silver	White
5.3	**Transparency (Clarity)**	Excellent	Excellent	Opaque	Opaque
5.4	**Lightweight**	Heavy	Light	Light	Light
5.5	**Flexible**	No	Yes	No	Yes
5.6	**Rigid**	Yes	Yes	Yes	No
6	**Preservation Properties**				
6.1	**Preservation of Taste, Color, and Aroma**	Yes	Yes	Affected by high storage temperatures	Yes

Analyzing the findings of the previous comparison of the characteristics of the materials used in packaging Egyptian black honey, the researcher found that the materials can be arranged as follows:

- **Tetra Pak** is the most balanced option, offering excellent preservation and sustainability. Making it an excellent choice for packaging Egyptian black honey.
- **Glass** is a close second, with superior preservation qualities but higher environmental costs due to its weight and fragility.
- **Tin** provides strong mechanical properties but has potential chemical interactions and environmental concerns. However, its preservation properties are affected by high storage temperatures, which can impact the quality of the product.
- **PET** is durable and lightweight, but has lower recycling rates and potential chemical interactions, making it a practical option for packaging Egyptian black honey

3- The Environmental Impacts of the Packaging Materials for the Egyptian Black Honey

Choosing packaging materials requires a major focus on environmental sustainability. Different factors help one to evaluate how packaging affects the environment, including:

Energy Consumption: Energy use is the energy needed to manufacture, move, and dispose of packaging materials. High energy input materials increase environmental damage more (Stramarkou et al., 2021).

Recycling Rates: Recycling rates show how much of the packaging materials can be recycled and reused. (Simon & Others, 2016). Higher recycling rates support a circular economy by lowering the demand for virgin materials and cutting waste. (Back to Blue Project, 2022)

Waste Generation: Waste generation refers to the amount of packaging waste generated during manufacturing, distribution, and consumption. Materials that generate less waste or are biodegradable contribute to reducing the overall environmental burden. (Yadav et al., 2024)

Carbon Footprint: The carbon footprint of packaging materials is a measure of the greenhouse gas emissions, especially carbon dioxide, produced during their life cycle. Materials with a lower carbon footprint contribute less to climate change. (Anaya, 2022)

End-of-Life Options: End-of-life options are how packaging materials can be handled after use, including recycling, composting, or landfill disposal, which help sustainable end-of-life solutions reduce environmental effects. (Green Whale, 2022)

Effects on Product Quality: Packaging material selection can affect the quality and integrity of the packed product. Overall, sustainability is supported by materials that protect product safety, prevent contamination, and help preserve the product's freshness to be preserved. (Turner, 2020)

Global Warming Potential (GWP): It measures the impact of packaging materials on global warming and climate change. Materials with a high GWP contribute more to the greenhouse effect and should be minimized in favor of more sustainable alternatives. (Quist, 2024)

Overall sustainability: Examining the sustainability of packaging materials from a holistic perspective, including their environmental, social, and economic effects. Sustainable materials should be economically feasible, socially responsible, and environmentally friendly. (Bassi & Others, 2022)

3.1 Comparison of Environmental Impact Statistics of the Packaging Materials for the Egyptian Black Honey

THE RESEARCHER ASSESSED THE ENVIRONMENTAL IMPACT OF EACH PACKAGING MATERIAL APPROVED FOR EGYPTIAN BLACK HONEY AND CONDUCTED A COMPARATIVE ANALYSIS, AS SHOWN IN TABLE 2, TO ARRANGE THESE MATERIALS BASED ON THEIR ENVIRONMENTAL IMPACT FACTORS AND ADHERENCE TO INTERNATIONAL ENVIRONMENTAL STANDARDS.

TABLE 2 - COMPARISON OF ENVIRONMENTAL IMPACT STATISTICS FOR GLASS, TETRA PAK, TIN, AND PET MATERIALS FOR PACKAGING THE EGYPTIAN BLACK HONEY - IT IS IMPORTANT TO NOTE THAT SOME DATA MAY VARY BY REGION.

Sources (Simon et al., others, 2016), (Tetra Pak, 2023), (Stramarkou, & others, 2021), (M., (Bassi et al., 2022), (Brock and Williams, others, 2020), (Vignali, 2016), (Yadav et al., others, 2024), (Green Whale, 2022), (Anaya, 2022), (Turner, 2020), (Quist, 2024).

Criteria	Glass	Tetra Pak	Tin	PET
Energy Consumption	15-20 MJ per kg	6.67–10 MJ per kg	10-15 MJ per kg	5-7 MJ per kg

Recycling Rate	33% globally	26% globally	84-85.5% (recent figures) globally	29% globally
Waste Generation	5% of total municipal solid waste	Less than 1% of total municipal solid waste - Not closed loop, often ends in landfill or incinerator, lots in the waste stream	7% of total municipal solid waste	40% of non-recycled bottles end up in the environment, breaking down into microplastics over 450 years
Carbon Footprint	500-760 g CO2e/liter	77-103 g CO2e/liter	200-300 g CO2e/liter	350 g CO2e/liter (virgin PET)
End-of-Life	It can be reused multiple times, reducing the need for new raw materials	Often ends up in landfills if not properly recycled	Can be recycled indefinitely without loss of quality	Often ends up in landfills or as litter if not properly recycled
Impact on Product Quality	Excellent barrier properties preserve quality well	Good barrier properties preserve quality well	Good barrier properties, preserve quality well	Good barrier properties, but the potential for chemical leaching
Global Warming Potential	High due to energy consumption	Lower climate impact compared to glass and PET	Moderate, better than glass in terms of recyclability	Lower than glass, but concerns about microplastics
Sustainability	High recyclability, but high energy use	Uses renewable materials, improving recycling	Good recyclability, moderate energy use, without quality loss	Lower energy use, but issues with microplastics and chemical leaching

3-2 The final classifications for the materials for packaging Egyptian black honey

The researcher arrived at these last classifications for the materials for packaging Egyptian black honey based on a comparative study of the environmental effects of the four packaging materials:

- **Energy Consumption:** Examining the energy use of several packaging materials reveals notable differences. According to Fig. 2, Glass has the highest energy consumption (17.50

MJ/kg), making it the least efficient despite its preservation benefits. Tin follows at 12.50 MJ/kg, with good recyclability but high energy use. Tetra Pak offers a balanced option at 8.50 MJ/kg, combining sustainability and function. PET consumes the least energy (6.00 MJ/kg). Though there are questions about recyclable materials and the tiny plastic particles' effect.

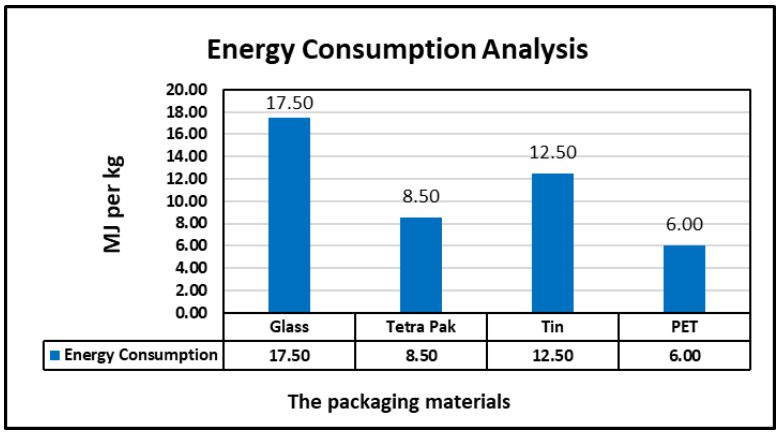

FIGURE 2 COMPARISON OF ENERGY CONSUMPTION OF THE PACKAGING MATERIALS FOR EGYPTIAN BLACK HONEY

- **Recycling Rate:** The researcher found that there are differences in the recycling rates of the four packaging materials. Tin is the most recyclable material, with the highest recycling rate of 85%, as shown in Fig. 3. Tetra Pak has the lowest recycling rate of all the materials taken into consideration, while glass and PET show moderate recycling rates.

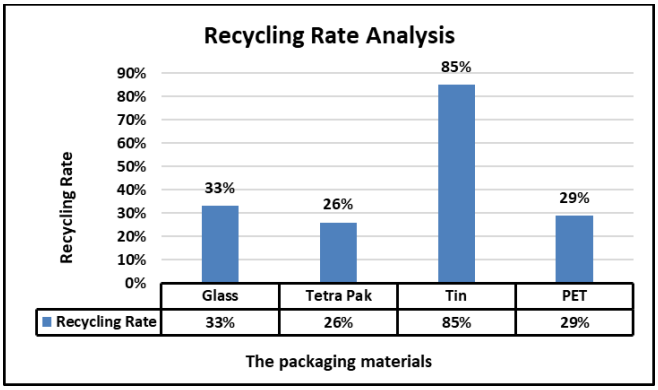

FIGURE 3 COMPARISON OF THE RECYCLING RATE OF THE PACKAGING MATERIALS FOR EGYPTIAN BLACK HONEY

- **Waste Generation:** It is the recycling rate to consider in the context of waste generation. According to Fig. 4, tin emerges as the most recyclable material with a recycling rate of 7%. Glass and PET have the highest recycling rates, but Tetra Pak has the lowest recycling rate among the materials analyzed.

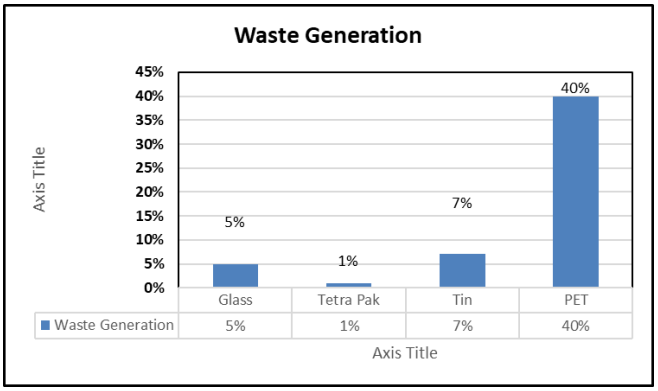

FIGURE 4 WASTE GENERATION COMPARISON OF PACKAGING MATERIALS FOR EGYPTIAN BLACK HONEY

- **Carbon Footprint:** When assessing the carbon footprint of various packaging materials, recycling rates are a significant consideration. According to Fig. 5, Glass stands out with the highest recycling rate at 630g CO2e/liter, making it the most recyclable material. Tin and PET have moderate recycling rates, while Tetra Pak has the lowest recycling rate among all materials.

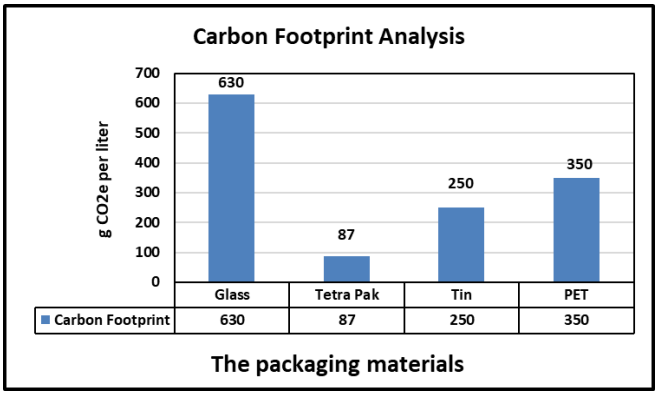

FIGURE 5: THE COMPARISON OF CARBON FOOTPRINT OF THE PACKAGING MATERIALS FOR EGYPTIAN BLACK HONEY

- **End-of-Life:** The end-of-life stage of packaging materials is rather important for their overall environmental impact. Though it usually winds up in landfills if not correctly recycled, glass may be reused several times, hence greatly lowering the need for new raw materials. Tetra Pak often ends up in landfills if not properly recycled because of its multi-material makeup. Tin is unique as it can be recycled endlessly without losing any quality. If not properly recycled, PET, like glass and Tetra Pak, usually ends up as trash or in landfills.
- **Impact on Product Quality:** Manufacturers must carefully evaluate how packing materials affect product quality. Glass preserves product quality very well by providing great barrier qualities. Tetra Pak keeps product quality well and has decent barrier qualities as well. Likewise, Tin guarantees the preservation of product quality with its excellent barrier qualities. Though it has decent barrier qualities, PET causes worries about possible chemical leakage into the product.
- **Global Warming Potential:** The global warming potential of packing materials is a key component of their environmental effect. Because of its great energy use, glass has a tremendous global warming potential. Compared to glass and PET, Tetra Pak has less

environmental impact. Tin is more recyclable than glass, hence it has a fair global warming potential. Though worries regarding microplastics exist, PET has less global warming potential than glass.

- **Sustainability:** While its manufacture uses great energy, glass has great recyclability. Tetra Pak makes use of sustainable materials, hence improving its recycling possibilities. Tin is fairly recyclable with modest energy usage. Though it struggles with microplastics and possible chemical leakage, PET uses less energy than glass.

As a conclusion to all the previous comparisons and analyses, the researcher recommended the following choices for packaging the Egyptian black honey:

- **Tetra Pak** is the best overall choice for packaging Egyptian black honey due to its low energy consumption, low carbon footprint, and minimal waste generation.
- **Tin** is the most recyclable option because it has the highest recycling rate and can be recycled forever.
- **PET and glass** consume more energy to produce and have higher carbon footprints, putting them behind Tetra Pak and tin.

4- Design for Recycling Methodology for Packaging Egyptian Black Honey

Design for Recycling (DFR) methodology involves creating packaging that can be easily collected, sorted, and recycled, minimizing environmental impact. DFR aims to make products and packaging easier to recycle by considering their end-of-life stage during the design process, ensuring compatibility with sorting and recycling technologies to achieve high-quality material recovery (ECR Austria, 2020).

The main principles of DFR (shown in Fig. 6) are:

- **Material Selection:** Choosing materials with less environmental impact.
- **Simplification:** Reducing the variety of materials used in a single product helps streamline the recycling process.
- **Ease of Disassembly:** They may be readily disassembled for recycling.
- **Minimizing Contaminants:** Avoid employing additives or products that might pollute the recycling stream.
- **Consumer Engagement:** Offering obvious labels and directions to help customers with the correct disposal.
- **Infrastructure Considerations:** Making sure packaging fits the current recycling system for best recovery. (Martínez Leal et al., 2020)

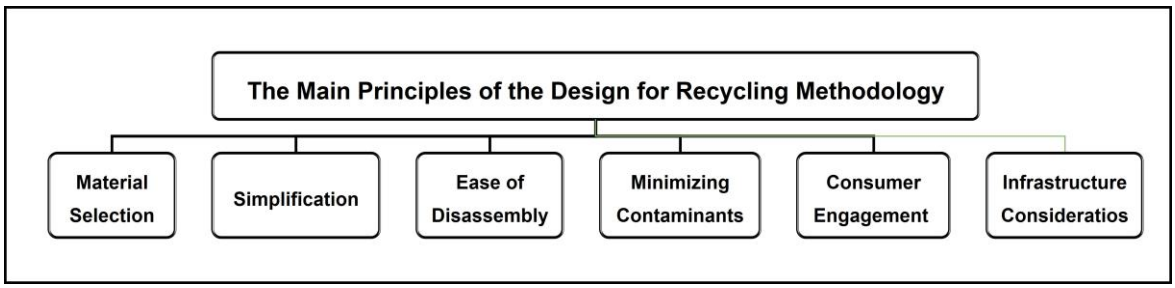

Figure 6 - The main principles of the design for Recycling Methodology

4-1 The main advantages of applying the design for recycling methodology

Using the design for recycling approach in packaging for Egyptian black honey products has many benefits. As shown in Fig. 7: It is reducing raw material utilization, saves resources, and decreases greenhouse gas emissions by reducing the demand for new manufacturing (Eco Design, 2024). By lowering manufacturing costs, this strategy also cuts expenditures (WPO, 2020). It also improves brand image as more people choose sustainable brands. Following sustainability rules helps businesses stay out of trouble and is considereds another advantage.

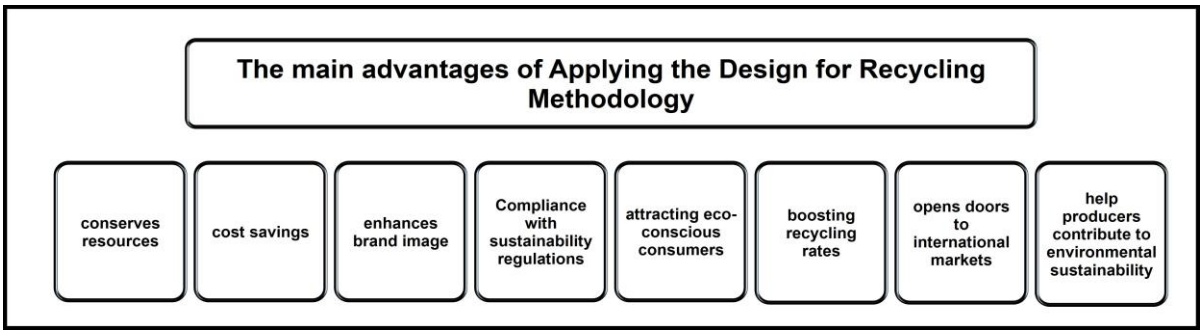

FIGURE 7 - THE MAIN ADVANTAGES OF APPLYING THE DESIGN FOR RECYCLING METHODOLOGY

By enabling consumers to recycle, sustainable packaging helps to distinguish businesses in the market, draws eco-conscious customers, and increases recycling rates. At last, it paves the way to foreign markets with rigorous sustainability criteria, hence offering fresh expansion prospects (Martínez Leal, 2020). These strategies support the manufacturers to support environmental sustainability and improve competitiveness (Nasr, 2024). Eventually, every material has its pros and cons of recyclability. The particular needs of the product and the existing recycling infrastructure will determine the material selection (Rousselle & Others, 2021).

4-2 Comparison of Packaging Materials-Based Applying DFR Principles

Comparing various packaging materials (Glass, tin, PET, and Tetra Pak) as shown in Table 3, across these factors based on applying DFR principles, supports understanding these aspects. Also, it helps in making informed decisions about the most suitable and sustainable packaging options.

TABLE 3 - COMPARISON OF PACKAGING MATERIALS-BASED APPLYING DFR PRINCIPLES

Sources (Farrell et al., others, 2023), (Sangroniz et al., others, 2019), (Simon et al., others, 2016), (Bassi et al., others, 2022), (Stramarkou et al., others, 2021), (Yadav et al., others, 2024), (Marsh and Bugusu, 2007), (Kirwan, 2013), (Turner, 2020), (Green Whale, 2022), (FSG Team, 2021), (Anaya, 2022), (Lewis et al., others, 2017), (Tencati et al., others, 2020), (Molina-Besch et al., others, 2019), (Hopewell et al., others, 2009), (Recycling Partnership, 2021), (Welle, 2011), (Cimpan et al., others, 2015), (Danish Plastics Federation 2023)

Factor	Glass	Tin (Steel)	Plastic (PET)	Tetra Pak
Material Selection	High-purity glass, recyclable in closed-loop systems with >80% recovery rates.	High-purity steel, recyclable in closed-loop systems with 90% recovery rates.	Mono-material PET, recyclable with 70% bottle-to-bottle efficiency.	Multi-layer composite, recyclable with 20–30% recovery rates in specialized facilities.

Simplification	Single-material design, avoiding coatings; compatible with glass-only streams.	Single-material design, avoiding non-recyclable coatings; compatible with magnetic sorting.	Mono-material PET, avoiding blends; compatible with PET-specific streams.	Multi-layer design, challenging to simplify; requires separate streams.
Ease of Disassembly	Easy to clean and sort	Easy to flatten	Easy to crush and sort, compatible with automated recycling systems.	Easy to flatten but requires specialized sorting for layer separation.
Minimizing Contaminants	Use water-soluble labels and removable adhesives to prevent residue.	Use recyclable coatings and removable adhesives to avoid contamination.	Use mono-material labels and water-soluble adhesives to enhance purity.	Use recyclable adhesives compatible with separation processes.
Consumer Engagement	Standardized recyclability labels, deposit system instructions, and QR codes for guidance.	Standardized recyclability labels, clear instructions, and consumer education campaigns.	Standardized recyclability labels, deposit system instructions, and digital recycling apps.	Clear recyclability labels with specialized instructions, and educational outreach for facility locations.
Infrastructure Considerations	Widely available, high-capacity sorting	Widely available, magnetic sorting	Bottle-specific streams, automated sorting	Limited to specialized facilities

4-3 Assessing Packaging Materials Through the Lens of DFR Principles:

The research indicates that effective DFR methods include material simplicity, strong recycling infrastructure to reduce environmental impact, Consumer Engagement, Consumer Behavior, and promote a circular economy (Recycling Partnership, 2021). Consequently, the researcher proposed the essential design for recycling. The factors to consider are:

- **The simplicity of materials:** Glass and tin are two unique materials that may be readily recycled owing to their uniform, single-layer composition. In contrast, the intricate, multi-faceted design of Tetra Pak containers needs specialized processing for recycling.
- **Infrastructure Requirements:** PET recycling thrives in advanced systems, but Tetra Pak's recyclability depends on dedicated facilities, often limited in regions like Egypt.
- **Consumer Engagement:** Clear labeling and simple designs enhance recycling rates for glass and tin, while complex packaging reduces consumer participation.
- **Consumer Behavior:** Address low awareness and participation (El-Bassiouny et al., 2015) by recommending clear eco-labeling on Tetra Pak, Glass, and Tin packaging, coupled with community-based education campaigns.
- **Circular Economy Integration:** Single-material packaging easily interacts with closed-loop systems, whereas composite materials need innovative disassembly solutions.
- **Environmental Trade-offs:** Glass offers limitless recyclability but entails significant transportation energy costs; PET's lightweight properties are offset by potential degradation and dependence on fossil fuels.
- **Implementing Stage:** DFR principles in Egypt require addressing the lack of mandatory source separation laws and insufficient consumer awareness, since recycling participation is hindered by illiteracy and limited infrastructure (Nassar & Others, 2023).
- **Enhancing customer engagement:** container designs should have clear eco-labeling and recycling instructions targeting Egypt's environmentally conscious consumer segment (El-Bassiouny et al., 2015).
- **Economic Constraints:** Mitigate financial obstacles by advocating for cost-effective DFR methodologies, such as streamlining Tetra Pak's multilayer configuration to decrease recycling expenses.

Furthermore, the researcher recommends using the main global standards to help ensure a comprehensive and environmentally responsible approach to eco-friendly packaging design, enhance consumer trust, facilitate global market access, and strengthen relationships with retailers and suppliers.

These standards include the following:

- **ISO 18604:2013:** Packaging and the environment–Material recycling. (ISO, 2013)
- **FSSC22000 (Food Safety System Certification Scheme):** FSSC 22000 V7 is a set of packaging standards that emphasize the importance of safe packaging in the food supply chain. It includes ISO 22000 for food safety management systems and ISO/TS 22002-4 for food packaging and materials. (FSSC Foundation, 2023)
- **BRCGS (Brand Reputation Compliance Global Standards) Packaging Materials:** BRCGS is a global quality and safety certification. It sets criteria for production, packaging, storage, and distribution to ensure product safety and quality. BRCGS helps companies demonstrate commitment to best practices and consumer safety. Earning a BRCGS packaging materials certification signals quality and trust, helping companies grow their global market presence. (BRCGS, 2024)

Conclusion:

- Sustainable packaging for Egyptian black honey products must balance product preservation, environmental impacts, and market competitiveness.
- Developed methodologies to select sustainable packaging materials, enhancing product quality, shelf life, and global marketability for Egyptian black honey.
- Tetra Pak is the most suitable packaging material for Egyptian black honey due to its many advantages, such as impermeability, durability, non-reactivity, thermal stability, and preservation properties. Moreover, it preserves taste, color, and aroma, making it an excellent choice for packaging.
- Glass has strong barrier properties and chemical inertness; nonetheless, its fragility and weight may pose challenges in handling and transportation.
- Tin has robust barrier properties and durability; nevertheless, high storage temperatures may degrade product quality over time.
- PET exhibits versatility and durability, along with superior preservation properties, making it an effective option for packaging Egyptian black honey.
- **Circular Economy Contribution:** Applying design concepts of the design for Recycling to lower the environmental impact helps to enhance the circular economy in Egypt by complementing its objectives.
- Continuous research and development in sustainable packaging materials for Egyptian black honey are essential to address evolving environmental challenges, the global market, and consumer expectations.

Results:

The comparative analysis of packaging materials for Egyptian black honey reveals distinct environmental and functional profiles:

- Tetra Pak: Emerges as the most sustainable option, with the lowest energy consumption (8.5 MJ/kg), moderate carbon footprint, and effective barrier properties for product preservation. Its multilayer structure, while complex, supports sustainability through renewable materials and potential waste-to-energy applications, though specialized recycling facilities are required.
- Tin: Offers the highest recycling rate (70%), enabling indefinite recyclability without quality loss, making it ideal for circular economy integration. However, potential chemical interactions at high storage temperatures slightly impact its suitability for black honey.
- Glass: Excels in product quality preservation due to superior barrier properties but is hindered by high energy consumption (17.5 MJ/kg), significant weight, and fragility, increasing transport-related emissions. Its recyclability is high but limited by Egypt's infrastructure.
- PET: Provides durability and lightweight properties but has a lower recycling rate (moderate in Egypt at 3% for plastics) and risks chemical leaching, making it the least sustainable option despite cost-effectiveness.
- The environmental impact assessment, supported by DFR principles, indicates that Tetra Pak and Tin align best with Egypt's Vision 2030 goals, while Glass and PET face challenges due to energy demands and recycling limitations.

- These findings underscore the need for infrastructure improvements and consumer engagement to enhance recycling efficacy for the Egyptian black honey product in Egypt.
- Investigate consumer preferences and perceptions regarding sustainable packaging for the Egyptian black honey to better understand market demands and opportunities for eco-friendly packaging solutions.

Recommendations:

- Packaging designers are advised to prioritize Tetra Pak as the primary packaging material for Egyptian black honey due to its exceptional properties and performance.
- Stakeholders are encouraged to allocate resources for further research focusing on optimizing Tetra Pak for black honey packaging, including viscosity of the black honey adjustments to enhance user-friendliness and product compatibility.
- Collaboration with recycling facilities is essential to ensure proper disposal and recycling of packaging materials, aligning with the principles of a green economy.
- Increase consumer awareness and engagement through educational initiatives and campaigns that encourage sustainable waste disposal practices. Clear labeling on packaging aids consumers in making informed choices about recycling.
- Alignment with International Standards will ensure Compliance with global sustainability standards, such as ISO 18604, FSSC22000, and BRCGS, ensuring quality and environmental responsibility in packaging practices. Partnerships with international organizations support continuous improvement.
- Support for Policy Development and Research through introducing policies that incentivize sustainable packaging practices and investing in research, which drives innovation in material design and recycling technologies. Continuous refinement of packaging materials enhances their suitability for international markets.
- Authorities are advised to establish systems and standards for sustainable packaging and recycling practices by international norms to bolster Egyptian black honey exports.

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