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Contents

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Challenges of Implementing Packaging Design in Rural Food Entrepreneurship Owned by Underprivileged Women – A Case Study

ABSTRACT

This project was implemented to help low-income and underprivileged women grow their small businesses. This project aims to identify and analyse the problems faced by underprivileged women, focusing on food packaging. The participants were from Kampung Pinggan Jaya, Kuching Sarawak in Malaysia, who run small and medium food businesses. The food categories were based on dry and frozen foods, which were mainly homemade. The participants were housewives aged between 30 and 45 years with low monthly household incomes ranging from US $45 (MYR 200) to US $168 (MYR 750). Thus, the project's main objective is to improve product packaging to establish itself in the local market. Empathy mapping was the technique of choice as it demonstrates collaborative visualisation. Consequently, an entrepreneurship workshop was organised to identify potential products and participants interested in the project. Some problems and constraints during project implementation were due to financial concerns, attitudes, and illiteracy.

KEY WORDS
Packaging design, small businesses, food industries, empathy map

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Introduction

Growth and poverty reduction are the common ultimate goals of all development endeavours. International development, financial, and trade organisations, practitioners, and academics attest to this assertion (Akoum, 2008). Opposite Balsas (2017) explained that most economic revitalisation of suburban areas relies on neighbourhoods and their dynamic community rather than central resources and political attention.

Meanwhile, Vicino (2008) explained similar issues relating to suburban decline with municipal urban decentralisation. He maintains to enforce local autonomy by strengthening them and thus eliminating decentralisation decisions and barriers regarding revitalisation projects.

Likewise, this article relates several similarities to other projects by policymakers, local governments, and NGOs worldwide to increase the livelihood of deprived communities in suburban areas.

Furthermore, Yayasan Sejahtera Foundation welcomed any assistance from welfare bodies and NGOs to help the poor community in Sarawak, Malaysia and identified potential economic activities that could be implemented in the area before rendering the appropriate assistance (Borneo Post, 2015).

This project explains the economic revitalisation of a suburban village by assisting the villagers in increasing their income by educating them about the importance of marketing strategies in product sales.

Therefore, one of the marketing strategies is to improve product packaging, which is the main purpose of this project. Revitalisation development in the village is categorised as a part of the service design project in which the plan provided extensive solutions for the *Kampung Pinggan Jaya* villagers with education, information on cleanliness, and food preparations. It also extends educational marketing skills for the village community as a sustainable means of support.

The project was conducted to help low-income and underprivileged women to grow their small businesses. Those involved were from *Kampung Pinggan Jaya*, Kuching Sarawak, who run small and medium food businesses. The food categories were based on dry and frozen foods, mainly homemade.

Hence, this project aims to understand the participants' attitudes, participation, and acceptance of the packaging design project.

Kampung Pinggan Jaya

Kampung Pinggan Jaya is located about 45 minutes from Kuching, Sarawak of Malaysia. The village could be developed as a local *gula apong* (Nypa fruticans) industry centre. The villagers are experts in harvesting the nipa sap to produce *gula apong* and promote the location as a business hub.

Due to its high commercial value, the Sarawak state government views this as potential and plans to expand the nipa palm sugar industry. In supporting this industry, 17 selected entrepreneurs were assisted under the guidance of the Agriculture Department and generated an income estimated at US $273 thousand (MYR 1.2 million) for the Sarawak state in 2012 (Borneo Post, 2014).

Project Approach

Selections of Potential Products and Participants

The research team discovered a variety of products produced locally by the villagers. The participants were housewives aged 30 to 45 with monthly household incomes ranging from US $45 (MYR 200) to US $168 (MYR 750). Participants in the program must be born and raised in the neighbourhood. There were just six (6) participants in this project. Early investigations revealed that one of the volunteers was illiterate, while the rest were high school graduates.

The products chosen as listed in Table 1 are in demand and have the potential to be marketed.

The marketing team identified the participants and their potential products for this research. The participants had agreed to attend the marketing group's entrepreneurship classes and workshops.

Furthermore, the packaging design team was invited to participate in the workshop activities to understand better the product that would be featured and improved. The design team also initiates an empathy approach to acquire feedback from participants on their backgrounds, their level of knowledge, education, and motivation to participate in the program.

Throughout the event, participants expressed enthusiasm to take their businesses to the next level.

They learned the significance of packaging design, product labelling, and branding.

Project Details and Method

The objectives of the packaging design project are to:

Design the brand identity (logo), and
Propose a new packaging design.

Packaging design is one of the elements in the marketing process; it is considered a vital part of the whole marketing program (Calver, 2004).

Therefore, the brand of the community gives a vital impression that becomes an instrument of product recognition. The graphic elements such as logo, colour, and illustrations must be visibly displayed on the packaging.

Secondly, each product's packaging was examined to see how it could be improved. The selection of packaging materials, functionalities, cost, and availability are key considerations. The timeframe and activities for the packaging design project are shown in Table 2.

» **Figure 1:** *Nipa trees and gula apong producer at the village*

Table 1 (part 1)

List of local potential products

Participants	Products	Price (RM/MYR)
Category 1: Gula Apong-Based Product		
Participant 1	*Keretop* (Rice cracker) 	US $0.22 (MYR1) for 3 pieces
Participant 2	*Gula Apong* (Nypah sugar) 	US $1.79 (MYR8) for 1 kg
Category 2: Frozen Food		
Participant 1	Frozen curry puff 	US $0.45 (MYR2) for 6 pieces
Participant 2	*Pau Bun* 	US $0.22 (MYR1) for 3 pieces
Category 3: Titbits/ Chips		
Participant 1	*Popia Kacang Merah* 	US $0.45 (MYR2) for 6 pieces
Participant 2	*Kerepek Keladi* (Yam chips) 	Not specified (new proposed product)
Participant 3	*Bahulu* 	US $0.65 (MYR2.50) for 10 pieces

Table 1 (part 2)

List of local potential products

Participants	Products	Price (RM/ MYR)
Participant 4	*Rempeyek* 	US $0.22 (MYR1) for 4 pieces
Participant 5	*Biskut Koyong* 	US $2.68 (MYR12) per container

Note: MYR is the currency code for the Malaysian Ringgit. MYR1 = US$ 0.22 (money currency as of February 2023).

Table 2

Project timeline and activities

Activities (Year 2017)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Find potential products (Table 1)		•	•	•	•	•	•					
Product analysis & Workshop								•	•			
Brand identity design									•			
Packaging design									•	•		
Mock-up presentation											•	
Refinement & distribution											•	•

Note: Packaging distribution was done in March 2018

Product samples were collected and evaluated at an earlier stage of the research. Some products were packaged in low-cost packaging, while others were newly planned products that were not packaged.

In order to gain better knowledge of the items and other issues, the researchers employed the empathy mapping technique whereby participants were interviewed and asked what they liked or disliked as well as what they hoped or feared about the product or other scenarios.

According to Marsden (2017) & Brand Genetics (2020), empathy is an experiential insight in which we can feel and experience things from someone else's point of view. Furthermore, Gibbons (2018) stated that empathy maps are commonly used in design communities, and they are defined as a collaborative visualisation used to explain the sort of person. In this regard, it provides us with an awareness of the individual's needs, allowing us to make decisions on pertinent concerns. The questions were on packaging design, namely what challenges they were experiencing and their future expectations. Table 3 contains the indications for Say & Do, Hear, Think & Feel, See, and Pains and Gains.

Table 3

The indicator of Empathy Map's section (Gibbons, 2018)

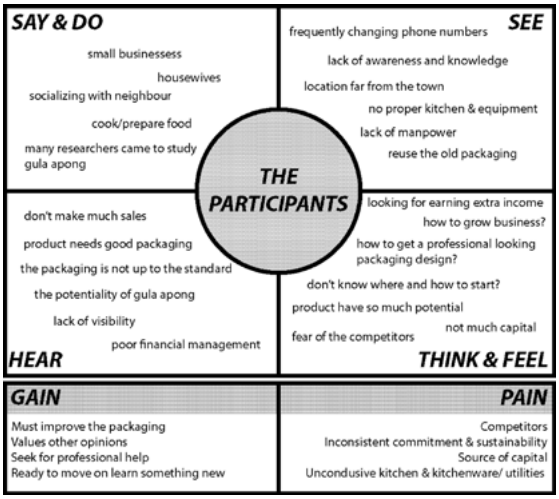
Section	Indicator
Say & Do	Defining the problem to be solved, a product they are looking for, or things they might mention in general conversation. It also relates to a participant's actions and how they will affect the project.
Hear	Includes everything they hear others saying. A way to identify the community that they live in.
Think & Feel	To consider the positive and negative sides of thoughts. What makes the participant feel good or bad? Something that they are worried about. How do they feel?
See	Document what participants observe in their immediate environment.
Gain	Brainstorm what the participants would gain from the project. How would it make their life better?
Pain	Brainstorm all the pains that they might have and how they can be solved.

Observation and Result

Empathy Map

All six (6) participants provided feedback and information during the interview. The interview activities were conducted in a group setting, so the conversations may be spontaneous and relaxed (Figure 2).

Since most of them are shy and quiet, this strategy is effective. Using the empathy map observation and results, we assessed the six (6) sections where the subjects answered. The outcome from this session is shown in the empathy map in Figure 3.



» **Figure 3:** *Empathy map*

Say and Do

Participants stated they were housewives who wanted to supplement their husbands' income by starting small businesses. As a result, they are involved in producing and selling homemade food. Three (3) participants are working on *gula apong-based* food products (nipa sugar).

Their income is derived from the nipa trees that grow in the settlement area. Housewives who had completed high school were among those who took part. One of them is a high school dropout and illiterate. They enjoy getting together and doing activities other than cooking.

Aside from that, they claim that many groups of researchers are visiting their villages to research nipa trees. They have been advised several times to sell their products more appropriately due to discussions with the group of researchers who came and discovered the potentiality of the products.

» **Figure 2:** *The interview, discussion, and brainstorming session with the participants*

Hear

As a result of this section, the findings found that participants are unlikely to be able to increase product sales revenue. This is because their businesses are small and only sold to neighbours in the village.

However, one participant selling *gula apong* products obtained more comprehensive coverage as it is popular among large-scale restaurants and food operators. The participant does not have to go out to sell and distribute the products in the market because the customers will self-pick up their orders.

The *gula apong* products sold are packaged in rectangular plastic containers. Sometimes entrepreneurs reuse plastic containers or get free containers from other sources. Generally, all food products sold inconsistent use of the same packaging. As expected, entrepreneurs need the initiative to brand and label their products, which can expand product visibility in the market.

The participants also need help with financial management, where the profit from sales is too small and spent on unnecessary things.

See

As a result of the group discussion, it was found that one of the participants frequently changed their phone numbers. This has made contacting the participants difficult. Another challenge is the village's remote location from the city, making it harder to advertise products to a larger audience.

This can be evident when participants need more awareness of the procedures and the importance of product promotion. Aside from that, limitations in kitchen facilities and equipment are a big issue, particularly in terms of food preparation hygiene.

Finally, the lack of personnel and assistants is another crucial reason the product cannot be produced in large quantities.

Think and Feel

Based on the discussion, the participants wanted to increase their salary to assist the family financially.

However, their primary issue is more ideas and techniques for expanding the business. Furthermore, upgrading packaging is critical, and consulting with professionals is crucial.

Finally, they know that the product generated has potential but are concerned about competition in the external market.

Gain

The participants have gained optimistic hopes for better packaging as a result of this project. They have received professional feedback and are ready to move on to the next level.

The attitude demonstrated must be cooperative. They must be aware of the commitment made to the project. This project must be completed and deliver benefits to entrepreneurs in the form of knowledge and company sustainability.

Pain

The pain experienced is from insufficient capital for marketing and product promotion. It is because packaging design is one of the ways to market a product.

Moreover, the adequacy of cooking equipment, a conducive kitchen, and packaging machine equipment is very much needed for growing their business.

On top of that, competition from other entrepreneurs who produce the same product is of great concern to them. Hence, consistency and commitment are essential to sustain their business.

Product Sample Analysis

On 12th – 13th August 2017, an entrepreneurship workshop was organised to identify the participants interested in participating in the project. They were among those who volunteered to join this program.

On the first day of the program, six (6) participants showed their interest in product packaging. More products were brought in on the second day of the program.

Overall, a total of nine (9) products were received to be packaged. The products were clustered into three categories: frozen food, titbits/chips, and *gula apong-based* products. The producer will only prepare the product based on customer orders. According to them, the product is sold within the neighbourhood community.

Table 1 displays the nine (9) products that need to be marketed. Based on the images in Table 1, all products were packed in plastic material. The entrepreneur used standard cheap packaging such as poly bags, plastic containers, disposable clamshell plastic, and printed IPP bag (Isotactic polypropylene). The participant's reluctance to improve their packaging format due to financial constraints.

Table 4 indicates the type of material used to pack the product. Other than that, there were no labels and brands implemented on the packaging.

Table 4

Analysis of the packaging material and format

Product	Material and format
Category 1: Gula Apong-Based Product	
Gula apong	Rectangle plastic container
Keretop	Poly plastic bag
Category 2: Frozen Food	
Karipap (Curry puff)	Disposable clamshell plastic
Pau bun	No specific packaging (depending on the quantity), sometimes using disposable clamshell plastic
Category 3: Titbits/ Chips	
Kerepek keladi (Yam chips)	Printed IPP bag
Popia Kacang Merah	Disposable clamshell plastic
Bahulu	Printed IPP bag
Rempeyek	Printed IPP bag/ cylindrical plastic container (depend on the quantity)
Biskut koyong	Cylindrical plastic container

Based on the analysis of the product samples and empathy map, it should be noted that the participants showed inadequate knowledge of packaging design. As a result, they rely on researchers to help them design packaging suitable for their products.

Packaging Design Project

The packaging design project is to 1) design the brand identity for the community products and 2) propose a new packaging design for each of the products. A group of five (5) graphic design students from the Universiti Malaysia Sarawak participated in this project. Their participation in this project was to gain experience in working with the community and demonstrate their practical skills and talent in packaging design. A community logo for *Kampung Pinggan Jaya* was initially designed as an indicator to promote community projects and products. The brand name is 'Pinggan Jaya Community Product', and the logo will appear on packaging, social media, and other marketing platforms. The Nipa fruticans flower inspired the concept of the logo (Figure 4).

Shades of green were used for the logo because this colour is associated with nature and symbolises ecology and the environment (Color Matters, 2019).

The logo design process began with brainstorming to identify the most appropriate features to represent the community of *Kampung Pinggan Jaya*. Then, the rough ideas were sketched and rendered as vector graphics in Adobe Illustrator. Finally, the ideas were presented to the community group, and the final logo was selected, as shown in Figure 4.

» **Figure 4:** *Logo design*

A few challenges will influence the researchers' decisions during the project.

The first challenge was to educate participants on the importance of packaging and how to make it more sustainable. Indeed, they agreed that having adequate packaging may enhance sales. The participants were ecstatic at the prospect of designing packaging for their products. They looked forward to selling their product at the local mini-mart.

However, the budget constraint may limit the packaging format, materials, design elements, and printing output. In this case, the researcher had proposed affordable packaging for them. As a result, the quantity and price of their product must be revised.

It is observed that participants employed conventional low-cost packaging materials such as poly bags, plastic containers, disposable clamshell plastic, and printed IPP bags (Isotactic polypropylene). It should be noted that the packaging is chosen and purchased subject to availability from the closest supplier.

Furthermore, the packaging material and format options are limited. As a result, logistics, location, and material selection affect production costs. Furthermore, a lack of understanding of the significance of label use and branding makes marketing the products challenging. Most participants believe their products can still be sold without the brand and labelling.

Therefore, they do not have to spend unnecessarily. At first glance, they are correct because their market and location only encompass the immediate neighbourhood. However, they could consider implementing a more robust business strategy, such as giving the product a brand name, labelling it, and utilising good packaging.

Products, such as *Biskut Koyong* and *Kerepek Keladi* were poorly packed. On the other hand, the *Pau Bun* is a new proposed product that requires packaging.

According to the participant, they usually make the food depending on the customer's request and allow the customer to self-pick up using the container that they brought from home.

As soon as the researchers learned about the participants' obstacles and challenges, assistance was provided to satisfy some of these criteria.

The 4 criteria include economical packaging design, locally acquired packaging material and format, creating a single brand for all items (as described in diagram 2), and design labels for each product.

Due to financial constraints, the participants were advised to pursue low-cost packaging solutions where the materials and supplies are easily obtained nearby.

Table 5 shows the proposed container for each product. The solution was made based on the practicality, resistance, and size that can store the food adequately.

According to ChemicalSafetyFacts.org (2022), plastic food containers are strong, lightweight, and resistant to bacteria.

Therefore, plastic containers are commonly used for packaging many types of food to protect them from damage, ensure food safety and prolong food freshness.

For aluminium food containers, AskUSDA (2019) notes that this material is suitable for freezing food to keep the air out and protect the food from freezer burn for more extended storage.

Table 5

Proposed packaging / food container

Product	Suggested packaging format
Gula apong (grade A)	Plastic Disposable Food Container with lid
Keretop	Clear food plastic bag
Karipap (Curry puff)	Disposable plastic food container / Aluminium food container
Pau bun	Disposable plastic food container / Aluminium food container
Kerepek keladi	Resealable Plastic Bag (zipper)
Popia Kacang Merah	Disposable plastic food container (clamshell)
Bahulu	Plastic Disposable Food Container with lid
Rempeyek	Resealable Plastic Bag (zipper)
Biskut koyong	Resealable Plastic Bag (zipper)

Figure 5 depicts the *Keretop bar* label design process and design recommendation. *Keretop* is a popular food among the locals. It is made of rice and flavoured with *gula apong* (nipa sugar). This crispy snack is a promising good for widespread distribution.

As seen in Figure 5, the 'Pinggan Jaya Community Product' logo is applied on the label as a symbol or sign of ownership to the *Kampung Pinggan Jaya* community.

While Figure 6 shows the rest of the products; *Pau Bun* and *Karipap* packed in aluminium containers, *Bahulu* and *Gula Apong* packed in a plastic container with a lid, *Popia Kacang Merah* packed in a clamshell plastic container, and *Kerepek Keladi*, *Rempeyek* and *Biskut Koyong* packed in resealable zipper plastic bag. The packaging chosen meets the participants' expectations and is suitable for use as food packaging.

During the design stage, packaging prototypes were presented and discussed with participants. The initial design was created based on the participants' suggestions, which were then taken into account and modified as applicable. In addition, they learned how to pack the product.

Finally, each participant was given a packaging label. Packaging materials or containers were not provided to them as it is essential to observe their commitment to their business. Participants must take responsibility for their businesses and learn how to manage their budgets, especially those for packaging and label printing. The excitement and acceptance of the design motivate them to take their business more seriously (Figure 7).

This event took place at the community shop in the exact location where their product will be sold and displayed.

» **Figure 5:** *Label design ideas and prototype for Keretop bar*

Discussions and Conclusions

Several issues and limits have arisen during this undertaking. This financed project was primarily intended to assist small businesses in learning about entrepreneurship, particularly marketing strategy. It is envisaged that the participants will be able to operate independently and strategically. However, this project has limitations due to financial concerns, attitudes, and illiteracy. In addition, participants' reliance on funders and project coordinators will make it difficult for them to work independently.

» **Figure 6:** *Label design ideas and prototypes for the products*

» **Figure 7:** *Discussion and presentation of the packaging prototypes*

Many small businesses are still not registered with the Malaysian Companies Commission (SSM). It is due to illiteracy in paperwork preparation, financial management, and the inability to consistently produce food supplies. As a result, they only produce a small volume of food. Furthermore, the food preparations were done at home with insufficient cooking equipment, an unfriendly environment, and unhygienic practices. This stumbling block makes it impossible for them to sustain themselves in the food industry, further increasing the number of unregistered businesses.

Indeed, many food products from local small businesses are packed without labels that should contain important information such as nutrition facts, net weight, expiration date, brand name with logo, manufacturing address, contact information, and others. A product without a brand name imparted a negative perception and thus a bad reputation for the product (Shaharuddin, 2007). Therefore, branding and packaging are seen as important tools for marketing, promotion, and advertisement.

Financial knowledge is the most concerning problem for small business owners. They would rather spend the money on more critical things like debts and household necessities. As a result, they should have noticed corporate growth, including branding and marketing strategy. Nonetheless, investing in branding and packaging is a long-term investment. According to Shaharuddin (2007), the first batch of packaging manufacturing will undoubtedly be more expensive. However, it will remain less expensive than subsequent production due to economies of scale and a consistent fixed cost.

Another significant challenge is the attitude and mindset of local entrepreneurs, particularly in small-scale businesses. They work on their own time and are limited by the availability of resources because they are self-employed. Once the resources are accessible, they can process and create the goods. For example, the *gula apong* can only be prepared once the sap from the nipah tree is ready to be extracted. A nipah tree may typically yield optimal sap for 6-7 months. Manufacturing *gula apong* is traditionally done in a "large crater" where the nipah sap is cooked for 3-4 hours. Moreover, the manufacture of *gula apong* requires less workforce.

The findings suggest that a lack of manpower, cooking utensils, space, and logistics will limit production capacity. As a result, this influences their view and decision to forego good branding and packaging. Furthermore, they intend to sell in a local market.

The final challenge that occurred in this project is the issue of illiteracy. All participants ran their businesses without legal and documentation knowledge, such as obtaining permission from industry authorities. They need to learn how to manage the business, the documents needed, financial records, and tedious company registration. Due to this problem, they could not apply for *halal* certification and other forms of endorsement from the related agencies.

Other than that, the participants also take things for granted when packing their products. The net weight or the size of each of the products was unequal. Proper packaging machinery is necessary to maintain consistency and product quality, affecting customers' trust.

Unfortunately, for many unexpected reasons, this project could not be continued after the distribution of the packaging label. Thus, the sales, income, and customer feedback data could not be provided. The commitment and attitude of the participants are the main concerns that will be discussed in future studies.

In conclusion, an in-depth study must be conducted to solve the above issues. Importantly, business agencies should take the opportunity to become a partner or mentor small business entrepreneurs to operate their businesses.

For example, the partners can buy the products from small entrepreneurs, repackage, plan for the branding, and market them. It is one of the Malaysian government's missions to expand business opportunities among the poorer communities so that they can generate income and open job opportunities for others.

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Color preferences among selected adults in Ghana

ABSTRACT

This paper presents a study on color preferences among a sample of Ghanaian adults. Two surveys were conducted, with a total of 143 participants (50 in Survey 1, and 93 in Survey 2). The participants completed both printed and digital questionnaires to gather data on their color preferences. The results showed that blue was the most preferred color by both males and females in general, but not for specific items. In survey 2, a chi-square test on categorical variables revealed a significant relationship between gender and preference for light, dark, or bright colors (p=0.025), as well as gender and number of preferred colors per personal item (p=0.02). However, no significant relationships were found between gender and change of colors from childhood (p=0.73), gender and number of preferred colors (p=0.204), gender and most preferred colors (p=0.216), age, and the number of preferred colors (p=0.19). Interestingly, 66.3% of the participants in Survey 2 indicated that their preferred colors were based on innate attraction, regardless of whether their color preferences had changed or remained the same since childhood. Overall, blue and red were the most preferred colors, with a score of 34.4%. These findings provide valuable insights for design practitioners and communicators and offer a basis for future research on color preferences among Ghanaians.

KEY WORDS
Color, preference, favorite, light, bright, dark

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Introduction

The changing world of technology has diversified the use and application of color in printing, publishing, product design, and architecture. Color significantly impacts the appearance of a product as it is employed in designing, printing, and producing various artifacts. Many people express how they feel through the colors they choose as color carries meanings that go beyond mere valuation (Jonauskaite et al., 2018).

Globally, color is used in all areas of endeavors because they communicate emotion and philosophy. In Ghanaian traditional functions, for example, black and red are used for mourning. The use of color in emblems represents the philosophies of a group or society. The Ghanaian national flag is made of two hues and one achromatic color viz; red, yellow, green, and black – red symbolizing the blood of the forefathers who fought for political freedom gold symbolizing the rich mineral resource (Bowell, 1992), green for her rich forests and natural wealth and black for the African race/heritage. Traditional Ghanaian art made use of colors from nature (Owens & Green, 2016).

Colors are used in all production or manufacturing processes. People make choices every day about colors; eg. buying from a grocery shop, choosing consumable products, etc. A typical bookstore is filled with book covers in different colors. Also, a cosmetic store is filled with products that have labels in different colors.. Consumers can develop preferred color associations for a particular product category in advertising and marketing.

Color preference study has ignited a very insightful debate among researchers, and has been investigated by various topics; eg. mood, age, sex, personality, etc. (Hanafy & Sanad, 2015). These studies have mixed results because of different focal areas. Universally, many researchers have tried to establish patterns of color preference.

A very common color preference pattern cited in previous studies is cool colors for males and warm for females. Among the factors that account for color preferences are biological and psychological influences (Palmer & Schloss, 2010; Baniani & Yamamoto, 2014).

The psychological process of associationism is a causative factor in how people relate and give meaning to color (Hurlbert & Ling, 2007, Baniani & Yamamoto, 2014).

According to Palmer & Schloss (2010), everybody's color preference is determined by their affective response to objects in the environment. The environment in which a person lives may also have cultural and philosophical ideologies that come to play concerning color. Crozier (2008) also agrees that human color preference is not innate but a result of social life. Therefore, man's response to color is influenced by different life experiences.

Saito (1996) discovered among nine cultural groups that blue was generally the most preferred color. He also found that respondents from four large cities in Japan had a profound inclination toward white because of its associative image with purity and freshness.

From that same research, subjects from Taipei preferred blue and green because of their association with the natural environment. He concluded that culture influenced color choices. In cross-cultural research conducted by Baniani and Yamamoto between 2011 and 2012, 319 participants made up of Iranians, Japanese, and foreigners living in Japan were given two drawings (interior and exterior) and a set of colored pencils, 24 each.

This research aimed to compare how participants simply used their favorite colors and how they relate them to other objects. It was surprising to note that most people used their favorite colors in painting small objects and bedroom walls. At the end of that study, participants who lived close to the coast used a lot of blue in their drawings.

This stands to reason that people are attracted to colors they can relate to. Positive feelings are evoked towards green because it represents vegetation; and others are repelled by colors that connote negative reactions like brown which represents rotten fruits (Bawa & Osei, 2022).

The preferred color (hue) of an individual may not extend to other items or products due to the influence of value (lightness or darkness) and chroma (saturation).

Jonauskaite et al. (2016) conducted a study in Australia on psychology students and observed that the chromaticity of colors chosen for walls was relatively lower compared to other items. Additionally, the colors preferred for T-shirts were darker than those for other products. Similarly, Fortmann-Roe (2011) found that in a sample of one million Twitter users, males demonstrated a higher affinity towards blue, while females preferred pink-themed colors. Furthermore, males preferred darker and lighter tones, whereas females preferred brighter ones. Jiang et al. (2020) also conducted research among 508 Chinese children between the ages of 12 and 16 and observed that their color preferences influenced their furniture choices, although this varied for different furniture categories.

Being male or female plays a major role in color preference. According to Silverman, Choi & Peters (2007), gender accounts for the spatial differences in activities between males and females. This difference has been developed from 'survival pressure'. A woman's brain is wired for gathering activities like locating ripe fruits or green berries engulfed in foliage. A woman will consequently show a strong liking for 'warm' colors (Red-Yellow hues). The man, on the other hand, will go for 'cool' colors seen in his environment like sky-blue (Hurlbert & Ling, 2007, He et al., 2011).

Other researchers who agree with the warm-cool color preferences of males (blue-green hues) and females (pink-red hues) include He et al. (2011); Ou et al. (2011); Hurlbert & Ling (2007); Bonnardel et al. (2018) and Jiang et al. (2020). He et al. (2011) mention that gender differences accounting for color preferences arise from stereotyped gender roles and ways of thinking and behaving.

The influence of age on color preferences has been studied extensively, with research indicating that most people's reaction to colors changes at different stages of their life, although it may not necessarily be a decisive factor in selecting a particular hue.

Dittmar (2001) conducted a study involving 842 German adults aged between 19-90 years and found that older adults (55-90 years) exhibited a decreasing preference for blue, red, green, and yellow. This trend was attributed to a reduction in visual function in older people. Similarly, Ou et al. (2011) found that lighter colors were rated as less active but cooler among older participants.

Despite the abundance of evidence on color preferences, further investigation is still relevant as research approaches and conditions can impact the results. Although the majority of research on color preference has focused on Asia, America, and Europe, a study of a cross-section of Ghanaians can provide additional knowledge to the field.

Therefore, this research aims to explore the general and specific color choices for various items among Ghanaians, given the limited existing research on color preferences in Africa.

Four important research questions arise from this objective. These are:

1. What are the most preferred colors (general and specific) of males and females in Ghana?

2. Is a color's property (dark, light, bright) a factor in preferred colors for males and females?

3. Have males and females in Ghana changed their preference colors from childhood?

4. Is there a difference in the number of preferred colors for adults between 25 and 60 years?

Method and Data

To answer our research questions, we conducted two surveys within 3 months. Initially, 50 subjects (21 females, 29 males) from 6 institutes of the Council for Scientific and Industrial Research (CSIR-Ghana) participated. These institutes are the CSIR-Food Research Institute (CSIR-FRI), CSIR-Institute of Industrial Research (CSIR-IIR), CSIR-Science and Technology Policy Research Institute (CSIR-STEPRI), CSIR-Soil Research Institute (CSIR-SRI), CSIR- Institute of Scientific and Technological Information (CSIR-INSTI), and CSIR-Water Research Institute(CSIR-WRI).

The selection of these institutions was due to the availability of adults within the age groups, proximity, and convenience of administering questionnaires. Participants in the first survey were handed printed questionnaires for data collection. About a month later, about 100 participants were sent an electronic questionnaire (Google Forms). The second survey was necessitated because more data was needed on other variables. This sample size included respondents from CSIR and other government and private companies. A total of 93 participants responded. These participants were workers with different professional backgrounds eg., engineers, administrators, and accountants to mention but a few.

In all literature, one basic method that exists for getting information about color preferences is the presentation of color; either on calibrated screens or printed color cards with color names. The data collection instrument designed for this study was a questionnaire that followed a similar pattern to the one used by Bakker et al. (2013) which tested participants on general and specific color preferences for other items.

Questions in both surveys were multiple choice questions. In the first part of both questionnaires, demographic characteristics included age, sex, professional background, region of birth, and place of work. Ages were grouped into three categories namely: 25-35, 36-45, and 46-60 to represent young, middle, and old. Age restriction to 60 years was due to visual deficits in old age (Ishihara et al., 2001). The second part involved the selection of general and specific color preferences for personal items. A color palette made up of primary, secondary, and tertiary colors from the color wheel, bearing in mind the properties of hue, value, and chroma as employed in the Berkeley Color Project (Palmer & Schloss, 2010; Bakker et al., 2013; Baniani & Yamamoto, 2014) was used.

A total of 64 colors including achromatic colors were used in this study. This procedure of simply selecting colors from printed cards or screens is common in literature because it is the first step to getting information about color preferences (Bonnardel et al., 2018, Yu, Westland & Li, 2020). The second part of the questions was tailored towards preferred colors for personal items, number of preferred colors, change of colors over a period, and effect of dark light and bright color properties on color preference.

» **Figure 1:** *Colors presented to participants*

Data collated from this assessment were treated as ordinal values in SPSS. This study employed the chi-square (x^2) test to assess the relationship between categorical variables. It helps ascertain whether the distribution varies from what is expected by chance. This test checks the difference between the observed and expected value. Mathematically, the chi-square is expressed as:

$$\chi^2 = \sum_{i=1}^{n} \frac{(O_i - E_i)}{E_i} \quad (1)$$

Oi = observed (actual) value *Ei* = expected value

In this study, we employed the p-value approach to make our decisions, and our significance level was set to 0.05 (α). The chi-squared test was computed using the 'crosstab' command in SPSS. The null hypothesis (H_0) for the chi-square test is: There is no relationship between variables A and B.

If a p-value is less or equal to 0.05 means that there is a significant relationship between variables. To determine the strength of the relationship between variables, an effect size (Cramér's V) was computed by ticking the option in the 'crosstab' dialog box.

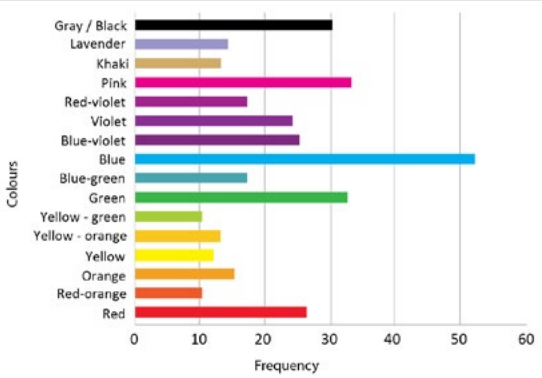
A Cramér's V (effect size) has a reference range of 0 to 1. A value of 1 gives a perfect relationship (Cramér, 1946). If the value is greater than 1 but less than 039, it is a weak association. A value above 0.39 - 0.69 is a moderately strong relationship; 0.69 and above indicates a strong relationship (David & Sutton, 2004).

Results and Discussion

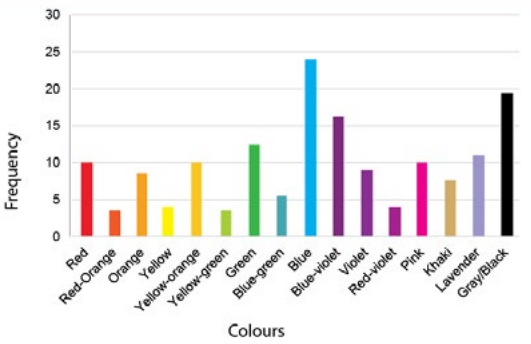
In both surveys, participants were instructed to select their favorite color randomly, without considering its association with any object (see Figures 2, 3, 4).

A total of 16 color names were shown to the participants for selection (see Figure 1). Upon analyzing the data from all 50 participants in the first survey regarding color preferences, it became evident that blue scored the highest (41%) in its category, corroborating the findings of Saito (1996) and Bonnardel et al. (2018) as the most preferred color for both males and females.

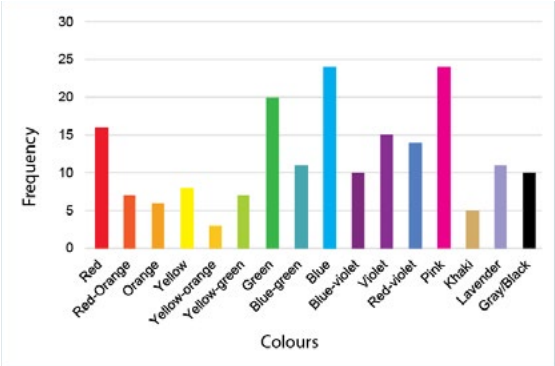
The next most preferred colors were black/gray (37%), red (33%), and violet/purple (29%). In the second survey, blue was still the most preferred with (37%). A compilation of the results from both surveys (n = 143) amplified the general preference for blue.



» **Figure 2:** *General color preferences for males and females (surveys 1 and 2)*



» **Figure 3:** *General color preferences for males for surveys 1 and 2*



» **Figure 4:** *General color preferences for females for surveys 1 and 2*

Table 1

Data Summary for best two colors for personal items in Survey 1

Item	1st color	Color Property	Score	2nd color	Color Property	Score
Bedroom wall	Gray	Light	17%	Yellow	Light	10%
Living room	Yellow	Light	34%	Gray	Light	26%
Blouse / Shirt	Yellow	Light	27%	Gray	Light	26%
Business card	Gray	Dark	26%	Blue-violet	Dark	8%
Couch	Khaki brown	Dark	17%	Black	Dark	17%
Laptop	Black	Dark	28%	Gray	Light	21%

Results in Table 1 display the most preferred colors for specific items. A total of six personal items were listed for the 50 participants in the first survey. Lighter colors of yellow or cream-yellow recorded the highest for room walls as observed by Jonauskaite et al., (2016). A sense of color harmony was observed in the choice of colors for couches and room walls.

Dark brown and black were selected in combination with cream-yellow or light yellow. Of all the colors selected for personal items, achromatic colors (black and gray) were the most preferred. This is consistent with Jiang et al's. (2020) study that reported, reported that dark colors were the most preferred by adults for furniture. The results indicate that pure hues are not preferred for personal items.

To answer objective 1, three different tests were run: 'the number of preferred colors (males and females)', 'most favorite color for (males and females), and 'favorite colors for personal items for males and females). Table 2 gives a representation of the relationship between gender and the number of preferred colors. The null hypothesis for this test assumed there is no relationship between gender and the number of preferred colors.

Table 2

Relationship between Gender and most favorite color (Survey 2)

			Number of preferred colors					Total
			1	2	3	4	5	
Gender	Female	Count	5	4	10	19	14	52
		% within Gender	9.6	7.7	19.2	36.5	26.9	100
	Male	Count	2	6	15	11	7	41
		% within Gender	4.9	14.6	36.6	26.8	17.1	100
Total		Count	7	10	25	30	21	93
		% within Gender	7.5	10.8	26.9	32.3	22.6	100

$x^2 = 5.934$ df = 6 p = 0.204 Cramér's V=.25

The chi-square test retains the null hypothesis ($x^2 = 5.934$ df = 6 p = 0.204 Cramér's V=. 25). The effect size (.25), however, was moderate in the group. The highest count for males was recorded for three colors.

The females scored 36.5% for four colors. Among males and females, it was realized that there was a wide preference selection because the conditional probability of choosing only one color was 7.5%. Males and females had a 32% probability of selecting four colors. Even though females have been found to have a stronger sense of variety in color naming than males (Anderson et al., 2014); and have an innate appeal for a variety of colors (Arthur, Johnson & Young, 2007); the results of this test were not significant in that regard.

Table 3 illustrates the difference between gender and most favorite colors in general. Participants were asked to select their favorite colors from all 16 sections. Colors were grouped according to the dominant hue.

Table 3

Relationship between Gender and most favorite color (Survey 2)

			Most favorite color for personal items							Total
			Blue	Green	Orange	Pink	Red	Violet	Yellow	
Gender	Female	Count	13	4	4	2	22	2	5	52
		% within Gender	25	7.7	7.7	3.8	42.3	3.8	9.6	100
	Male	Count	19	3	6	1	10	1	1	41
		% within Gender	46.3	7.3	14.6	2.4	24.4	2.4	2.4	100
Total		Count	32	7	10	3	32	3	6	93
		% within Gender	34.4	7.5	10.8	3.2	34.4	3.2	6.5	100

$x^2 = 8.316$ df = 6 p = 0.216 Cramér's V = .299

The results show that there is no significance between favorite colors and gender ($x^2 = 8.316$ df = 6 p=0.216 Cramér's V =.29) and the color blue and red are the most favorite colors across gender (34.4%). Comparing the two colors (blue and red), females recorded a higher value for red (42%) while males also recorded a higher for blue (46%). The color yellow was the least liked but most preferred for living room walls in Survey 1.

From this test, it can be suggested that colors are always considered in context. Even though males were more than females, our results show that females are in a higher probability of choosing reddish colors as found by Bonnardel et al. (2018). It was not surprising to see blue as the leading color because other researchers like Franklin et al. (2012) found that babies remarkably reacted more to blue and red. However, yellow-dominated hues (yellow, yellow-orange) were generally not preferred.

Table 4

Relationship between Gender and favorite color per personal items (Survey 2)

			Number of favorite colors for personal items				Total
			More than 5	Less than 5	None	All items	
Gender	Female	Count	13	27	1	11	52
		% within Gender	25	51.9	1.9	21.2	100
	Male	Count	7	32	1	1	41
		% within Gender	17.1	78	2.4	2.4	100
Total		Count	20	59	2	12	93
		% within Gender	21.5	63.4	2.2	12.9	100

$x^2 = 9.387$ df = 3 p = 0.025 Cramér's V= .31

Table 4 addressed the inquiry, "There are 10 items listed below. How many would you want to see in your favorite colors?: bedroom, living room wall, couch, car, t-shirt, trousers or skirt, laptop, curtains, diary, handbag, or backpack." The findings revealed a gender-based association concerning the number of colors for personal items (x^2 = 9.387, df = 3, p = 0.025, Cramér's V = .31). The effect size (.31) of the analysis was weak.

One intriguing observation was that about 63% of respondents chose "less than 5," indicating that males and females preferred different colors for the items mentioned. Females had a 51% likelihood of preferring less than 5 colors for personal items, while males had 78% within their group, suggesting that more males preferred less than 5 items in their favorite colors.

Table 5

Relationship between Gender and Color property (bright, dark, light, a blend of all) (Survey 2)

			Number of favorite colors for personal items				Total
			Bright	Dark	Light	Blend	
Gender	Female	Count	25	3	6	18	52
		% within Gender	48.1	5.8	11.5	34.6	100
	Male	Count	6	6	9	20	41
		% within Gender	14.6	14.6	22	48.8	100
Total		Count	31	9	15	38	93
		% within Gender	33.3	9.7	16.1	40.9	100

x^2 = 12.220 df = 3 p = 0.007 Cramér's V= .362

In Table 5, participants were asked to describe or select the property of colors they preferred for a list of 10 personal items, including bedroom, living room wall, couch, car, t-shirt, trousers or skirt, laptop, curtains, diary, and handbag or backpack. They rated their favorite colors for each item as either bright, light, dark, or a blend of bright, dark, and light. The relationship between gender and color property (dark, light, bright, or a blend of all three) was found to be significant (x^2=12.220, df=3, p=0.007, Cramér's V=0.362). Both males and females preferred an equal blend of colors the most, indicating a taste for variety.

However, females were found to opt for brighter and lighter colors more than males, while males recorded a higher preference for lighter colors. The difference in the count for dark colors was not very significant, with males recording a preference for 3 dark colors and females for 6. The overall effect size (0.362) within the group was weak, but both sexes recorded low percentages for darker colors. Males also showed a higher preference for an equal blend of colors compared to females. These observations point to the difference between general and specific color preferences, as documented by Baniani & Yamamoto (2014) and Jonauskaite et al. (2016).

Table 6

Relationship between Gender and change of colors from childhood (Survey 2)

			Change of colors		Total
			Yes	No	
Gender	Female	Count	21	31	52
		% within Gender	40.4	59.6	100
	Male	Count	18	23	41
		% within Gender	43.9	56.1	100
Total		Count	39	54	93
		% within Gender	41.9	58.1	100

x^2 = .117 df = 3 p = 0.733 Cramér's V = .035

Table 6 examines the relationship between gender and changes in favorite colors from childhood. Our study investigated whether males and females have altered their favorite colors since childhood.

The analysis revealed no significant relationship between gender and color change (x^2 = .117, df = 3, p = 0.733, Cramér's V = .035), with a weak effect size (.035). The proportion of females who answered 'Yes' to changing their colors was 40.4%, while 59.6% responded 'No'. For males, 43.9% answered 'Yes', and 56.1% responded 'No'.

In total, 'Yes' responses constituted 41.9%, and 'No' responses constituted 58.1%. Participants cited several reasons for their answers, which were summarized into four keywords: 'Age', 'New interests', 'Environment', and 'Innate attraction'.

Of these, 66.3% of the population chose colors based on innate attraction while 17.4% discovered new colors that became their preferences. Only 7.4% admitted to changing their preferred colors due to age, while 12% reported a shift in color preference related to different working environments. These results suggest that color wavelengths that attract the eye are complex mechanisms that can both be static and dynamic.

Table 7 provides insight into the relationship between age and the number of favorite colors. The null hypothesis assumes that there is no relationship between a person's age and the number of preferred colors.

Table 7

Relationship between age groups and Number of Color varieties (Survey 2)

			Number of Color Varieties					Total
			1	2	3	4	5	
Age Group	25-35	Count	5	4	10	22	12	53
		% within Age Group	9.4	7.5	18.9	41.5	22.6	100
	36-45	Count	1	6	12	7	7	33
		% within Age Group	3	18.2	36.4	21.2	21.2	100
	46-60	Count	1	0	3	1	2	7
		% within Age Group	14.3	0	42.9	14.3	28.6	100
Total		Count	7	10	25	30	21	93
		% within Age Group	7.5	10.8	26.9	32.3	22.6	100

$x^2 = 11.049$ df = 8 p = .19 Cramér's V = .24

Each color sample has four variants as indicated in Figure 1. The test results confirm the null hypothesis (x^2 = 11.049, df = 8, p = .19, Cramér's V = .24). The number of preferred colors ranged from 1 to 5, with 32.3% of the total population opting for 4 colors, regardless of gender. This was followed by 22.6% for 5 colors; the least common number of preferred colors was 1 (7.5%).

These results indicate that respondents had a wide range of color preferences. When examining age groups, participants in the 25-35 age group had the highest percentage (41.5%) for 4 colors. In the 35-45 age group, the highest percentage was 36.4% for 3 colors. Participants in the older age group (45-60) had the highest percentage of 32.3% for 4 colors.

Conclusion

This study has established that color is a powerful force and expression of human emotions, whether it changes over time or not. The findings are consistent with previous research that has suggested color preference as an emotional response to environmental stimuli, with warm colors preferred by females and cool colors by males. Interestingly, blue was the most commonly preferred color by both males and females in this study, reflecting its global popularity and association with the natural environment. Additionally, all Ghanaian participants in this study also favored red as much as blue. The brightness, lightness, and darkness of colors also influenced participants' preferences for specific objects. Light yellow and achromatic colors (gray/black) were the most preferred colors for personal items in survey 1. In the chi-square analysis for survey 2, a significant relationship was found between gender and color properties (bright, light, dark, and a blend of all three) as well as gender and the number of colors for personal items.

The other three relationships (age – number of colors; gender – number of preferred colors; gender – change of colors from childhood) were not significant in the population. The study also revealed that whether an individual changes or retains a favorite color is dependent on an innate attraction. The results offer valuable insights for design practitioners and communicators, providing a general overview of color preferences among Ghanaians and a foundation for future research.

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The correlation of lighting and mood in the workplace: digital image-based research

ABSTRACT

Mood affects an individual's performance, whether relaxed/tense or alert/fatigued. This article was based on research to study a correlation between the lighting setting with relaxed-tense and alert/fatigued moods in the workplace by observing the illuminance level, the correlated color temperature (CCT), and the overhead/peripheral placement of lighting. The research was conducted with two online image-based questionnaire evaluations of 7 different lighting settings specifying their illuminance level, CCT, and placement as overhead or peripheral lighting depicted in images from the DIALux simulation. In the first questionnaire, subjects were asked to rate the difference between the two lighting displays being compared and the combination of the seven lighting settings. In the second questionnaire, subjects were also asked to rate their relaxed-tense and alert-fatigued perceptions of the lighting diplayed in the image. The results of these two questionnaires were analyzed by multidimensional scaling and correlation analysis. This image-based research concluded that a relaxed/tense perceived mood correlated negatively with the CCT, and an alert/fatigued perceived mood correlated negatively with the illuminance level and the CCT.

KEY WORDS
Alert, correlated color temperature, fatigue, illuminance level, lighting placement, relaxed, tense

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Introduction

Lighting that provides visual comfort will positively impact the recipient's mood. The lighting relates to employees' work performance and positive mood (Katabaro and Yan, 2019). Attention should be carefully paid to the issue of mood conditioning, as a person being too activated might lead to an uncomfortable level of hyperarousal and pressure that disturbs that person's (a worker's) mood. Such a situation may indirectly lead to decreased work performance (Daurat et al., 1996; Lamb and Kwok, 2016). In such a case, relaxation mood conditioning, which reduces focus or activation levels, might be needed (Baas, de Dreu & Nijstad, 2008), notably to support an optimum night's sleep. Providing relaxation that suits and complements humans' circadian cycles is expected to improve an individual's sleep quality. The good quality of prior sleep seems to be essential in influencing a person's positive mood the following morning (Bower et al., 2010).

Workplace lighting that considers the correlated color temperature (CCT) and illuminance level can be a stimulus for both activating and relaxing, where both are needed. Such a stimulus can be created by artificial lighting (Kim, 2018). The activating function can be achieved by lighting; therefore, relaxation is also expected to be achievable via a lighting stimulus. This article aims to explain the results of research related to subjective perceptions of a room with different lighting settings, highlighting the variables of illuminance level, the CCT, and the placement of the lighting, to study a correlation between the lighting setting with relaxed/tense and alert/fatigued moods in the workplace.

Literature Study

According to the Coldwell Banker Richard Ellis (CBRE), by 2040, the office will be seen as 'a reward', and working will be a comfortable and luxurious experience, not merely a place to enable something to happen. The tendency and driver that may develop is increased concern over the mental health of employees/workers. This concern can be met by providing a system that cares for and implements their psychological and physical health, performance, and productivity. By improving the employees' commitment at work and ability to deal with organizational pressures, the expected result should lead to competitive benefits in productivity and staff wellbeing. At least half of the absenteeism numbers in an organization result from stress caused by work (CBRE, 2016). Work conditions deemed 'too hard' lead to decreased mental and physical quality, frequently culminating in what is referred to as 'burnout' (Philips, 2013). It has also been stated that emotional needs and absenteeism levels were closely related to the levels of individuals' workloads (van Woerkom, Bakker & Nishii, 2016).

A desired or optimal mood in the workplace needs to be maintained to activate the employees' motivation levels, as well as increase and support their work focus (Baas, de Dreu & Nijstad, 2008), perform improvement (Boubekri & Wang, 2012) and also positively influencing levels of work satisfaction (Judge & Ilies, 2004). Positive mood is indicated when employees are alert, enthusiastic, and active (Watson, Clark & Tellegen, 1988); factors depicting strength and satisfaction (Hsieh, 2015). A good mood will support cognitive ability and motivation (Liew & Tan, 2016), resulting in more creativity in some types of work activity (Davis, 2009) and in certain conditions (George & Zhou, 2007). Meanwhile, a negative mood is a condition where the subject feels uncomfortable and/or unmotivated (Watson, Clark & Tellegen, 1988); a situation where the appearance of pressure, tension, stress, nervousness, depression, and fatigue can be noted (Hsieh, 2015). A positive mood can often foster creativity, whereas a negative mood can be a sign or symptom of problems that hinder an employee from thinking creatively (George & Zhou, 2007).

Lighting may be seen as a simple system that only affects visuals. This argument does not pay attention to the impacts of lighting on *neuroendochrine* and psychological states (Bickford, 1980), such as mood and depressive behavior (Lamb & Kwok, 2016; Lee, Moon & Kim, 2014; Stephenson et al., 2012). Lack of lighting exposure can negatively affect the condition known as Seasonal Affective Disorder (SAD), which can negatively affect a person's sleep and reduce their alertness (Gomes & Preto, 2015; Stephenson et al., 2012). This impact will continuously occur, exacerbating the SAD syndrome as the lack of sleep will increase mood sensitivity (Dinges et al., 1997).

Two lighting parameters often related to lighting research regarding mood are illumination level and CCT. The illuminance level relates to the issue of subjective alertness (van Duijnhoven et al., 2018). It influences an employee's alertness level and the quantity and quality of their work errors, as seen through the decrease in work speed as a form of fatigue in low illuminance level environments (Boyce, 1970). However, a high illuminance level might lead to a slower response rate as the background lighting can be too bright, distracting the individual's attention during task performance (Min et al., 2013).

Meanwhile, CCT of the lighting is important to worker productivity (Zumtobel, 2014). The variety of CCT impacts visual comfort, especially for color clarity (Revantino et al., 2018). CCT relates to the perception of light brightness (Toftum et al., 2018) and significantly influences spatial lightness, visual comfort, satisfaction, and subjective productivity (Wei et al., 2014). Lighting with high CCT (17.000 K) can be an effective intervention for increasing productivity levels in a workplace (Mills, Tomkins & Schlangen, 2007).

Meanwhile, not only to condition alertness, providing relaxation in the workplace might be needed to reduce emotional fatigue and increase the pace of a person's physiological and psychological recovery as they respond to or are affected negatively by a stressor: for example, anxiety (Wilczyńska et al., 2019). Our body has an important role in coping with work stress and manifesting its ability to recover so that we can be motivated when waking up the following morning (Parker et al., 2020). If the need for resting cannot be fulfilled, the employee might become more stressed, resulting in reduced work performance and possibly physical or even mental sickness (Mednick, 2002). Time pressure and a heavy workload make it hard for workers to detach themselves from their work during their break time (Sonnentag & Fritz, 2007). Moreover, prolonged and/or heightened activation levels can

often result in an individual finding it difficult to relax during their break time (Sonnentag & Fritz, 2007).

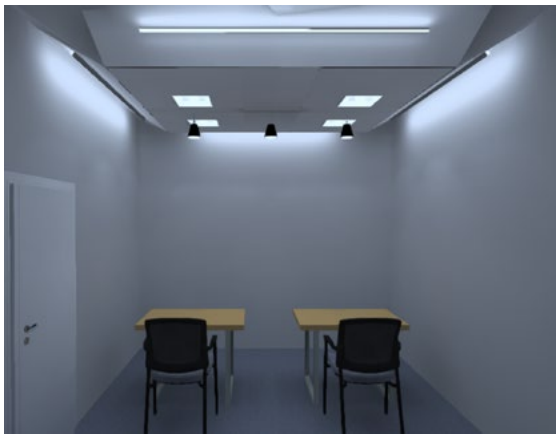
Relaxation can be provided by the lighting setting (Kim, 2018). Another article stated that the relaxation process could be speeded up using a blue lamp rather than a lamp giving off a white light (Minguillon et al., 2017). The rapid changing of the lighting hue to a higher chroma creates a lively atmosphere that can lead to activation; equally, the arrangement in reverse can be calming and supportive of relaxation (Li et al., 2019). Previous research on lighting and relaxed mood (Flynn et al., 1979) concluded that relaxed perception could be conditioned in a room with dim, peripheral, non-uniform lighting. In other literature, besides non-uniform and peripheral lighting, the issue of lighting color has been said to strengthen subjective relaxed impressions (Flynn, Segil & Steffy, 1988).

Methodology

This study observed the impression of subjective perceptions of a room with different lighting settings in: a) the illuminance level, b) the CCT, or c) the placement. Data collection was carried out by distributing online questionnaires since the researchers, in the context of data collection, avoided conducting face-to-face meetings in closed rooms during the Covid-19 pandemic.

This questionnaire displayed the appearance of a room with seven lighting settings taken from a DIALux simulation that was made as realistic as possible. The use of static visual media (Heft & Nasar, 2000; Jones & Reinhart, 2017; Manav, 2013; Totir, 2007) for the research related to perception (Huang, 2004) was considered able to represent the physical conditions of the room, particularly lighting (Eissa & Mahdavi, 2001; Mahdavi & Eissa, 2002); besides video and virtual reality (Chen, Cui & Hao, 2019). Image can be a tool for research to replace real settings that are more expensive (Newsham, Marchand & Veitch, 2004) as well as a simulation in lighting (Schielke, 2016).

The test cell of the simulation is a room of 3.3 m x 2.8 m x 3 m and equipped with two worktables and chair sets with wooden surfaces and 40% reflectance. The drop ceiling and wall color were white, with 85% and 57% reflectance, respectively. The floor carpet was a single-colored grey with 20% reflectance. The door material was plastic white 0.90 m x 0.13 m x 2 m with 76% reflectance. The test cell used the surface-mounted type Philips BN132C PSU L900 1 x LED9S/830 for the overhead lighting and Philips NA 1x Bulb 9W 2700K E27A60 929001150 NA for the peripheral lighting. The overhead lamp was 950 lm, 10 watt, with 95 lm/W efficacy and 100% light output ratio. The peripheral lamp was 807 lm, 9-watt, 98 lm/W efficacy and 100.2% light output ratio. Both overhead and peripheral lighting have a maintenance factor of 0,8. The lighting was arranged on 2700 K, 4000 K, and 6500 K of CCT.

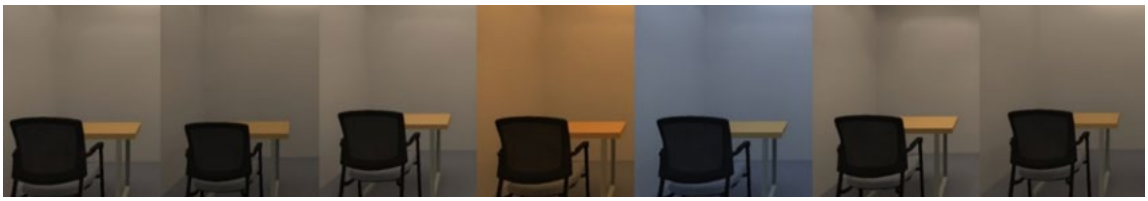


» **Figure 1:** *The DIALux-based image of the test-cell*

The seven lighting conditions were simulated and displayed in different terms of (1) illuminance levels, (2) CCT, and (3) lighting placement as the independent variables. The visualization results of the DIALux simulation were used to explore the effect of relaxed-tense and alert-fatigue perceptions as dependent variables. The images from the simulation result were displayed without showing the lighting setting so that such information would not affect the subjects' assessment responses. The following is the sequence of lighting settings:

1. The control condition that combined overhead peripheral lighting in 4000 K and created 258,5 lx in the workplane
2. The dim lighting that combined overhead peripheral lighting in 4000 K and created 124,8 lx in the workplane representation of dim lighting
3. The bright lighting that combined overhead peripheral lighting in 4000 K and created 390,3 lx in the workplane
4. The warm lighting that combined overhead peripheral lighting in 2700 K and created 255,0 lx in the workplane
5. The cool lighting that combined overhead peripheral lighting in 6500 K and created 254,3 lx in the workplane
6. The direct lighting distribution that only turned on the overhead lighting in 4000 K and created 254,3 lx in the workplane
7. The indirect lighting distribution that only turned on the peripheral lighting in 4000 K and created 254,3 lx in the workplane

The three illuminance levels were compared to study the effect of bright and dim lighting on viewers' relaxed – tense, or alert – fatigue mood. The chosen levels were based on the technical specification of the lamps



» **Figure 2:** *The appearance of seven lighting settings*

used in the simulation. When the test cell was exposed to only overhead or peripheral lighting to assess the placement variable, the 100% direct and bulb lighting, or 100% peripheral lighting, could only achieve 254 lx, hence adopted as the controlled setting standard at 260 lx. This value was then applied in other settings when observing the CCT variable. The bright lighting was set to a higher illumination level than the control condition. It can be achieved by turning on 76% of the bulb and 100% of the peripheral lighting. A lower illuminance level presented a dim setting by turning the lighting on 20% of the bulb and 35% of the peripheral lighting. The bright and dim lighting level was arranged to have the same 130 lx differences with the control condition.

This research compared two different 2700 K and 6500 K to observe the effect of CCT. Some studies compared the same level of CCT for researching the effect of lighting on mood (Hsieh, 2015; Smolders & de Kort, 2017) or alertness (te Kulve et al., 2018). Like this research, a study applied 4000 K beside 3000 K and 6500 K to observe the effect on mood and visual response (Lee, Moon & Kim, 2014). At the same time, the overhead and peripheral lighting placement was included as the variable to assess the differences between placements' effects. This method was applied by other researchers that studied the effects of lighting distribution on occupants' emotions (Fleischer, Krueger & Schierz, 2001; Shin et al., 2015) or mood (Hsieh, 2015), which were eventually affected by the placement of the lighting.

This research consisted of two questionnaires. In the first questionnaire, the seven lighting settings were compared to each other to assess their differences. The questionnaire was compiled by comparing two lighting settings presented in sequence. The test scale included in the questionnaire used a scale of 1 - 7. A value of 1 meant no difference, while 7 meant a massive difference between the two compared images. In this similarity-dissimilarity test, 42 setting pairs were compiled, a comparison combination of 7 lighting settings. The data from the first questionnaire was analyzed by multidimensional scaling (MDS) from SPSS. The MDS analysis could provide information about lighting variables needed to interpret the correlation analysis result of the second questionnaire.

In the second questionnaire, the research explored impression ratings with a bipolar rating scale. Bipolar scaling in the form of a semantic differential was used to express the subjective effect of various lighting settings on a room (Flynn et al., 1979). The impression rating of the selected evaluative scales was adjusted for the study, namely *relaxed–tense* and *alert-fatigue*. Subjects were asked to assess the room due to the influence of the seven lighting settings. The ratings were in the range of 1 – 7. In the relaxed-tense assessment, 1 means a 'relaxed impression,' and seven represents a 'tense'. In the alert-fatigue assessment, 1 indicates an 'alert impression' and seven as a 'fatigue impression'. The result was then analyzed with the SPSS Pearson Correlation test to see the correlation between the dependent and independent variables.

The subjects of this study were 42 students and alums (16 males, 26 females) from an interior design department of Universitas Sebelas Maret who were not colour blind, either totally or partially. Subjects were categorised as adults with an age limit of 18-40 years and had very similar social and professional backgrounds, ages, and education.

Results

This study observed subjective perceptions relating to relaxed-tense and alert-fatigued mood states in a room exposed to different types/levels of lighting. This study included the CCT variables in the 3D model not presented in Flynn's 3D model. The CCT variables replaced the uniform / non-uniform variables from the Flynn model that were not observed in this study. The MDS result was then used to interpret the correlation test result based on the subjective ratings in relaxed-tense or alert-fatigue mood assessment. In the range of 1 – 7, the lower level given means, the more relaxed or alert mood perceived by the subject. On the contrary, the higher level resulted means a more tense or fatigued mood perceived by the subject.

The perception of differences between lighting settings

The differences between lighting settings perceived by the subjects were analyzed with MDS. Table 1 presents the coordinate positions of the seven lighting settings resulting from the analysis for each of the three dimensions observed. The distance between 2 or more lights

on the dimensional axis showed the lighting characteristics that distinguished them. The analysis results only showed the position of each lighting source; hence naming the dimensions was the researchers' interpretation (Flynn et al., 1979) after examining the seven lighting settings and was based on the characteristics that distinguished each of the seven settings.

Table 1

Coordinate of MDS result

Lighting Setting	Dimension 1	Dimension 2	Dimension 3
Setting 1	0.8023	0.0591	0.5217
Setting 2	0.7298	-0.0418	-1.0287
Setting 3	0.8868	0.0107	0.1591
Setting 4	-2.1425	1.8379	-0.0225
Setting 5	-1.9624	-1.9546	0.0703
Setting 6	0.7925	0.1080	0.6736
Setting 7	0.8935	-0.0193	-0.3734

This explanation could be seen from settings 4 and 5 that differed in the CCT. They had opposite coordinated positions on dimension two; dimension 2 was CCT axis with warm white on the positive coordinate and cool white on the negative coordinate. The same tendency also occurred in settings 6 and 7, which differed in the lighting placement. They had opposite coordinated positions on dimension three, so it can be interpreted that dimension 3 was the lighting placement axis with overhead representing positive values and peripheral representing negative values.

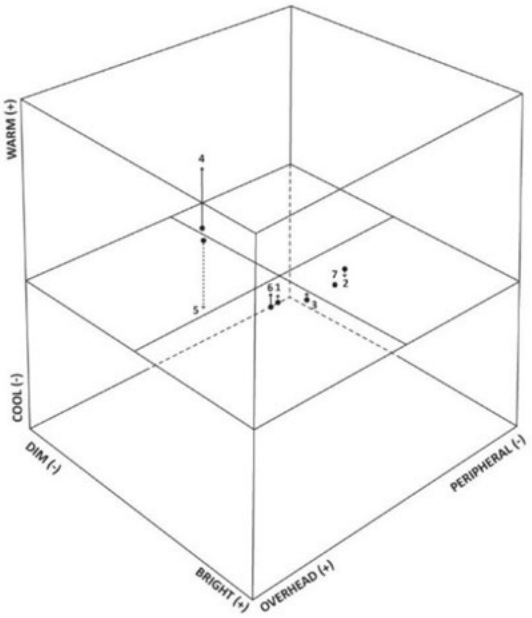
Although the other two axis had been named except for dimension one, and the rest variable was the illuminance level, the interpretation could not be made directly. It was because the dim–bright lighting conditions did not show opposite coordinates of difference perceived by the subject. This result might be because if the dark state were in the zero position, there would be no brightness level that a negative coordinate can represent. However, the result of dimension one can be arranged in order of lighting 3 (bright in 0,8868), 1 (control in 0,8023), and 2 (dim in 0,7298). So, the more positive coordinate can be interpreted as bright lighting. Meanwhile, the negative coordinate may represent dim lighting.

The dimension interpretation is summarized in Table 2. The interpretation and the MDS result coordinates can be modeled in Figure 3.

Table 2

The interpreted dimension for MDS analysis result

Lighting Setting	Dimension 1
1	Bright (+) / Dim (-)
2	Warm (+) / Cool (-)
3	Overhead (+) / Peripheral (-)



» **Figure 3:** *The position of seven different lighting in MDS analysis result with interpreted axis names*

The perception of relaxed-tense and alert-fatigued mood perceived between lighting settings

Subjective perceived relaxed-tense mood states showed a correlation with CCT (r stat = 0,172 > r table = 0,114, Sig (2-tailed) = 0,003 < 0,01) in negative coefficient.

Different results appear on the relaxed-tense mood states with illuminance level (r stat = 0,086 < r table = 0,114, Sig (2-tailed) = 0,140 > 0,01) and placement (r stat = 0,012 < r table = 0,114, Sig (2-tailed) = 0,834 < 0,01) as they did not show any correlation.

Subjective perceived alert-fatigue mood states showed a correlation with illuminance level (r stat = 0,172 > r table = 0,114, Sig (2-tailed) = 0,003 < 0,01) and CCT (r stat = 0,266 > r table = 0,114, Sig (2-tailed) = 0,000 < 0,01), both in negative coefficient.

Different results appear on the alert-fatigue mood states with placement (r stat = 0,074 < r table = 0,114, Sig (2-tailed) = 0,209 > 0,01) that they did not show any correlation.

Discussion

The correlation analysis results can be interpreted as the axis had been named. The Pearson analysis showed a correlation between relaxed-tense mood and CCT. This result was in line with the conclusion that CCT significantly affects the relaxed feeling (Chen, Tsai & Tsay, 2022). The negative coefficient on the result means

that the warmer CCT, the subject will be more relaxed and the cooler the CCT will lead to a more tense mood. This finding is in line with another research finding that relaxation can be provided warm (Kim, 2018) or low CCT (Chao et al., 2020); hence it can be used for relaxation (Dugar & Agarwal, 2019) and resting (Yu & Akita, 2019). On the contrary, the cool white with high CCT was concluded to provide a tense feeling (Kim & Mansfield, 2021). However, this result was the opposite of some research statements that cool CCT had a relaxing effect on the subjects (Iwata, 2012).

The Pearson analysis showed a correlation between alert-fatigue mood with illuminance level and CCT. The negative coefficient on the result means that the brighter lighting (He et al., 2020; Leichtfried et al., 2015; Maierova et al., 2016) and warmer CCT, the subject will be more alert. In line with these findings, another research concluded that the bright CCT leads to alertness, so recommended to be applied in the office (Zhu et al., 2019). Meanwhile, the lower CCT makes the subject react faster (te Kulve et al., 2018). On the contrary, the dimmer lighting and the cooler CCT relate to fatigue mood. This result was the opposite of another research that concluded higher CCT (Askaripoor et al., 2021; Chou, Lu & Huang, 2016; He et al., 2020; Kazemi et al., 2018; Toftum et al., 2018) and low illuminance level lead to alertness (He et al., 2020).

Unfortunately, there is no sufficient proof to show the correlation between the relaxed-tense mood with illuminance level and both moods with lighting placement. The correlation found in this research also seemed questionable, as both relaxed and alert mood perceived by the subjects relates to the same high CCT. This result might be affected by the image as the research tool since another research found an inconsistency of CCT perception between simulation and actual size mock-up research (Schielke, 2016).

Moreover, the image is accessed from the subjects' devices. The researchers did not control the device's brightness, the time, and the lighting condition of the place (indoor or outdoor) where the subjects filled out the questionnaire. This missing point can be the weakness of this research, as there was research using an image-based approach. The previous study was conducted in a particular time and a room with the same lighting condition by using printout images (Totir, 2007), projecting the calibrated appearance images (Newsham et al., 2005), or displaying the images in a computer screen (Heft & Nasar, 2000; Prasetyaningsih, 2006). Therefore, future image-based research might need to consider the timing, device brightness, and room lighting used by the subject when filling out the questionnaires.

Conclusion

This image-based research observed subjective perceptions relating to relax-tense and alert-fatigue in a room exposed to different types/levels of lighting with the illuminance level, CCT, and lighting placement. The data were analyzed with MDS and Pearson correlation tests. The MDS analysis resulted in a 3D model with dimension one representing the bright (+) and dim (-) illuminance level axis, dimension 2 representing the warm (+) and cool (-) CCT axis, and dimension 3 representing the overhead (+) and peripheral (-) lighting placement. This dimension was used to interpret the correlation analysis result. The Pearson correlation analysis found:

1. Negative correlation between the relaxed-tense mood state with the CCT, which might mean the warmer lighting relates to a relaxing mood, and

2. The negative correlation between the alert mood state with the CCT and illuminance level, which may mean the warmer and brighter lighting relates to alert mood.

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Properties and interaction of layers in board-biodegradable primer-printing ink screen-printed system

ABSTRACT

Surface interactions of the materials during and after the printing process are extremely important for understanding and optimizing the process of graphic reproduction. In screen printing on porous and absorbent substrates, mesh type and ink composition significantly influence the properties of the printed product. To protect the absorbent printing substrates such as board from moisture penetration and to ensure the optimal interaction of the printed ink layer and the substrate, board substrates can be coated with protective primers before printing. In this research, biodegradable primers made of poly(ε-caprolactone) and poly(lactic acid) were applied on the board substrate which was then screen-printed using two screen rulings of the mesh and two different types of water-based printing inks on unprimed and primed board substrates. Printed ink layer thickness, surface roughness, water vapor transmission rate, surface free energy and adhesion parameters were measured/calculated on all produced samples. Microscopy of the printed elements was performed to visualize the influence of the primers on the printed line edge. Results of the research have shown that the primers influence the roughness reduction of the printed ink layer. Furthermore, thickness of the printed ink layers increased when the primers were applied on the substrate, pointing to the decreased permeability of the board, which was confirmed by the reduced water vapor transmission rate of the primed and printed substrates. The surface free energies of the tested surfaces and the adhesion parameters between biodegradable primers and prepared printing inks differed depending on the type of the ink and primer, pointing to the optimal combination of the primer and ink for the favorable acceptance of printing ink on the substrate. Results of this research have enabled the optimization of the quality of screen-printed board product.

KEY WORDS
Biodegradable primer, PCL, PLA, screen printing

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Introduction

Modern packaging production has a significant share on the market of printed products (Kipphan, 2001). In recent years, packaging industry has faced the new trends in terms of design, ecology, protection, and the added value of the printed products while at the same time maintaining or even increasing the quality of the packaging products (Makower, n.d.). Printed packaging products have to protect the product they contain, while being visually appealing to the end customer (Sharma et al., 2017; Kovačević, Brozović & Itrić Ivanda, 2019). Furthermore, the trends regarding the application of biodegradable and other new functional materials have resulted with the modification of the conventional printed packaging products (Khwaldia, Arab-Tehrany & Desobry, 2010; Anselmann, 2001). Board printing substrates generally have acceptable printability properties, but due to their surface and physical properties, they often need to be coated before the printing to ensure all their intended

purposes in the lifespan of the final product. Board coatings (primers) can improve the visual, as well as mechanical, surface, and other properties of the substrate. They can have a purpose of a barrier to the gas and liquid. However, primers applied to the board substrates must preserve, or even improve the printability of the substrate, since the properties of the printing substrate greatly influence its suitability for the commercial graphic reproduction techniques (Mahajan & Bandyopadhyay, 2020).

Considering the increasing use of biodegradable materials in many industries with the aim of reducing the environmental impact of conventional materials, the need to switch to environmentally friendly processes and materials has arisen in the printing industry, as well (Vruno, n.d.; Wilson, n.d.). The advantage of biodegradable polymers over the conventional ones is their ability to degrade faster than conventional polymers (Song et al., 2009; Tokiwa et al., 2009).

Therefore, chosen primers for the board printing substrate used in this research consisted of biodegradable polymers: poly(ε-caprolactone) (PCL) and poly(lactic acid) (PLA). PCL is a synthetic biodegradable polymer with hydrophobic properties and a semi-crystalline structure. Its melting point is as 60°C, and its glass transition temperature is −60°C (Kelly et al., 2013). PCL has excellent elastic deformability. One of the most interesting properties of PCL is relatively good miscibility and compatibility with other polymers (López-Rodríguez et al., 2006; Woodruff & Hutmacher, 2010).

In polymer blends, the addition of PCL can improve the resistance to cracking of the material. PLA is one of the most widely applied biodegradable polymers today. It is obtained from lactic acid by the process of fermentation of agricultural crops.

Melting temperature of PLA is 170°C and the glass transition is at 60°C. PLA is very often used in packaging, agriculture, medicine, and in 3D printing application as a filament (Tokić, Fruk & Jemrić, 2011; Chavalitpanya & Phattanarudee, 2013; Nampoothiri, Nair & John, 2010; Rasal, Janorkar & Hirt, 2010).

Previous research on PCL and PLA proved them as suitable board primers when using offset printing technique (Hudika et al., 2020). PCL/PLA composites have also been successfully applied as alternative materials for the relief printing plate production (Poljaček Mahović et al., 2021a; Priselac et al., 2022).

The aim of this research was to improve the physical and surface properties of the board printing substrate, specifically the water vapor permeability and adhesion between the printing ink and the substrate by application of PCL and PLA primers prior to the printing process.

By printing on the primed substrates in screen printing technique and using two types of water-based printing inks, it was possible to determine the influence of the applied biodegradable primers on the printed boards' properties of interest.

Materials and methods

Preparation of the samples

In this research, uncoated offset board Sappi Tauro with grammage of 300 g/m^2 was used as a printing substrate. Uncoated board was chosen for this research specifically because of the application of the PCL and PLA primers prior to the printing process. Board was stored in conditioned environment at temperature of (23 ± 1)°C and (50- 55)% relative humidity prior to the application of the primers, printing and measurements.

Biodegradable primes were prepared by stirring the PCL/ethyl acetate mixture, and PLA/chloroform using magnetic stirrer in air-tight container for 120 min to obtain the homogeneous solution. Primers were prepared by dissolving 10 grams of poly(ε-caprolactone) 6800 Capa in 90 grams of ethyl acetate; and by dissolving 10 grams of poly(lactic acid) by InegoTM, 3251D, in chloroform. The prepared biodegradable coatings were applied on board samples using K202 Control Coater in controlled conditions defined by the ISO 187:1990 standard, using the rod number 4 (Hudika et al., 2020).

Printing inks used in this research were prepared by mixing 5 grams of black process K print pigment in 95 grams of water-based Midrol Bianco or water-based Midrol Transparente screen printing bases, produced by EPTA Inks. In this way, two types of screen printing inks were prepared: one ink with the transparent base, denoted TBI, and the other ink with opaque white base, denoted WBI. Printing process was performed using two screens with different mesh counts: 32 l/cm and 60 l/cm.

Meshes were produced by SEFAR® and made of polyethylene terephthalate. Printing process was performed using a screen-printing machine Bochonow Drucktisch 2000 50/70. Printed samples were air-dried for 48 h after the printing, at a temperature of 25 ± 2°C.

Methods of measurement and analysis

Surface roughness of the board, primed board and prints were measured to define the influence of the primers and different screens on the surface of the prints. The profiling method for the roughness measurements was defined by international standards (ISO 11562, DIN 4777, DIN 4762).

Two basic roughness parameters were measured: Ra- the arithmetic mean deviation of the profile, and Rz- mean height of unevenness in ten points, numerically the difference in mean height between the five highest peaks and the five lowest peaks within the reference length. The device MarSurf PS 10 (Mahr GmbH, Germany) with the stylus method was used for the measurements. The diameter of a stylus was 2 µm and measuring force was 0.00075 N. Measurements were performed ten times in two directions (in the grain direction and in the opposite direction), on each sample and the results of the mean values with standard deviation were presented.

Thickness of the printed ink layer was measured using SaluTron D4-Fe device, using the principle of magnetic induction for measuring the thickness of layers on non-magnetic surfaces. The results of the printed ink layers' thickness obtained using different inks and by printing on different primers were used to determine the possible decrease of the substrate's absorptiveness after the application of the primers.

Water vapour transmission rate (WVTR) is an important indicator of the efficiency of absorbent packaging materials such as board (Song, Xiao & Zhao, 2014). The higher the water vapour permeability of the material, the faster the vapour passes through it, i.e., the higher the WVTR. In this research, the 'cup method' was used to analyse the permeability of the unprimed, primed and printed board substrates to water vapour. Detection of the water vapour leaving the cup through the board samples was performed on unprimed, primed and printed substrates, using the same experimental setup and following the procedure described in (Cigula, Hudika & Tomašegović, 2021): the container was filled with 50 ml of water. Then, the lid with the hole (diameter of 35 mm) was put on the container and tightly covered with test sample. The samples fixed onto containers were placed in a desiccator containing silica, with (50 ± 5) % relative humidity after the initial weighing The temperature of the environment was (23 ± 1) °C. After the weighing of the samples, performed after one and two days, water vapour transmission rate (WVTR) was calculated using Equation (1) (Cigula, Hudika & Tomašegović, 2021).

$$WVTR = \frac{\Delta m}{\Delta t * A}, \quad (1)$$

where Δm is the difference in sample mass (in grams), Δt is the time period (in days) and A is the area of lid opening (in m^2). The calculated coefficient WVTR presents the weight of water vapor that passed through an area of 1 m^2 in one day (unit of measurement is $g \cdot m^{-2} \cdot day^{-1}$).

Contact angles of the referent liquids and surface free energy (SFE) of the samples were analysed using the Data Physics OCA 30 goniometer. Three referent liquids with known SFE were applied on the board, primed board and printed samples: water, diiodomethane, and glycerol. SFE of the referent liquids and their contact angles on the samples were used to calculate the SFE of the solid substrates. Contact angles were measured by sessile drop method, ten times on each sample, at different positions. The shape of the drop was a spherical cap, and the volume of the drop was 1 µl. All measurements of the contact angles were performed at 0.4 s (10 frames) after the drop had touched the sample surface, due to the absorption of the liquids in some samples. SFE was calculated using a well-known OWRK method. From the calculated SFE components, the adhesion parameters between the layers in the "board-primer-printing ink" system were calculated (Azarhoosh, Moghadas Nejad & Khodaii, 2017). The work of adhesion (W_{12}) (Equation (2)) between the layers in contact was defined in order to predict the strength of interactions (Żenkiewicz, 2007; Tomašegović et al., 2021):

$$W_{12} = \gamma_1 + \gamma_2 - \gamma_{12}, \quad (2)$$

where the subscript refers to SFE of the solids in contact and the γ_{12} denotes the surface free energy of the interphase. Surface free energy of the interphase (γ_{12}) was calculated according to Equation 3:

$$\gamma_{12} = \gamma_1 + \gamma_2 - 2\sqrt{\gamma_1^d \gamma_2^d} - 2\sqrt{\gamma_1^p \gamma_2^p} \quad (3)$$

The wetting coefficient (S_{12}) indicates the spontaneity of spreading on the solid surface if the value is positive or equal to zero, while the negative value implies that the wetting is not complete (Equation (4)):

$$S_{12} = \gamma_1 - \gamma_2 - \gamma_{12}, \quad (4)$$

where γ_1 and γ_2 denote SFE of the solid layers in contact (board and printed ink layer), and γ_{12} denotes SFE of their interface.

Finally, 2D microscopy of the edges of printed elements was used to visually analyze the influence of the primers on the edges of the printed motives using both water-based inks. Microscope Olympus BX 51 was used, and magnification was set to 50x.

Results and discussion

Roughness of the printed surfaces

Roughness parameters Ra and Rz of the board substrate were measured before the priming and printing: Ra = 2.34 ± 0.18 µm, Rz = 14.56 ± 0.99 µm. After coating the board with biodegradable PLA and PCL primers, no significant effect on Ra and Rz was observed, due to the evaporation of the solvents and partial absorption of the primer solutions in the porous surface layer of the board.

Specifically, Ra of the board coated with PLA primer was 2.24 ± 0.12 µm, and Rz was 14.62 ± 0.84 µm. Ra of the board coated with PCL primer was 2.50 ± 0.09 µm, and Rz was 14.98 ± 0.65 µm.

Ra and Rz parameters of the printed unprimed and primed surfaces are shown in Figure 1.

The lowest values of Ra were measured on a board substrate printed with WBI (Figure 1a), using screen with 60 l/cm (1.56 µm for WBI on board, 1.50 µm for WBI on PLA, and 1.62 µm for WBI on PCL). Highest values of Ra were measured on a board substrate printed with TBI (3.02 µm for 32 l/cm screen, and 2.80 µm for 60 l/cm screen).

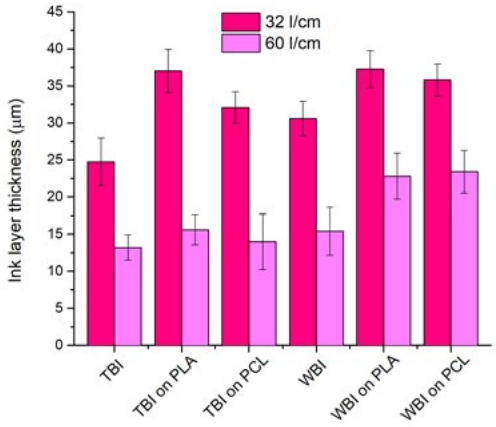
Similar trend of the results is visible when observing the parameter Rz (Figure 1b). The lowest values of Rz were measured on a board substrate printed with WBI, using screen with 60 l/cm (8.55 µm for WBI on board, 8.90 µm for WBI on PLA, and 8.66 µm for WBI on PCL). Highest values of Rz were measured on a board substrate printed with TBI (16.85 µm for 32 l/cm screen, and 15.29 µm for 60 l/cm screen).

With the addition of a layer of PLA or PCL primer under the TBI, the roughness of the printed surface decreased. Essentially, a smoother print due to the improved wetting of TBI on primed substrate (Figure 4c) was obtained compared to the TBI printed directly on board. Since TBI has lower values of SFE than WBI, (Table 1), the interaction of TBI with the substrates was favorable for obtaining a smoother and ink layer on the substrate. Biodegradable primers did not affect the roughness of WBI layer significantly. WBI is initially much denser than TBI and has SFE values closer to the values of the substrates it was printed on, which had a direct effect on the spreading of the ink on the substrate during the printing process.

Thickness of the printed ink layers

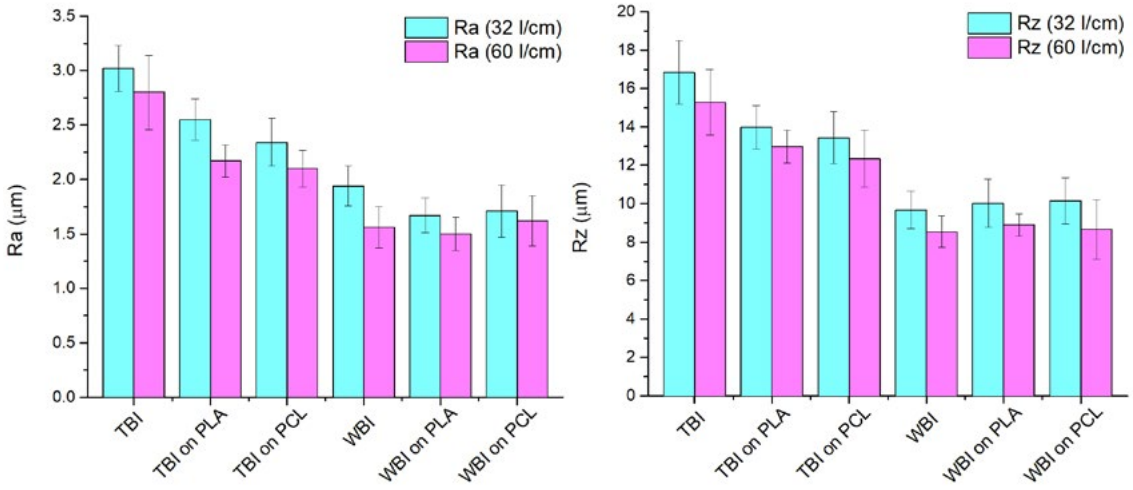
Printed ink layer thickness values are presented in Figure 2. The thickness of PLA and PCL on board could not be measured, since the primer layers were very thin due to their absorption in the board surface.

When observing the results presented in Figure 2, one can see that PCL and PLA primers had an effect of the increase of both TBI and WBI layer thicknesses. This effect can be related to the decreased absorptiveness of the board printing substrate after coating with PCL or PLA primers.



» **Figure 2:** *Thickness of the printed ink layers*

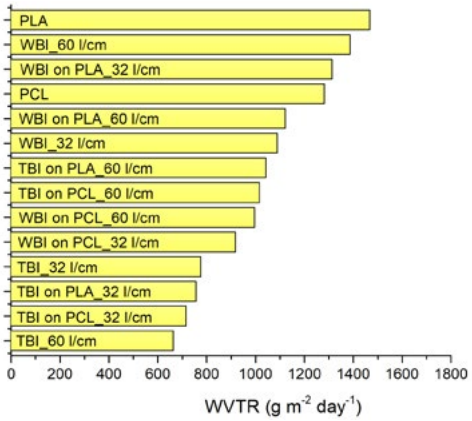
Furthermore, screen count had a noticeable effect on the thickness of the printed TBI and WBI layers. There is a clear and stable difference between the ink layers obtained using 23 l/cm and 60 l/cm screens. Furthermore, all printed WBI layers had higher thickness compared to the corresponding TBI layers, regardless of the applied primers or screen count. This occurrence is related to different compositions of transparent base and white base, which is thicker.



» **Figure 1:** *Roughness parameters of the printed surfaces: a) Ra, b) Rz*

Water vapor transmission rate

Figure 3 presents the relative WVTR in relation to the WVTR of the board without any primers or printed ink layers.



» **Figure 3:** *Water vapor transmission rate of the board, primed board and the samples with printed ink layers*

Calculated WVTR of the plain board was 1804 g·m^{-2}·day^{-1}. In Figure 3, the descending path is shown, ranging from the sample with the highest WVTR to the sample with the lowest WVTR. It is clearly visible that TBI as a layer on the board has the leading property of reducing the permeability to water vapor. The most expressed reductions of WVTR were achieved for four samples which contained a TBI layer and ranged from 663.54 g·m^{-2}·day^{-1} for TBI on board (60 l/cm screen) to 777.04 g·m^{-2}·day^{-1} for TBI on board (32 l/cm screen). Water vapor barrier properties of TBI can be related to the composition of TBI, where plastisol is present (Poljaček Mahović et al., 2021b).

On the other hand, PLA together with WBI presented the highest permeability to water vapor and thus contributed the least to the desired effect of reducing WVTR. Highest WVTR was calculated for PLA on board and amounted 1468.75 g·m^{-2}·day^{-1}. Similar results were obtained for WBI on board, obtained using 60 l/cm screen (1387.06 g·m^{-2}·day^{-1}), and for WBI on PLA, using the screen of 32 l/cm (1313.68 g·m^{-2}·day^{-1}). Due to its water vapor permeability (Halász, Hosakun & Csóka, 2015), PLA benefited from the combination with the printing inks used in this research, especially TBI. Furthermore, PCL alone on the board substrate was not the best solution for decreasing WVTR because its water vapor permeability was 1281.66 g·m^{-2}·day^{-1}. Similar to PLA, its combination with TBI or WBI improved the WVTR.

Although the PLA and PCL primers alone did not decrease the WVTR as much as TBI layer, their application on the board substrate was significant for the improvement of the ink adhesion, presented in 3.4.

Surface properties and interactions of layers in "board-biodegradable primer-printing ink" system

Although the contact angles were measured on the surfaces of all samples, no distinction between the same ink layers obtained using different screen counts was made when calculating SFE. Since the thickness of all printed layers was enough to achieve the uniform and complete coverage of the board, no effect of the screen count on the contact angle values was observed. According to the results of SFE calculations, presented in Table 1, the highest total SFE was calculated for the PCL primer (44.32 mN/m), and the lowest SFE was calculated for TBI layer (20.24 mN/m). Furthermore, it can be observed that all surfaces had a dominant dispersive component of SFE.

Table 1

SFE components of the layers in "board-biodegradable primer-printing ink" system

	Total SFE (mJ/m^2)	Dispersive SFE (mJ/m^2)	Polar SFE (mJ/m^2)
Board	24.00	23.98	0.02
PLA layer	30.25	29.65	0.60
PCL layer	44.32	43.24	1.09
TBI layer	20.24	20.14	0.10
WBI layer	30.01	29.09	0.92

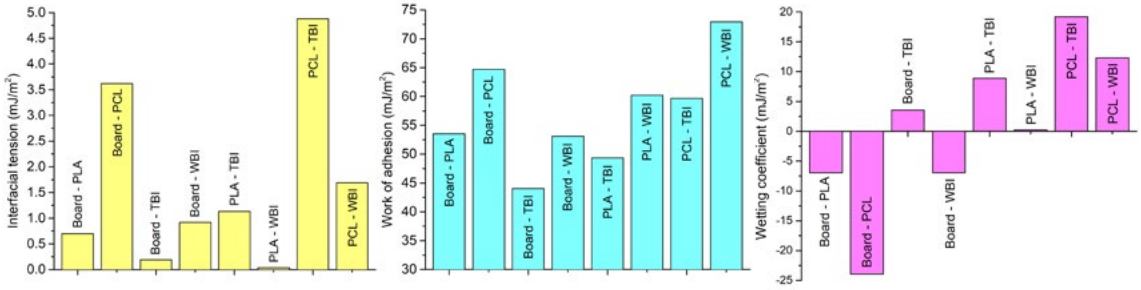
PLA and PCL primers have increased SFE of the board, which is an indication that the wetting and adhesion of the used inks on primed board should be improved.

In order to analyze the effect of the surface interactions of the primed board and the used inks and compare it to the interactions of unprimed board and the inks, adhesion parameters were calculated and presented in Figure 4.

Optimal adhesion is achieved when all three adhesion parameters meet the following criteria: the interfacial tension (γ_{12}) should be minimal, i.e., as close as possible to 0, the thermodynamic work of adhesion (W_{12}) should be maximal, and, finally, wetting coefficient (S_{12}) should be positive.

When observing Figure 4a, it can be seen that γ_{12} is closest to 0 for PLA and WBI (0.04 mJ/m^2), followed by γ_{12} between board and TBI (0.19 mJ/m^2). The highest, and least favorable γ_{12}, was calculated between PCL and TBI (4.88 mJ/m^2). W_{12} was highest between PCL and WBI (72.94 mJ/m^2), followed by W12 of 64.69 mJ/m^2, achieved between board and PCL (Figure 4b).

This means that the highest work is needed to separate these two pairs of layers. Lowest work of adhesion was calculated between board and TBI (44.04 mJ/m^2), pointing to the weaker adhesion between these two layers.



» **Figure 4:** *Adhesion parameters in "board-biodegradable primer-printing ink" system: a) interfacial tension, b) work of adhesion, c) wetting coefficient*

The last adhesion parameter, S_{12}, (Figure 4c), is positive for all combinations of primers and inks, pointing to the optimal adhesion of the inks and both PLA and PCL primer. Negative S_{12} is present between the board and the primers, as well as between the unprimed board and WBI. Negative S_{12} indicates that the spreading of the observed primer/ink layer on the board is not spontaneous, and could pose a problem with the mechanical properties and durability of the print (Tomašegović et al., 2021; Aydemir, Altay & Akyol, 2021).

However, in the case of PLA and PCL primers, this would not be the case, since they were applied on the porous, uncoated board substrate in the form of a solution which was partially absorbed in the surface of the board.

Furthermore, when assessing the adhesion performance, all three parameters should be considered at once. From the given results, it could be concluded that the best adhesion was achieved between PLA and WBI, and PCL and WBI.

Therefore, the primers had the most expressed effect on improving the adhesion of WBI ink on the board substrate. The adhesion of TBI ink on the board did not benefit from the application of the primers as much as WBI.

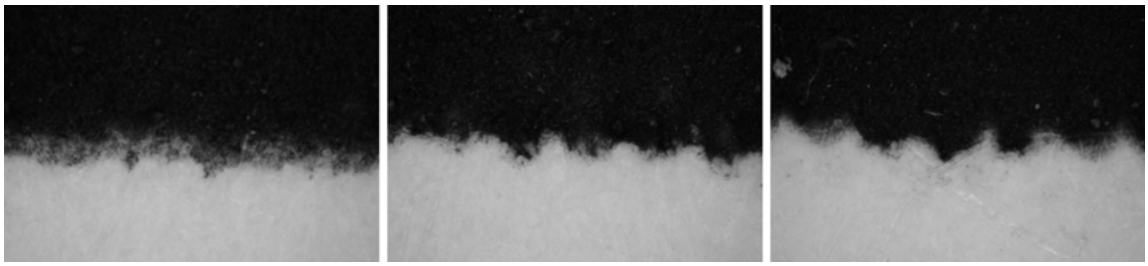
Nevertheless, W_{12} between TBI and the substrate was increased when the board was primed with PLA or PCL.

Microscopy of printed elements' edges

Figure 5 shows the chosen images of the printed element edges obtained by Olympus BX 51 microscope, with magnification of 50x. There was no noticeable difference between the printed element's edge when comparing TBI and WBI, and the effect of the PLA and PCL primers on the element's edge was more noticeable on the prints obtained using 32 l/cm screen. Therefore, the prints obtained using TBI and 32 l/cm screen were chosen for the comparison and presented.

When comparing the Figures 5a-c, it can be noticed that the gradient transition between the ink and board present on the print of the TBI on unprimed board, has disappeared when the ink is printed on the primed board. This can be attributed to the reduction of the board's absorbency after the application of the primers.

When comparing the edges of the printed elements, it can be seen that the realistic edge of the printed element is significantly more noticeable when the ink was printed on the primers (Figure 5b-c). The uneven character of the line edge is common in the screen printing and is a result of the mesh structure. This occurence is more pronounced when using the screens with lower mesh count, such as in this research. If the screen for the reproduction of the fine lines, with high mesh count, would be used, the prints on the primed board would have clearer line edges if the board was primed with PCL or PLA, compared to the prints on the plain board.



» **Figure 5:** *2D microscopy of printed elements' edges: a) TBI on board (no primer), 32 l/cm, b) TBI on PLA, 32 l/cm, c) TBI on PCL, 32 l/cm*

Conclusion

The aim of this research was to analyze the effect of biodegradable primers made of PLA and PCL on the properties of the uncoated board, in terms of the interaction with two types of common water-based screen printing inks (ink with the transparent base- TBI, and ink with opaque white base- WBI) and their influence on the permeability to water vapor.

Thickness and roughness of ink layers (printed using different inks and screen counts), as well as surface free energies and water vapor transmission rates, were measured/calculated. Surface free energy components were used to calculate the adhesion parameters between the layers in contact. 2D microscopy of the printed elements' edges was performed to visualize the effect of the primers on the line edge definition. From the obtained results, the following conclusions can be made:

- The addition of PLA and PCL primers under TBI caused the decrease of the roughness of the printed surface, but did not affect the roughness of WBI layer significantly;
- As expected, mesh count had a noticeable effect on the thickness of the printed TBI and WBI layers. Furthermore, PCL and PLA primers had an effect of increasing both TBI and WBI layers' thickness. The effect can be related to the decreased absorptiveness of the board after coating with PCL or PLA primers;
- TBI as a layer on the board had the leading property of reducing the permeability to water vapor, while PLA together with WBI presented the highest permeability to water vapor.
- Although PLA and PCL primers alone did not decrease the WVTR as significantly as TBI layer, or the combination of the primers and TBI ink, application of the primers on the board substrate was significant for the improvement of the ink adhesion,
- The best adhesion was achieved between PLA and WBI, and PCL and WBI. Therefore, the primers had the most expressed effect on improving the adhesion of WBI ink on the board substrate.

The results of the research have contributed to the optimization of the screen printed ink layers on the primed absorbent and porous substrates. They have described the important properties of the print obtained using two common types of water-based screen printing inks on the board substrate primed with PLA and PCL, specifically regarding the water vapor transmission rate and interaction of the biodegradable primers and printing inks for screen printing, thereby enabling the optimization of the quality of screen-printed board product.

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