Improving household waste management in Indonesia: A mixed-methods approach for waste Sorting

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ABSTRACT

This study explores effective interventions that improve household waste sorting and tests how labels, captions, and intervention campaigns enhance waste-sorting knowledge and improve waste-sorting practices. This study used a mixed–method approach using data collected from 29 households. The results from the survey were tested using a t-test comparison, the data obtained from the observation during the lab experiment were described, and the information from the interview was interpreted. The results show that the two interventions used in the study improved knowledge about waste and sorting practices. The results show significant differences between the groups before and after intervention exposure. Moreover, the findings highlighted that labels and captions do not help to reduce household waste generation. However, an intervention campaign was crucial in reducing the amount of waste produced by households.

1. Introduction

Solid waste is considered as a global challenge that causes various socioeconomic and environmental problems (Mir Mohamad Tabar et al., 2024). According to the study by C. H. Li et al. (2023) Global solid waste production is projected to increase significantly, reaching around 2.59 billion tonnes by 2030 and exceeding 3.40 billion tonnes by 2050. These growths are accelerated due to population, urbanization, and economic (C. H. Li et al., 2023; Zhang et al., 2024). As reported by the ASEAN Municipal Solid Waste Management Enhancement (2023), solid waste production in Southeast Asia is expected to increase by 150 % by 2025 compared to 1995 levels. Moreover, the World Bank documented that 33 percent of the global solid waste generated was poorly managed in 2018. Rakhmawati et al. (2023) argued that this is more prevalent in developing countries, where it exceeded 90 percent. Correspondingly, in 2020, the Indonesian Ministry of Environment and Forestry reported that 40.85 % of waste was mismanaged.

Solid waste poses significant threats to the environment, biodiversity, society, and the economy (C. H. Li et al., 2023). Among these

concerns, public health emerges as a primary consequence of solid waste. Moreover, environmental degradation and biodiversity loss are recognized as critical impacts of improper waste management. Specifically, household waste contributes to various physical and psychological health issues in the public (Fadhullah et al., 2022). Consequently, a concrete and well-established solid waste management strategy is critical to minimizing the adverse impact of solid waste. The Indonesian government established a comprehensive legal framework for solid waste management, the law 18/2008 on solid waste management (Listiningrum et al., 2023). This framework is further supported by Government Regulation 81/2012 regarding household waste and Minister of Environment Regulation 13/2012 regarding 3 R: Reuse, Reduce, and Recycle (Santoso and Farizal, 2019). These legal frameworks for waste management prioritize waste separation and encourage the public to tackle the problem at its source.

Effective solid waste management requires improved household sorting and a reduction in waste generation to minimize its environmental impact (Mir Mohamad Tabar et al., 2024). Waste management serves as a vital instrument in achieving sustainable development goals

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(Debrah et al., 2021) and accelerating the circular economy transition (Pretorius et al., 2023). Notably, effective waste separation at the source can also enhance resource recovery from household waste (Rousta et al., 2016). Accordingly, among the core principles of waste management is to establish practices and frameworks that facilitate the recovery and regeneration of resources from waste, thereby creating new value. This concept relates to a few aspects, including reuse, recycling, and reducing, which begin with sorting. For example, a study shows a strong correlation between circular economics and waste management (Crome et al., 2023). Besides, a review of household waste sorting behavior highlights that effective waste sorting is a crucial factor in advancing the principles of a circular economy (Jørgensen et al., 2023; Mielinger and Weinrich, 2023). Therefore, it is evident that sorting waste at the source into various categories is not only essential for achieving efficient recycling and waste recovery but also offers significant economic benefits (Rousta and Bolton, 2019).

The widely accepted household waste management method, particularly the waste sorting method, is based on waste composition and its utilization and disposal. In this regard, developed nations are leading in these practices, including Japan, Germany, and the Nordic Countries (Wang et al., 2020). However, it is still a drawback in developing nations. The absence of robust law enforcement, concrete regulation, and system support for these practices remains a barrier and challenge in tackling the problem. Furthermore, the lack of waste management education and know-how in these practices also persists as a significant challenge. Despite some government initiatives being considered in Indonesia, the issue is evident, particularly in rural areas (Pratiwi et al., 2019). Household waste management is often overlooked or misperceived by rural residents, primarily because practices like proper waste sorting are challenging and demand knowledge and skills for effectively separating materials. A survey reported that only 18.84 % of Indonesian residents separate waste at home (BPS (2017)). One of the reasons is that residents have little knowledge of waste sorting. Furthermore, Wang et al. (2019) argue that this is because of a lack of waste sorting knowledge, and many residents have low enthusiasm to participate in waste sorting activities, resulting in an unwillingness to sort waste in their daily lives. Besides, Government strategies, policies, initiatives, and lack of financial support are some of the drawbacks of solid waste management at the national level (Mir Mohamad Tabar et al., 2024). Furthermore, Zhang et al. (2024) reported that in 2020, the total household waste produced globally was approximately 1.8 billion tons. Indonesia alone was identified as one of the major contributors, generating approximately 67.8 million tons of trash in 2020, and almost 40 % of the solid waste generated originated from households, comprising various types of garbage. Thus, household participation in waste separation plays a significant role in minimizing the adverse impacts of solid waste and achieving waste management objectives.

In this regard, households can contribute by participating in waste separation and sorting their waste at home (Deus et al., 2022). In this context, household waste is all waste generated or produced at home. It includes both non-organic and organic waste, such as leaves, residue, plastics, bottles, and paper. In the context of household waste management, practices vary across geographic locations and demographic characteristics. Generally, household waste management includes reuse, recycling, reduction, and sorting. In terms of waste sorting, also known as waste separation (Zhou and Qiong, 2022). This topic has garnered significant attention among scholars focusing on developing countries, aiming to identify the driving factors behind household waste separation. It has been determined that these factors are closely related to sorting behavior and psychology (Rousta et al., 2020). Waste sorting practices involve classifying or categorizing disposable materials into fractions, ensuring that waste is correctly disposed of in appropriate bins. According to Rousta and Bolton (2019) Household sorting behavior encompasses three aspects: internal factors (e.g., personal beliefs and attitudes), external factors (e.g., incentives, facilities, and infrastructure), and socio-demographic factors (e.g., education and gender).

There has been growing interest in engaging households in waste sorting over the past few decades (Shahabuddin et al., 2023). Research on waste sorting has been growing, with extensive investigations into the internal and external factors, as well as demographic and socio-economic influences, that impact waste separation. *For example,* a recent study Mir Mohamad Tabar et al. (2024) Identified the major determinant of household waste separation in Iran, highlighting the importance of structural situational factors in improving household waste management practices. Other prior research has focused on food household waste management; the findings underscore the significant role of local government actions in encouraging waste management. The study also found that social factors, socioeconomic characteristics, and psychological factors play a role in these practices (Montero-vega et al., 2024). Likewise, Angouria-Tsorochidou et al. (2023) examine the socioeconomic and environmental link with household waste separation in Germany. Despite that, extensive studies have been conducted to explain this waste sorting using different approaches in various settings and contexts. Some studies focus on food waste or plastic waste (Labib et al., 2021; Montero-vega et al., 2024), some studies have focused on secondary school (Safo-Adu and Owusu-Adzorah, 2023), while others employ prominent behavioural theories (Jobson et al., 2024; Labib et al., 2023; W. Li and Wang, 2021; Ma et al., 2023; Nemat et al., 2019; Parajuly et al., 2020). It is imperative to recognize that broadening the current knowledge through an innovative approach is vital, particularly in studying waste sorting practices of households in developing countries like Indonesia, which remains scarce (Santoso and Farizal, 2019). Yet, it is worth noting that at the community level, challenges such as a lack of community awareness, knowledge, and participation hinder addressing this issue at the household level (Debrah et al., 2021; Hasan, 2004; Z. He et al., 2020a,b).

Several studies show that a lack of awareness and knowledge of waste sorting results in low engagement (Rousta et al., 2020). Zhang et al. (2024), in their review of the challenges and barriers to waste management in Asia and Africa, including Indonesia, synthesized that knowledge and awareness of waste sorting are low. Correspondingly, a survey conducted in Indonesia reported that Indonesian households have a low level of understanding regarding how to sort waste. As a result, only 18.84 % of families participate in waste sorting (Rakhmawati et al., 2023). Moreover, Ostrowska (2023) highlights that the effectiveness of waste management depends significantly on the residents' level of knowledge about waste management. Li and Wang (2021) arguing that enhancing awareness of waste sorting is vital for improving waste management practices. This can be achieved through campaigns and programs designed to provide relevant information and guidance on waste sorting. Correspondingly, Oduro-appiah and Afful (2022) assert that having the ability to recognize the different components of waste helps an individual to improve their waste management practices in their household. Moreover, Rousta et al. (2016) suggest that understanding what to sort, how to sort, and why waste sorting is necessary. This knowledge shapes sorting habits and enhances individual capability, considering situational factors. Based on existing evidence, we concluded that knowledge of waste separation can be improved through theoretical information and guidance through an intervention campaign. Practical guides, such as visible cues with captions and labels, are crucial in improving or acquiring this knowledge.

Reinforcing behavioral change to enhance household waste sorting participation is a cost-effective and sustainable strategy for waste management. Encouraging households to waste sorting is seen as a cost-saving measure that contributes to long-term waste management success. Behavioural changes in waste management have successfully reduced and effectively managed waste in several countries (Y. He et al., 2020a,b). Implementing behavioral changes through various mechanisms is crucial in minimizing the negative impacts of household waste (Kittithammavong et al., 2023). Therefore, this study empirically validated whether knowledge positively impacts waste sorting practices to

test prior findings within the context of households in emerging countries, identified effective interventions for household waste sorting, and assessed whether visual or verbal methods are more impactful.

Our work attempts to validate the existing findings in the context of Indonesia and offers a practical guideline for household waste management through an innovative approach. The prior objective of this paper is, therefore, to contribute a better understanding of household waste sorting practices in the context of developing countries that hope to provide input to waste management practices in other areas. In doing so, this work proposes an intervention strategy to improve sorting knowledge and practices. We aim to address the following research questions:

- *RQ1: How do labels and captions (Visual cues) improve household waste management (sorting practices and knowledge)?*
- *RQ2: How does combining intervention campaigns and images with captions (Visual and verbal cues) reduce household waste generation?*
- *RQ3: How do the intervention campaigns improve household waste sorting practices and knowledge?*

This study employs a mixed-methods approach to shed light on these above questions within the context of Indonesia. This work offers a twofold contribution. First, it enhances the theoretical landscape by validating existing studies and expanding the understanding of the underlying relationships between design intervention and waste sorting knowledge. Second, it provides practical contributions that support the development of effective waste management strategies. By bridging theory and practice, this work offers theoretical insights and practical solutions to address challenges in waste management practices.

2. Methodology

2.1. Research design

This study used a mixed-method approach involving user testing, adopting the solution enactment technique, self-reported surveys before and after the user testing, and semi-structured interviews after the user testing. Then, participants were observed while engaging with two different waste-sorting solutions using a solution enactment technique that allows participants to experience novel solutions by interacting with these solutions in a simulated environment following a script. This enabled the researchers to gather insights on the effectiveness of each intervention: trash bins without labels and captions, trash bins with labels and captions, and trash bins with labels, captions, and socialization. Finally, semi-structured interviews were conducted to understand the impact of the design interventions on waste-sorting knowledge and practices.

The study took place in the PISCES Living Lab. Living labs can be defined as "interaction spaces in which stakeholders form public-private–people partnerships within companies, public agencies, universities, users, and other stakeholders, all collaborate for creation, prototyping, validating, and testing of new technologies, services, products, and systems in real-life contexts" (Westerlund and Leminen, 2011). The PISCES Living Lab, located in Banyuwangi, Indonesia, is specifically dedicated to addressing the problem of plastic waste and pollution in Indonesia through co-designing, prototyping, and testing innovative solutions to tackle plastic waste and pollution and providing scientific evidence of their environmental, social and economic benefits.

This research was conducted in Banyuwangi, located in the southern part of Java Island, Indonesia, during May 2024. Households were targeted; the participants consisted of 29 households. Since our study employed a highly controlled experimental design to yield significant insights from the observations, we also incorporated qualitative methods prioritizing in-depth data. Additionally, due to constraints in time and resources, we utilized a smaller sample size that, therefore, still met the required statistical power. Similarly to Oke et al. (2022) Smaller

samples were used as the study focused on yielding in-depth insight from the information gathered from the participants. Participants were recruited from different neighborhoods in Banyuwangi using a snowball sampling technique. Prior to the experiment a pilot study was conducted on November 2023 to develop suitable instruments, measurements, and concepts for the present study. Additionally, a manipulation check was performed to validate the integrity of the baseline conditions.

Ethical conduct is crucial in experimental studies to ensure adherence to high standards of research ethics. This research adheres to ethical best practices, beginning with obtaining ethical clearance from the National Agency for Research and Innovation (BRIN) before data collection. Each participant received an introduction to the research objectives and was actively engaged in the entire research procedure. Moreover, all participants were informed about protecting their anonymity and privacy. The participants' consent was received in written form before participating in the study.

2.2. Data collection

The data collection procedures employed various approaches—including surveys, experiments, and interviews—to gather relevant information to achieve this research's objectives (Fig. 1). The data used in this study were collected from 3 different approaches, involving 4 researchers consisting of 1 observer, 2 instructors, and 1 researcher assistant. The observer recorded the necessary information in the observer sheet during the entire data collection process. The 2 researchers provided instruction and conducted the survey and interview assisted by the researcher assistant. The average duration allocated for each participant was 1 hour and a half. The pre-survey and post-survey were used to collect self-reported information, which consisted of the demographic profile of the participants and questions assessing the level of the household's waste sorting knowledge. From the lab experiment, data were extracted from the observation of the participants; the observation was conducted on each participant during the user testing experiment, and we gathered information, including the amount of missorted waste, how the participants performed the tasks and their reactions. Finally, the interview was conducted to explore the participant's perceptions about their experiences during the tasks and how it impacts their knowledge. The face-to-face interview between the observatory and participants lasted around 30 min all information was transcribed.

2.2.1. Self-reported survey

This study designed survey questionnaires with two primary objectives. The first objective was to establish participant profiles, while the second aimed to evaluate changes in behavior and knowledge among participants during the intervention. The initial survey was conducted face-to-face before the intervention to assess participants' initial knowledge and establish their profiles. The survey consisted of two parts: the first section included demographic and socioeconomic questions to build participant profiles. In contrast, the second section comprised self-reported questions evaluating the knowledge and sorting behavior of the participants. All of the questions were developed based on measurements adopted from prior studies (Z. He et al., 2020a,b; Wang et al., 2020) and measured using a 5 Likert scale range from 1-strongly disagree, 2- disagree, 3- neutral, 4-agree, 5- strongly agree. The second survey was conducted at the end of the intervention, utilizing only the second section of the first survey. This within-subject design enabled researchers to compare the impact of participant engagement with the intervention. This design was chosen for its advantage in economizing on subjects. The timeframe between the two surveys was 3 weeks to "reset" participants' memories about the evaluations to ensure that participants independently evaluated each study (Charness et al., 2012).

2.2.2. Experimental study

The experiment was undertaken in a living lab, where an observer

Approach	Pre-Survey	Lab-experiment	Post-Survey	Interview
Data Collection	Profile Building Self-reported Survey	Control Group Intervention 1 Intervention 2	Self-reported Survey	Semi-structured Interview
Results	Descriptive analysis	Observation Descriptive	T test Comparision	Interpretation
Objectives		Identify an effective interventions that improve household waste sorting	Statistically asses the impact of the interventions	Explain the impact of interventions on Household waste sorting knowledge and practices

Fig. 1. Data collection procedure.

was present to observe and record participant behavior. Clear instructions were provided to the participants without interruption before they performed the task. A comprehensive guide was given to the participants by the instructor on how each task was to be completed. Participants were asked to complete the task in three different series during the experiment.

- **Task 1**: The participant was asked to dispose of waste in three trash bins, each colored yellow, green, and red (Baseline).
- **Task 2:** Participants were asked to perform the same task of disposing of waste in three trash bins with different colors: yellow, green, and red, each with visual and written cues (labels and captions containing information about which waste goes into the bin and how the waste is used).
- **Task 3:** Participants were given a workshop on household waste sorting, which included comprehensive information about sorting practices. They were also shown a poster explaining the types of waste that should be placed in each of the three trash bins, colored yellow, green, and red, before being asked to perform the task (*Task 2*).

2.2.3. Interview

After the experiment, a one-on-one face-to-face interview using structured interview questions was conducted to investigate the impact of each intervention on participants' knowledge of household waste management and sorting practices. The interview questions were designed to evaluate the interventions' effectiveness in enhancing understanding and promoting sorting behaviors.

2.3. Data analysis

The survey was analyzed using a t-test and mean comparison. The t-test was employed for the longitudinal study that assessed changes in household knowledge over time, specifically before and after exposure to the intervention (Tanner, 2002). The percentages of misplaced and correctly sorted items during observations were recorded. The results from the observer's materials were later quantified and compared across tasks (Mateer et al., 2020). The interviews were transcribed, and quotes were selected based on repetitive themes found in the study, reflecting household perceptions. The qualitative approach was an appropriate method that allowed the researchers to access the participants' perceptions by gathering information collected from the interviews and analyzing and interpreting its meaning (Sovacool et al., 2018).

2.4. Research materials

The materials used and waste items collected in this study were designed according to the pilot study. The recycle bin and the label size were designed according to the prior recommendation from the pilot

study. All waste items selected were the most common items litter in the Indonesian Household. *Green Bin for Organic waste:* seaweed bag, dry leaf, apple, banana skin, spinach, bones, watermelon, food packaging made from leaf, eggshell. *Yellow bin for Recyclable materials:* newspaper, a box, glass bottle, soft drink can, recyclable zipper bag, plastic bottle, plastic cup, small recyclable container, recyclable bottle. *Red bin for Residue*: baby diapers, sanitary pads, instant noodles cups, polystyrene foam packaging, tissue, cigarette butts, waffle packaging, and instant noodles packaging (Fig. 2). A printed image was used to replace the organic waste, including the food waste, vegetables, and bones, to ensure the health and safety of the participants and avoid unpleasant smells; this consideration was based on our pilot study.

Task 1: In the first task, participants were asked to discard waste into the baseline bin. Three bins of different colors were used in the baseline tasks; no treatment or intervention was performed. This task aimed to observe the participants' actual waste-sorting knowledge.

Task 2: Participants were asked to discard waste from the first task into the bins. Label and Caption were the treatments used in this task, and they were stuck into each bin according to their color. Labels of the type of waste that goes into the bins were included, and a caption informing which waste should be disposed of and what kind of waste should be disposed of (Fig. 3). In this task, the impact of intervention 1 on waste sorting was observed.

Task 3: In the first scenario, participants were asked to discard waste into the Bins after the intervention campaign. During the workshop, a poster was used as a visual treatment. The poster contains an illustration of each bin and written information about the type and function of the bins. It also includes a comprehensive list of which kind of waste should

Fig. 2. Selected waste used in the experiment.

Fig. 3. Poster used during the intervention campaign.

be disposed of in each bin (Fig. 3). In this task, the resulting impact of intervention 2 was observed.

Figs. 2 and 3 represent the tools and materials used in the experiment. Fig. 2 shows the waste bin and selected items used in the experiment. Fig. 3 shows the intervention campaign material used.

3. Results

3.1. Participant profile

Table 1 describes the profile of the households participating in this study. All of the participants in this study were female from low- and

Table 1
Participants profile.

|		Number	Percentage
Marital Status	Married	25	86.2
	Divorce	2	6.9
	Widow	2	6.9
Education	Primary and below	5	17.2
	Secondary/High school	22	75.9
	Bachelor	2	6.9
Household Size	2	6	20.7
	3	8	27.6
	4	10	34.5
	6	3	10.3
	7	1	3.4
	8	1	3.4
Monthly Household Income (IDR)	bellow 1 million	6	20.7
	1 million −2.6 million	13	44.8
	2.6 million −5 million	10	34.5
Total		29	100.0

Note: 1USD= 16,320.305 IDR 30.07.2024

middle-income households in peri-urban Indonesian areas. Based on our pilot study, this study focused on female respondents because females were more knowledgeable about the household and were in charge of the household in the Indonesian context. The age of the participants ranges from 29 to 57 years old. The educational status of the person in charge of home duties varied among participants: 22 participants (75.5 %) completed senior high school, 5 completed primary education or below, and 2 held a bachelor's degree. Most of the participants are married, comprising 86.2 of the participants. The survey shows that the family size ranges from 2 to 8 family members; the majority have 4, composed of 34 percent of the household. Average household income (monthly): According to the survey, 44.8 percent of the household's monthly income was between 1.000.000IDR- 2.600.000IDR, 34.5 percent earned between 2.600.000IDR-5.000.000IDR and 20 % of the household earned below 1.000.000IDR monthly.

3.2. Experimental design

This section presents the results of the participants' observation of the first task. Fig. 4a shows the percentage of missorted waste in each bin during the baseline experiment. During the first task, 64 percent of the household waste disposed of in the yellow bin was wrong, 55 percent of the garbage disposed of in the green bin, and 50 percent in the red bin. This result implies that over half of the participants could not separate waste correctly from the bins with different colors.

Fig. 4b demonstrates the impact of the label and caption on the waste sorting practices/ ability of the household. In the second task, we observed that the number of missorted waste was reduced gradually after including the label and caption on each bin. The results show that the amount of missorted waste in the yellow bin was 18 percent, 9.76 percent for the green bin, and 20 percent for the red bin. This figure explained the impact of the treatment on the household's waste sorting
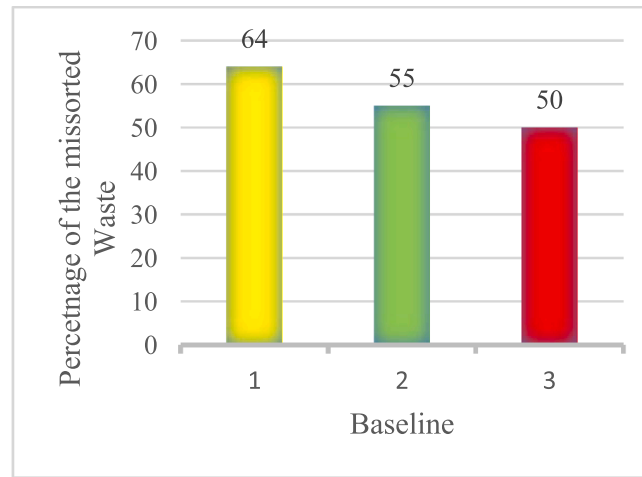
a) Baseline
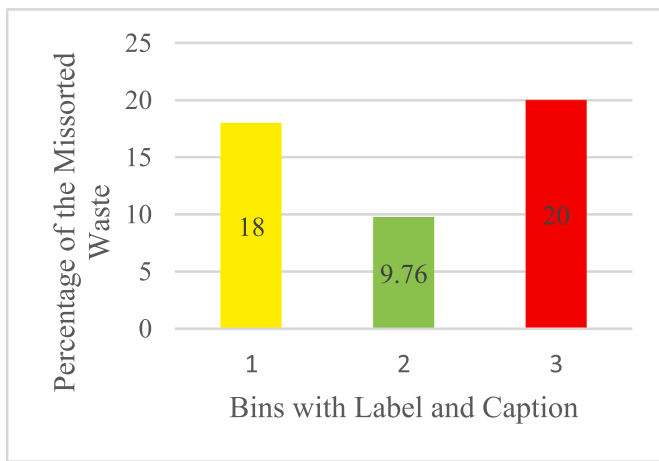
b) Intervention 1
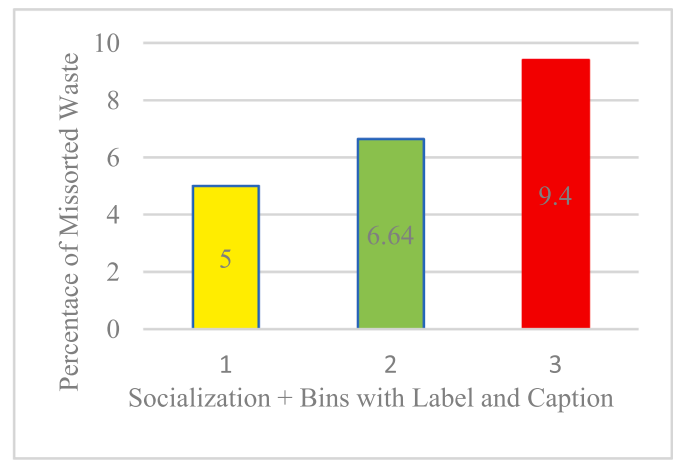
c) Intervention 2

Fig. 4. Observation results.

practices/ability. It concluded that waste sorting improved when participants were provided a visual guide on waste sorting.

The results of the intervention campaign's impact, accompanied by labels and captions on households' waste sorting practices/abilities, show that providing both workshop and label plus caption drastically improved waste sorting ability. Fig. 4c demonstrated that only 5 percent errors were found in the yellow bin, the missorted waste in the green bin decreased to 6.64 percent, and the red bin decreased to 9.4 percent.

Moreover, while the results indicate a significant improvement in household waste sorting, some mis-sorted items remain. This issue arises because participants often struggle to identify and distinguish between different types of waste and materials (i.e. sachet, biodegradable packaging, tissue, cigarette butt.)

Fig. 5 reports the results of the waste sorting practices between the control and the treatment groups. This result illustrates that waste sorting practices can adapt and improve based on the specific intervention. In the initial stage, it was found that households have a low ability of waste sorting practices, proved by a large number of the waste disposed in each bin was missorted. Subsequently, when an intervention is considered in performing the tasks, the results improve accordingly. Therefore, it can be concluded that waste sorting practices can be enhanced by providing a visual and written clue on the bin. In addition, considering a workshop that offers verbal guidance and shares comprehensive information about waste sorting enables households to sort waste correctly.

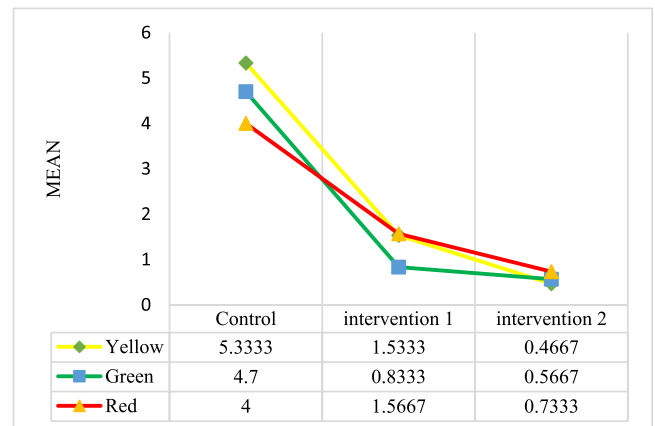|	Control	intervention 1	intervention 2
Yellow	5.3333	1.5333	0.4667
Green	4.7	0.8333	0.5667
Red	4	1.5667	0.7333

Fig. 5. Observation results mean comparison.

3.3. Self-reported survey

A T-test comparison was conducted to determine how the interventions enhance waste sorting knowledge. The data obtained from the pre-survey and post-survey were used. Table 2 compares the mean between the 2 periods, indicating a significant difference between the

Table 2
Independent samples test.

Knowledge	*t*-test for Equality of Means						
	t	df	Sig	Mean Difference	Std. Error Difference	95 % Confidence Interval of the Difference	
						Lower	Upper
Equal variances assumed	3.268	40	.002	.597	.182	.228	.967
Equal variances are not assumed.	3.818	34.090	.001	.597	.156	.279	.915

Note: Sig. (2-tailed)

two groups. The mean of knowledge from Survey 1 was 3.39, whereas Survey 2 suggested that the mean of knowledge increased to 4.794. These statistical results imply that the knowledge of household waste sorting improved after the interventions were incorporated. In other words, there is a significant difference between the baseline experiment and the group with treatment. The participants' waste management knowledge was relatively low before exposure to the intervention.

Table 2 shows the independent sample test comparing the knowledge before and after exposure to the intervention with a t-test comparison. The survey discovered that the participant's understanding of waste sorting improved after exposure to the intervention. The statistical results demonstrated a significant difference with F=45.504; t:4.904, with a mean difference of 1.404 with a p-value below 0.001, indicating that knowledge improved after the intervention. The study also revealed that intervention/ involvement in waste management programs/ activities improves participant knowledge about household waste sorting. The result statistically demonstrated that the F=2.565; t=3.268; mean difference 0.597 with a p-value of 0.002, suggesting differences in knowledge within the group before and after joining the program.

3.4. Semi-structural interview

The semi-structured interview helped to understand what makes the two interventions effective for this group of participants. We examined the effectiveness of various intervention components, focusing on why and how they worked. Using thematic analysis of transcribed interview notes, we gained insights into the knowledge participants acquired, as well as their emotions and motivations.

3.4.1. Knowledge gained on sorting waste

With the two interventions, participants gained several types of knowledge. First, they learned how to sort. Particularly mentioned as feedback for the first intervention (visual and written cues/labels and captions) were points on how to sort waste. This was helpful and effectively enriched the household's knowledge of waste separation. Participants suggested they felt assisted in identifying which materials or types of waste go to a specific bin.

P04 "Now I understand more about household waste sorting. Help us to avoid mistakes when sorting waste."

P14 "With the label and caption, I understand better which bin materials and waste belong in. The label, in particular, informs me about which waste can be composted or discarded as residue."

The caption and label also affected emotions and feelings around waste sorting. Participants mentioned feeling confused and uncertain about waste sorting practices, but with the label and caption, they gained confidence, felt secure, and said sorting waste was easier. Moreover, after the second intervention, some participants mentioned feeling more confident. Although it is difficult to determine which of the two interventions contributes most to confidence, we can safely say that participants seem to struggle with this lack of confidence, which could suggest a barrier to sorting waste in general.

P19 "The label and caption are beneficial; they make waste sorting easy. Now that I know more, I don't find myself confused anymore."

P21 "I used to be really confused with the trash bins without labels and captions. Now, it makes sorting easier because I know what to do."

P28 "Without the captions and labels, I always got confused. These tools have helped me understand waste separation much better."

P04 "Now I understand more about household waste sorting. Help us to avoid mistakes when sorting waste."

Second, participants gained knowledge on what to do with their (sorted) waste. The second intervention offered an extensive explanation of the value of each material; items that go to each bin are crucial in household waste reduction. Participants consistently highlighted the significance of understanding how to sort their waste, with some noting that they now have an improved grasp of the sorting process. Additionally, following the second intervention, they expressed greater awareness of how to manage their waste effectively. Participants expressed excitement about selling waste; some mentioned that garbage could be valuable. This suggests that if participants are aware that sorting their waste could help them earn (or save) money, they might be more motivated to do so. It suggests that visual guidance alone may not be sufficient for sorting, but knowing what the waste can be used for and why particular items need to be disposed of in specific bins is a vital motivator.

P21 "I used to be really confused with the trash bins without labels and captions. Now, it makes sorting easier because I know what to do."

"… I would say that the workshop was good, enjoyable, and provided an interesting learning experience. It is important for us because it imparts knowledge about waste management, especially correct sorting techniques."

P20 "The label and caption tell us what to put in which trash bin." … "I am happy to have gained experience from the workshop. It has provided me with knowledge on how to sort my waste, making the process much easier."

Finally, participants gained knowledge on why to sort. Although the feedback was less frequent, after introducing the second intervention, participants mentioned specifically that not sorting their waste would result in more waste going to landfills. This indicates that they are aware of the impact of sorting the waste. The intervention equipped participants with new knowledge on sorting waste and resource recovery, which enabled them to know the benefits of waste sorting practices.

P16 "The caption and label are very helpful in waste sorting. Both the caption and logo tell me something I did not know before. Actually, I didn't know that eggshells are compostable. Also, degradable food packaging made from plant leaves is something new to me.'

P04 "Now I understand more about household waste sorting. Help us to avoid mistakes when sorting waste."

3.4.2. Delivery mechanisms (type of intervention)

Interventions and waste reduction: Overall, this study reveals the crucial role of intervention in reducing household waste. In particular,

the interventions can only minimize the amount of waste collected from the household, not the amount they produce. The intervention equipped households with important information and practical guidance on adequately managing their households. As a result, it enables households to properly sort their waste and identify and know the benefits and function of each material. In other words, the intervention offers an extensive understanding of the function of each material; items that go to each bin are crucial in household waste reduction. In sum, having visual guidance alone is not sufficient for waste reduction. Knowing what the waste can be used for and why particular items need to be disposed of in specific bins is vital.

> P18 "I don't think it can reduce my waste. I will produce the same amount of waste on a daily basis, but maybe I can minimize the volume that goes to the landfill."

> P14 "Of course, it can help me reduce my waste. For example, by collecting recyclable materials in the recycling bin, I can sell them, which means my household will produce less waste."

Colored bins are designed to guide people in sorting waste. However, participants mentioned that color coding alone was insufficient, and they were often confused about sorting. They noted that they would just put everything in one bin instead, which corroborates the findings of the mis-sorting in the first task (Fig. 5). Participants appreciated the labels and captions and felt that - in combination with the colors - it properly assisted them in sorting their waste. Participants seemed to gain insights into specific materials and packaging types and could now sort them correctly (Fig. 5).

> P21 "I used to be really confused with the trash bins without labels and captions. Now, it makes sorting easier because I know what to do."

> P20 "The label and caption tell us what to put in which trash bin." … "I am happy to have gained experience from the workshop. It has provided me with knowledge on how to sort my waste, making the process much easier."

> P16 "The caption and label are very helpful in waste sorting. Both the caption and logo tell me something I did not know before. Actually, I didn't know that eggshells are compostable. Also, degradable food packaging made from plant leaves is something new to me.'

Further, participants found the socialization enjoyable and engaging. The intervention entailed a one-on-one workshop with the participant. Some explicitly mentioned they enjoyed learning something new, suggesting that there is a willingness to learn and engage with learning. In this intervention, participants were also taught about the value and impact of recycling, which increased their knowledge beyond the 'how to'. Reaching such levels of awareness can lead to more substantial and more lasting engagement with recycling and waste sorting (Hasan, 2004).

> P11 "… the workshop gives me a suggestion and provides important knowledge about waste sorting. Actually, I learn something new from it."

> P21 "… I would say that the workshop was good, enjoyable, and provided an interesting learning experience. It is important for us because it imparts knowledge about waste management, especially correct sorting techniques."

The results indicate that colored bins can be practical for waste sorting, provided participants have a fundamental understanding of what each color represents. Using labels, captions, and intervention campaigns has proven to be effective educational methods. The choice of method should consider factors such as time, budget, and other resources. Colored bins offer visual guidance for waste sorting and include theoretical knowledge about the benefits of each material and the specific function of each bin. This approach shows which items belong in

which bin and explains the importance of proper disposal practices. In other words, it provides visual cues and detailed information on handling waste and why proper sorting is essential. Overall, this intervention aims to educate people on proper waste sorting techniques and emphasize how their actions reduce waste contamination.

3.4.3. Impact of the interventions on behavior

Participants generally believed these interventions would not reduce the total amount of waste they generated (P02: *"My family will always generate the same amount of waste"*). Nevertheless, they did see how the amount of residue waste would decrease if they better sorted their waste. This suggests that the interventions can minimize the amount of residue waste collected from the household but not the amount produced by the household. Participants expressed being motivated to sort more recyclables to earn more money by selling them. They also mentioned they could burn more. The participant emphasizes that for the waste sorting system to work effectively, everyone must be responsible for sorting their household waste. This reflects an understanding that individual actions collectively contribute to the system's overall effectiveness.

> P18 "I don't think it can reduce my waste. I will produce the same amount of waste on a daily basis, but maybe I can minimize the volume that goes to the landfill."

> P14 "Of course, it can help me reduce my waste. For example, by collecting recyclable materials in the recycling bin, I can sell them, which means my household will produce less waste."

Lastly, it is worth mentioning that one participant noted that they could purchase more recyclable packaging. This indicates that the interventions could even affect purchasing behaviours, not just waste sorting behaviour. Changing purchasing behaviours is key to reducing waste and improving recycling, making this a valuable insight.

> P14 "[the intervention] encourages me to be more mindful of my purchases. For instance, now when I shop, I prioritize buying recyclable products or items made from recyclable materials and those that can be composted.

4. Discussion

Our observations indicate that both interventions have effectively assisted households with waste separation. The combination of visual and written guidance significantly simplifies household waste sorting and enhances their understanding of the process. These findings validated the recent work of Rogowska and Pi (2024), suggesting that visible and comprehensive information are key driving factors of household waste management. Furthermore, visual and written instructions (captions and labels) and verbal guidance (intervention campaign) increase their knowledge of waste sorting and reduce errors in sorting. These interventions have proven to be effective in enhancing household waste sorting practices. Additionally, while they may not directly reduce the overall amount of waste produced by households, the visual clue and intervention campaign aspect can help minimize the amount of waste sent to landfills. Second, the survey revealed substantial differences in household waste management knowledge between those exposed to the intervention and those who were not. The self-reported data confirmed a significant increase in knowledge among households following exposure to the intervention. Lastly, these findings were further supported and reinforced by household interviews. The intervention improved knowledge of waste sorting at home, helped households better manage their waste, and reduced the amount discarded. In conclusion, this research demonstrated that appropriate intervention can enrich knowledge and improve household waste separation. These interventions equip households with the necessary know-how to manage their household waste.

Households in developing countries like Indonesia often face significant challenges with waste sorting due to limited practice and inadequate guidance. Many lack effective resources or comprehensive information to help them understand and implement proper sorting practices. This situation is compounded by insufficient educational materials and support systems, which hinder their ability to manage waste effectively. In this study, it was observed that visual cue plays a significant role in improving waste sorting. Similarly to Shearer et al. (2017) asserting in the context of food waste that visual cue has proven to significantly and consistently improve waste management practices. Correspondingly, Shirleen and Kho (2023) affirmed in the context of waste separation in the Indonesian context that prompt sticker can increase the waste sorting knowledge. Moreover, this work discovers that combining visual cue with an intervention campaign found to be more effective approach to improve waste sorting knowledge, and reduce the amount of waste discarded from household. It is evident that the waste sorting error were relatively reduced. Temmerman and Veeckman (2024) emphasise that behaviour change interventions campaign is crucial for waste sorting practices, I was found to reinforce waste sorting practices. Consistently, Rousta et al. (2020) asserted that a campaign for waste sorting with constant succinct information could be leveraged as a strategy to encourage waste sorting. Therefore, combining visual prompts on recycling bins with a comprehensive waste sorting guide as part of an effective awareness campaign is crucial for enhancing waste sorting practices, particularly reducing waste sorting errors and reducing the amount of household waste discarded.

5. Conclusion and implication

This work demonstrated the effective intervention in improving household waste sorting and revealed the influence of these interventions on waste sorting practices. This work offers twofold implications, namely theoretical and practical implications. In terms of theoretical implication, this work not only empirically validates the impact of intervention campaigns on knowledge in waste sorting but also establishes the linkage between visual, written, and verbal guidance about waste sorting, knowledge, and household waste separation. Besides, this work enriches the literature on waste sorting, particularly in the context of developing countries. Regarding the practical implications, this work is a meaningful asset for practitioners, providing insight for building strategies to promote household waste management, specifically in designing an effective intervention to encourage households to sort waste properly. This would yield benefits in creating value for waste, promoting a circular economy, and reducing the impact of household waste.

Despite the contribution of this paper, this work also has some limitations. First, regarding the sample size, due to the constraint of time and resources, the sample used in this study was relatively small, particularly the survey; for future research, it is recommended to expand the sample for a survey to benefit broader information. Moreover, the study focused on Indonesian households' waste sorting practices, specifically from low-income households. To validate the generalizability of the findings, it would be beneficial to vary the characteristics of the sample and include low- and middle-income families. this study also suggests future research to carefully consider local conditions when adopting this model and the approach, specifically regarding demographic characteristics and knowledge of household waste management. In addition, we suggest future studies to explore this issue with longitudinal studies to investigate behavioral change and the longevity of the practices over periods.

CRediT authorship contribution statement

Zayinatun Biladiyah Al Khoeriyaha: Project administration, Investigation. **Anouk Zeeuw Van Der Laan:** Writing – review & editing. **Fabrizio Ceschin:** Writing – review & editing. **Susan Jobling:** Resources, Project administration. **Emenda Sembiring:** Writing – review & editing, Validation, Supervision, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Maminirina Fenitra Rakotoarisoa:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Dangkuaa Aisya Rahmania:** Project administration, Investigation.

Declaration of Competing Interest

Acknowledgment

Data Availability

No data was used for the research described in the article.

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