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Assessment of food waste generation and composition among Korean households using novel sampling and statistical approaches

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ABSTRACT

Food waste management in Korea has become increasingly important as the country continues to champion the transition into a circular economy among the OECD countries to achieve sustainable development target goals. However, reliable primary data on food waste quantity and composition to achieve its prevention and managementtargets by understanding food waste patterns among Korean households is poorly documented. This study investigates the quantity and composition of food waste generation rates among the sampled households by considering two important influencing factors of seasonality and housing types in the Buk-gu province of Daegu, South Korea. The food waste generation rates from three different housing types during four representative seasons were assessed, considering the availability of different food types at different seasons. The identified 46 food waste items from sampled data were statistically analyzed using the Kruskal-Wallis statistical test. The results showed that food waste generation rates were 0.88 ± 0.37 kg/household/day (0.26 ± 0.11 kg/capita/day), which varied seasonally. Significant seasonal variations ($P < 0.002$) in food waste generated from the selected housing types were shown by K–W mean rank analysis. The food waste generation rate followed the seasonal order of summer > autumn > winter > spring. The effect of housing type was also a pivotal factor affecting the food waste generation. This study adds to the ground-level insights of food waste generation trends in different seasons and housing types of Korea.

1. Introduction

Food waste is one of the challenging issues the world is contending to address in recent times. This is due to its various adverse impacts on food security, sustainable use of natural resources, and environmental degradation. The production of food that is never eaten required substantial agricultural land to grow crops and rear animals, and an enormous quantity of water for crop irrigation and drinking for animals. Furthermore, reliable energy sources are needed at different stages of food production such as processing, transportation, and storage, leading to significant greenhouse gas emissions (Godfray and Garnett, 2014). Similarly, the changing dietary and consumption patterns, increasing per capita incomes among the emerging and developed nations, and growing urbanization are some of the factors leading to more food demand, especially meat and dairy that highly resource-intensive to produce (Lemaire and Limbourg, 2019).

Meanwhile, there is already a high level of stiff competition on these food production resources due to population explosion, industrialization, and climate change (Vasilaki et al., 2016; Vermeulen et al., 2012; Adelodun et al., 2019). Moreover, the need to curb the environmental effects resulting from food production is continuously increasing (Godfray and Garnett, 2014). So bringing more land and other resources to addressing the food shortages as a touted immediate solution to meeting the targeted 70 to 100% production increment by 2050 to feed the increasing population successfully are deemed not feasible, considering the varying degree of inefficiencies in agricultural production systems (Adelodun et al., 2020). Besides, there are increasing higher priority giving to other competing human use of resources (Viccaro et al., 2019). These narratives have propelled considerable research interests and interventions among the researchers and policymakers, both at national and international levels, on a possible solution to food waste problems. In this regard, a specific target goal, codenamed "Target 12.3", was adopted by the United Nations as part of

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the Sustainable Development Goals (SDGs) to reduce global per capita food waste by half at both retail and consumer levels as well as food losses along the supply chains by 2030 (United Nations, 2015), starting from the quantification of food waste generation (van Herpen et al., 2019; Zhang et al., 2018).

While there have been increasing studies on the quantification of food waste generation, a comprehensive review study by Xue et al. (2017) covering reported data from 1933 to 2014 showed that the majority of the studies relied on secondary data sources, which might not represent the accurate estimate of the food waste status in the study area. The estimates of food waste generated in some regions of the world were based on derived data from indirect measurements and literature (Corrado and Sala, 2018), which have led to differences in the amount of food waste reported and several inconsistencies in the status of food waste (Corrado et al., 2019). For instance, Food and Agricultural Organization (FAO) estimated that one-third of global food production is lost annually (Gustavsson et al., 2011), while Parfitt et al. (2010) estimated the quantity of food wastage at 10 – 40% of the total food production globally. Corrado et al. (2019) further asserted wide variations in the figures of food waste estimates and attributed the reasons to complexities involved in data gathering and lack of a common ground on what is termed as food wastes. The lack of details and accurate information on the quantities and composition of food waste generation rate could lead to erroneous prevention measures and specious assessment of any intervention program to be adopted to tackle the food waste issue (De Laurentiis et al., 2020). Even though food wastages occur across the food supply chain (Gustavsson et al., 2011), the majority of the food waste studies centered on the consumer stage, households in particular, due to its single largest source of food waste, especially in industrialized and high-income countries (Xue et al., 2017; Thyberg and Tonjes, 2016). The availability of accurate data on food waste quantity and its composition is pivotal to policy design and intervention strategies on food waste prevention/reduction (Nicholes et al., 2019; van Herpen et al., 2019). The quantification and account of food waste and its compositions among the Korean households are, however, poorly documented.

To address the inconsistencies and inaccurate estimation of food waste and its compositions, direct characterization of food waste from the generating sources is highly required to fill the obvious knowledge and data gap in other to achieve food waste prevention target and, by extension, food waste management (Nicholes et al., 2019). This method is considered the most accurate and objective (Elimelech et al., 2018; Delley and Brunner, 2018). Most importantly, it provides the opportunity to address the potential influencing factors that occur in different geographic locations regarding living conditions, which are most times cultural-based and vary among the countries (Schanes et al., 2018). Being able to accurately and consistently quantify the food waste generation and the relative contributions of food items to the total household food waste would assist in understanding food waste generation patterns. Moreover, this would enable to track the progress made on the food waste reduction target while providing some useful insights into the development of appropriate policy on intervention strategies and preventive measures to achieve the required SDG target on food waste issues (Ilakovac et al., 2020).

Therefore, this study investigates the quantity and composition of food waste among Korean households in the Buku-gu district of Daegu, South Korea. Unlike the previous studies on household food waste characterization, we employed a novel direct measurement of sample sorting as it addresses some of the previously reported inadequacies and difficulties. Furthermore, the influencing factors of seasonality and housing types on the food waste generation rate were also investigated to help achieve prevention targets by understanding food waste patterns.

2. Material and methods

2.1. Study area

Daegu metropolitan city is the third-largest city after Seoul and Busan in South Korea. Buk-gu district, the study area, is located in the northwestern part of Daegu with 173, 151 households (444,759 residents), and a total area of 94.08 km^2 in 2018 (KOSIS, 2020). The Buk-gu district was selected because of the existing implementation of food waste source-separation from other household wastes, including food packages. Also, there was total cooperation of the participants in the food waste study and access to participants' information through the support of the Buk-gu district's waste management department. There are three major living housing types in the study area: apartment, villa (townhouse), and single-family housing types. The demography and standard of living among the household population vary slightly according to the housing type, with a similar pattern across the country (Kim et al., 2010). The high-income class and few older people reside in both apartment and villa, while single-family housing is made up of older generations with relatively large family members, which could lead to potential variations in their living and consumption patterns (Kim et al., 2010).

In this study, Food waste refers to any discarded food materials that were initially procured for household consumption, excluding drinks and beverages. This is in line with what is considered food waste in Korea, and it is termed as what animals can eat. The food waste in all the households was source-separated from other residual household waste, including the packaging, as required under South Korean law (Ju et al., 2016). In line with the circular economy agenda of South Korea, the residual household wastes popularly called general waste such as bottles, plastic, cans, paper/cardboard, glass, metal, and other items have a separate collection, sorting, and disposal scheme different from the food waste management scheme due to its organic nature. The general wastes are disposed of using the pay-as-you-throw bag (available in the supermarkets) or a shared waste bin specifically meant for the general waste, which is collected by the waste management personnel on a daily basis, except Saturday. The food waste disposal systems, however, varied with housing types. In apartment and villa, the households used a shared food waste disposal system, numbering 3 to 6 wheeled food waste containers of 120 L capacity each, placed within the apartment and villa complexes where each household discarded their daily food waste. However, in the single-family houses, individual households used separate plastic food waste bins of 2 – 5 L capacity, placed in front of their houses. The collection schedule for disposal of food waste was three days per week in the study area. Each of the households bore the cost of food waste disposal, irrespective of the disposal system adopted.

2.2. Data collection

2.2.1. Recruitment of participants and questionnaire survey

For the recruitment of participants for this study, permission was first sought from the Buk-gu district office in Daegu, South Korea. After that, the flyers were pasted in strategic locations in the study area, including the apartments' billboards, street notice boards, and parks where people usually gather to relax by indicating the purpose and other information about the study. The flyers contained dates, time, and venues to converge for the acceptance to participate in the study by the interested participants, and to fill the questionnaire regarding the basic demographic information. These were selected in such a way to recruit a representative sample of households from the three major living residential types (FLW Standard, 2016). The information requested from the participants includes age, residential address and house number, type of residential, and number of household members (**Table A1**). All the information collected from the participants were promised to be kept anonymous. During this process, more enlightenment and instructions regarding the study were disseminated. The recruitment process lasted for four weeks (June 1–29, 2019). Fig. 1 illustrates the procedures used in this study.

A total of 85 households agreed and signed the consent to participate in the study. However, only 84 households consisting of 33 from the apartment, 31 from the villa, and 20 from the single-family housing types successfully participated in the study, while the remaining one household missed out in one of the seasons considered. This sample size represents 0.02% of the total population in the study area. Since the standardization of food waste characterization is still evolving (Elimelech et al., 2018; Jörissen et al., 2015), there is no absolute recommendation method for determining the appropriate sample size in household waste composition studies (Dahlén and Lagerkvist, 2008). However, it is assumed that a sample size greater than thirty (n > 30) would result in a normally distributed sample means (Ogwueleka, 2013). Correspondingly, Khalid et al. (2019) used 51 household samples in their explorative household food waste composition analysis study, while Nordtest (1995) recommended between 40 and 100 households for an appropriate representative sample for the population when different housing types are involved. Furthermore, Sahimaa et al. (2015) argued that seasonality, type of housing, and collection system stratifications, among others, would lead to increase accuracy with fewer sample sizes in household waste composition studies. Thus, the number of 336 samples collected from 84 households for the four seasons among the three different housing types was assumed adequate and represented temporal variations of typical food waste generation in the study area. Each household participant was compensated with ₩10,000 (Korean won) worth coupons for their efforts at the end of the study.

2.2.2. Food waste sampling and characterization

The three major housing types in the study area were selected to accommodate food waste patterns from different living conditions. A shelf was placed beside each of the shared food waste bins in the apartment and the villa **(Fig. A1).** The food waste plastic containers of 2 L capacity were well arranged on the shelf, each with tags bearing the house numbers of the participating households, collected during the survey questionnaire. Each household was asked to put their daily food waste in the plastic container with their house number tag instead of disposing it in the shared food waste container, for the study period. For households in single-family housing with no shared food waste collection system, their food wastes were sampled and characterized three times per week, according to the existing food waste collection schedules by the waste managers.

For the composition analysis, food waste from each household was sample sorted individually and continuously for two weeks in Summer (July), Autumn (September), Winter (December) of the year 2019, and Spring (May 2020). The food waste was first sorted into food items and then categorized into major food groups. This procedure aimed to identify the potential seasonal variations in the composition of food waste generated among the households, and to also avoid the risk of sampling error (Dahlén and Lagerkvist, 2008; Sahimaa et al., 2015). With this, the potential of undesired changes in the regular food waste patterns and their compositions by the participated households was avoided. The food wastes were characterized on a flat plastic table, and the components were weighed using an electronic weighing scale capacity of 10 kg (e = 0.005 kg) (Model number: C-05-12). The weighted average value of food waste generated and its composition at the household level was computed following population distribution by housing types in the study area (KOSIS, 2020).

This novel procedure allows the sample-sorting of household food waste at the point of entering the waste stream (*in situ*) individually and consistently for each household without incurring the extra cost of transportation to the sorting center. The various concerns ranging from the arduous task and impossibility of quantifying food waste from multi-apartment buildings with a shared waste collection system (Dahlén and Lagerkvist, 2008; Edjabou et al., 2016), uncomfortable privacy invasion from house to house sampling (Khalid et al., 2019), physical degradation of samples due to compaction during transportation to sorting centers (Elimelech et al., 2018; Lebersorger and Schneider, 2011), and chemical degradation due to long intervals between disposal and characterization of food waste (Edjabou et al., 2015; Langley et al., 2010) that were reportedly associated with the direct weighing method were adequately addressed. Briefly, the plastic container was used to sample food waste generated from each household, including those in multi-apartment housing, without necessarily invading their privacy. The collected food waste by each household was characterized individually and consistently at the point of entering the main waste stream to avoid any potential physical and chemical degradation.

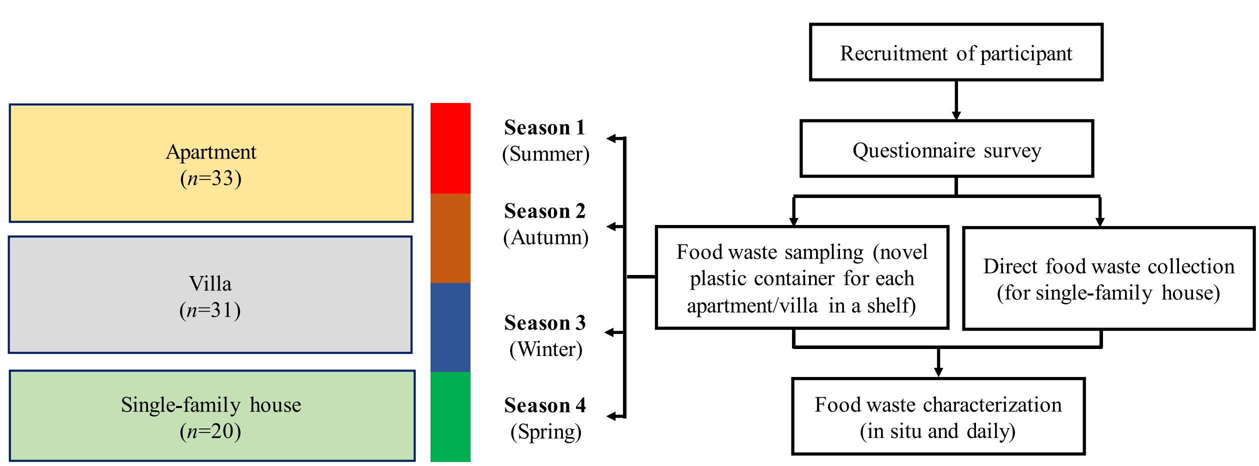

Fig. 1. Framework for the study plan and sample collection.

2.3. Data analysis

2.3.1. K-W analysis for variation in seasonal and household-based waste generation

In order to understand the variations in the food waste generation rate and composition, we employed Kruskal-Wallis (K-W) test to analyze and test for significant differences among the four seasons, and the three housing types, and also for composition of major 9 food groups, separately. This test is usually applied for calculating the significant differences between two or more data groups of independent nature. The significant difference among the different seasons and housing types was calculated using K-W significance (H) and the mean rank of the respective group. Besides this, the pairwise comparison of seasons was also performed to understand how the four seasons were associated with each other in terms of food waste generation. However, the pairwise comparison was established when the pairing of two participating groups had a significance level of $P \leq 0.05$. For this, the following **Eq. (1)** was used to compute the H significance to compare the mean rank of food waste data generated in different seasons and household types:

$$H = (N-1)\frac{\sum_{i=1}^{g} n_i(\bar{r_{i\cdot}} - \bar{r})^2}{\sum_{i=1}^{g}\sum_{j=1}^{n_i} n_i(r_{ij} - \bar{r})^2} \quad (1)$$

where H is the K-W significance, N is the total number of samples for all seasons/household type, n_i is the number of observations in for the group of particular season/household (i), r_{ij} is the group rank among all observations, $\bar{r}_i$, and $\bar{r}$ are the average ranks of particular food waste group, respectively.

2.4. Software and statistics

Microsoft Excel 2013 (Microsoft Corp., USA) was used for data analysis. SPSS 23.0 (IBM Corp., USA) was used for the K-W analysis.

3. Results and discussion

3.1. Quantitative status of household food waste generated

The weighted average quantity of food waste generation rate among the sampled Korean households over the four seasons investigated was 0.88 ± 0.37 kg/household/day (0.26 ± 0.11 kg/ca pita/day). The quantitative distribution of food waste generated in the different housing types and among the four seasons are presented in Table 1.

To determine the influence of specific sample size of 84 households (33 in Apartments, 31 in Villas, and 20 in in Single-family housing type) on the food waste data distribution, we employed a Power Analysis test (z test) using SPC for Excel Toolkit (BPI Consulting, USA). For this, a curve was generated to establish an interrelationship between the power of sample size (0.90) and the difference to detect (2.47) at 95% of confident interval. The sample size selection can be verified using the curve provided in Fig. 2.

The single-family housing type had the highest average food waste generation rate of 39% of the total (7.62 ± 3.25 kg/house hold/week), followed by apartment and villa with 37% (7.18 ± 2.1 5 kg/household/week) and 24% (4.56 ± 0.32 kg/household/week), respectively. The high quantities of food waste generated in the households of the apartment and single-family housing types could be attributed to the large family household members (57.6% comprises of 5 and 4 members) and high-income levels in the apartment housing, and more aged household members (31.5% of the members are above 61 years of age) living in the single-family housing, as compared to the villa housing which comprises of majorly middle-aged (41–60 years) with an average of 2.7 household members **(Table A1).** These results indicate that household size and age group of household members could be important factors influencing the food waste generation rate among the sampled households. Expectedly, similar patterns of food waste generation rate were observed for the per capita distribution among the housing types, following the order quantities of 42% of the total food waste rate (2.93 ± 1.22 kg/capita/week), 33% (2.28 ± 1.13 kg/capita/week), and 25% (1.69 ± 0.13 kg/capita/week), for a single-family house, apartment, and villa, respectively.

The quantity of food waste in this study indicated a higher amount of about 43% when compared to a recent study of an average value of 3.64 ± 2.52 kg/household/week (1.44 ± 1.08 kg/capita/week) reported for Croatia (Ilakovac et al., 2020). The disparity in these figures can be attributed to the different methods used since the study for Croatian households was based on the self-reported method. The possibility of underestimation has been previously noted for the self-reported method of quantifying food waste in the households (Delley and Brunner, 2018), which the authors also confirmed in their report (Ilakovac et al., 2020). However, our result is very similar in value range to figures obtained for some selected OECD (Organization for Economic Co-operation and Development) countries. A study conducted by Delley and Brunner (2018) for Swiss households reported an average of 89.4 kg/household/year of food waste quantity using a national waste composition analysis report in 2012. The author stated that the figure represented mostly avoidable food waste, which indicates the minor difference between their estimate and the result of this study. Also, Elimelech et al. (2018) reported an average 0.26 kg/capita/day of food waste quantity for Israelite households based on the weighing method, which, when extrapolated, indicates 94.9 kg/capita/annum. They also found out that avoidable food waste generation rates constitute 54% of the food waste, excluding the food package. Furthermore, WRAP (2008) reported an average 109.3 kg/capita of food waste quantity for United Kingdom households using survey and garbage collection method in 2007, Filho and Kovaleva (2015) reported an average 93.5 kg/capita of food waste quantity for German households using literature and food balance method in 2013, Scholz et al. (2015) reported an average 81 kg/capita of food waste quantity for Swedish households using literature and recording method in 2012, and Segrè et al. (2014) reported 85 kg/capita for an industrialized Asia using literature data in 2012, as compiled in Xue et al. (2017). Although it is difficult to compare the results from these reported studies because of different methods employed and the cultural differences that could influence the consumption and waste patterns among the diverse households, the reported figures, however, have similarities with our findings.

Edjabou et al. (2016) also reported the significant contributions of food waste generation rates from large households compared to the smaller size of Danish household members. Similarly, Jørgen et al. (2016) reported that the bracket age of 40–54 years generated the most food waste among Norwegian households. Furthermore, the value of the coefficient of variation (CV) of 7% for the food waste generated in villa housing type when compared to 30% and 43% for the apartment and single-house housing types, respectively, indicated the less dispersed distribution of the generated food waste in the villa households. This implies that the households in the villa housing type have closely pattern of food waste generation rates compared to the households of other two housing types.

Compositionally, we identified 46 food items, which varied considerably in quantities (percentage mean), with leafy vegetables, rice, and apple being the major wasted food items, representing 14.08%, 12.51%, and 7.44%, respectively, of the average total food waste (Table 2). However, sugarcane, broccoli, and kiwifruit were

Table 1
Descriptive statistics of household food waste generation rates as functions of housing types and seasonality.

Housing type	Seasons	*n*	*e*	Determination	Mean	CV (%)	Skewness	Kurtosis
Apartment	Summer 2019	33	3.5	kg per household per day	1.06	56.69	1.31	1.30
				kg per person per day	0.30	46.68	1.14	0.92
	Autumn 2019	33	3.5	kg per household per day	0.90	47.85	1.17	2.17
				kg per person per day	0.26	37.97	0.63	−0.47
	Winter 2019	33	3.5	kg per household per day	0.81	64.18	0.85	−0.05
				kg per person per day	0.22	42.93	0.33	−0.53
	Spring 2020	33	3.5	kg per household per day	0.78	53.86	0.77	0.67
				kg per person per day	0.22	39.86	0.76	2.09
Villa	Summer 2019	31	3.5	kg per household per day	0.66	47.14	1.00	0.29
				kg per person per day	0.25	35.49	0.60	0.39
	Autumn 2019	31	2.7	kg per household per day	0.65	46.56	0.75	0.14
				kg per person per day	0.24	37.69	0.50	−0.70
	Winter 2019	31	2.7	kg per household per day	0.70	43.88	0.64	−0.18
				kg per person per day	0.26	32.55	0.25	−0.15
	Spring 2020	31	2.7	kg per household per day	0.59	42.35	1.23	1.41
				kg per person per day	0.22	21.27	0.15	0.28
Single-family house	Summer 2019	20	2.7	kg per household per day	1.44	48.06	0.85	0.53
				kg per person per day	0.56	36.31	0.07	−0.09
	Autumn 2019	20	2.7	kg per household per day	1.53	42.73	0.25	0.36
				kg per person per day	0.58	33.86	0.74	−0.62
	Winter 2019	20	2.7	kg per household per day	0.74	47.12	0.51	0.15
				kg per person per day	0.27	27.25	−0.04	−1.06
	Spring 2020	20	2.7	kg per household per day	0.61	44.52	0.99	−0.08
				kg per person per day	0.25	37.00	1.93	4.81

n is the household number; *e* is the average number of person per household.

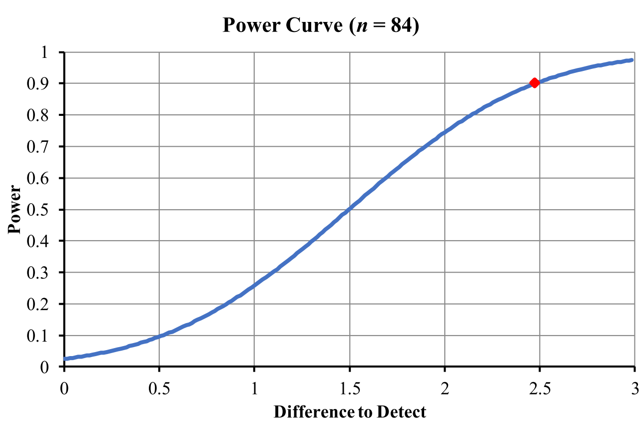

Fig. 2. *z* test Power Curve for the selection of 84 households as sample size.

the least wasted food items with 0.23%, 0.39%, and 0.43%, respectively. The order of waste rates of food items among the three housing types was slightly different by percentage mean mass with rice, leafy vegetable, and apple accounting for the higher proportions of wasted food items in the apartment (12, 10, and 10%, respectively) and villa (11, 18, 7%, respectively), while leafy vegetable (16%), rice (14%), and potato (9%) had higher wasted proportion in the single-family house (Table A5). Nevertheless, there is an observable similar pattern of percentage distribution of wasted food items among the three housing types, indicating similar food consumption items among the Korean households irrespective of their housing types.

For the close comparison of our results with previous reports on food waste composition studies, we grouped the identified 46 food items into 9 major food groups (**Table A2** and **Fig. A2).** The 9 food groups are the staple food, vegetables, fruits, bread and pastry products, meats, eggs, soy foods, sauce, and others. Fruits (29% of the total food waste), vegetables (30% of the total food waste), and staple food (22% of the total food waste) groups were the most wasted among the Korean households while egg (2% of the total food waste), Bakery products (2% of the total food waste), fish (4% of the total food waste), meat (3% of the total food waste), soy foods (4% of the total food waste), and sauce and others (4% of the total food waste) (Fig. A2). While the single-family housing had the highest proportion of wastage of staple (43%), fish (35%), and bakery products (44%), among all the three housing types, they recorded the lower proportion of wasted meat products (26%). The villa housing type had a higher proportion of egg waste (37%). The households in the apartment had a higher waste proportion of meat and meat products (38%). The apartment housing types have more high-income occupants than the villa and single-family housing in the study area, and this could be responsible for the slightly higher percentage of wasted meat and meat products. There is a close distribution of vegetable waste among the three housing types with apartment, villa, and single-family housing responsible for the waste proportions of 31.8%, 31.4%, and 36.8% respectively. The composition of these food groups does not indicate any significant differences among the three housing types as shown by the K-W post-hoc statistical test (Table A4). The high wastage quantities of fruits and vegetables can be attributed to the Korean traditionally heavy-vegetable and fruit diets, coupled with the fragility and perishability of these food groups due to over-purchasing, which make them susceptible to spoilage (Lee, 2018; Lee et al., 2014). These results are in agreement with previous composition food waste studies in Croatian households (Ilakovac et al., 2020), Greece households (Abeliotis et al., 2019), Israelite households (Elimelech et al., 2018), Danish households (Edjabou et al., 2016), and Norwegian households (Jørgen et al., 2016), where the authors reported fruits and vegetable as topping the chart of wasted food categories. These households are of similarly developed countries with households in Korea.

3.2. Seasonal variation of food waste generation among the different sampled households

The distribution of food waste generated among the sampled Korean households as a function of seasons for the three housing types is shown in Fig. 3, while the Kruskal-Wallis post-hoc statistical test results were presented in Tables 3. It was observed that all the three housing types had significant seasonal variability in the

Table 2
Descriptive statistics of the percentage data of food waste composition.

Food items	Mean	SD	Max	Min	Median	Skew	Kurtosis
Rice	12.51	15.18	84.91	0.00	8.12	1.56	2.66
Noodles	3.42	8.18	54.66	0.00	0.00	3.37	13.67
Potato	6.10	10.91	75.49	0.00	0.00	2.71	10.16
Bread	2.20	5.68	49.02	0.00	0.00	4.07	21.52
Onion	5.45	9.81	100.00	0.00	1.70	4.63	33.62
Radish	1.36	4.05	30.90	0.00	0.00	4.11	19.55
Cabbage	3.82	7.67	57.65	0.00	0.00	3.13	12.43
Carrot	0.57	2.65	26.06	0.00	0.00	6.88	55.71
Garlic	0.71	3.90	38.76	0.00	0.00	7.47	61.74
Lettuce	0.05	0.62	10.94	0.00	0.00	16.46	287.34
Broccoli	0.01	0.16	2.92	0.00	0.00	17.93	325.35
Ginger	0.15	1.11	12.68	0.00	0.00	8.49	76.84
Leafy vegetables	14.08	15.21	100.00	0.00	11.04	1.40	3.03
Cucumber	1.04	3.47	27.00	0.00	0.00	4.27	20.47
Tomato	0.72	3.15	31.78	0.00	0.00	6.20	45.16
Mushroom	1.37	3.65	32.51	0.00	0.00	4.24	23.58
Pork	1.88	4.29	29.09	0.00	0.00	3.26	12.54
Chicken	1.36	5.37	68.57	0.00	0.00	7.78	80.71
Beef	0.12	1.01	11.37	0.00	0.00	9.25	88.02
Fish	4.17	7.07	63.88	0.00	0.00	3.46	19.22
Tofu/cheese	0.60	3.10	28.29	0.00	0.00	6.38	43.71
Soybeen	3.58	7.11	45.34	0.00	0.00	2.47	6.96
Egg	1.43	2.95	23.21	0.00	0.00	3.38	14.79
Watermelon	4.12	10.65	81.47	0.00	0.00	3.31	13.07
Apple	7.44	9.68	50.36	0.00	4.03	1.82	3.49
Orange	3.84	8.72	68.22	0.00	0.00	3.27	14.26
Oriental melon	3.77	7.89	39.64	0.00	0.00	2.24	4.30
Banana	2.48	6.30	41.98	0.00	0.00	3.15	10.77
Persimon	0.51	3.15	32.69	0.00	0.00	7.76	66.97
Lemon	0.27	1.82	22.10	0.00	0.00	8.62	84.70
Plum/peach	0.95	5.25	67.10	0.00	0.00	8.71	90.61
Aubergine	0.40	1.96	18.20	0.00	0.00	6.60	48.55
Grape	1.68	5.59	47.48	0.00	0.00	4.84	28.47
Apricot	0.18	1.56	20.62	0.00	0.00	11.21	134.01
Asian pear	0.84	3.49	28.04	0.00	0.00	4.93	26.60
Kiwi	0.06	0.46	5.39	0.00	0.00	8.37	76.76
Strawberry	0.60	2.46	21.77	0.00	0.00	4.81	26.16
Pumpkin	1.80	7.99	75.41	0.00	0.00	6.51	47.73
Pineapple	0.07	0.87	11.86	0.00	0.00	12.95	167.05
Jujube	0.14	0.92	9.19	0.00	0.00	7.12	53.87
Spice	2.64	5.62	34.45	0.00	0.00	3.01	10.26
Ginseng	0.15	1.32	19.12	0.00	0.00	10.94	137.71
Seaweed	0.82	2.16	23.56	0.00	0.00	5.03	39.44
Sugarcane	0.00	0.06	1.12	0.00	0.00	18.33	336.00
Corn	0.50	2.09	19.13	0.00	0.00	5.15	30.71
Teabag	0.07	0.88	15.45	0.00	0.00	16.45	285.55

amount of food waste generated. In the four-season period, food waste generated from the single-family housing had the highest seasonal variability ($P < 0.01$) compared to those of villa and apartment housing types. However, the villa had the least significant (0.002) seasonal variation for the amount of waste generated as revealed from the mean rank and H significance values. Also, the t-statistics value was highly significant in the case of the single-family housing (41.14) compared to those of villa (14.86) and apartment (23.15), respectively.

Furthermore, the seasonal food waste generation patterns were similar for household and per capita in all the housing types. The pairwise comparison identified the patterns of overall food waste generation in four seasons. The pairwise comparison of seasons presented in Fig. 4 revealed the significant association between the different seasons and food waste generation amounts from the selected household types. The pairwise comparison showed a similar distance of mean rank for the households in the apartment housing type in all four seasons. However, in the case of the villa and single-family housing types, the seasonal pairing varied significantly. The yellowish relationship line in Fig. 5 showed a significant variation between the two seasons, while black lines showed a non-significant relationship. More specifically, the order of food waste generation amounts in the apartment was identified as summer > autumn > winter > spring, whereas it was identified as summer > autumn > spring > winter for villa and single-family house.

The food waste generated amounts among the Korean households as analyzed by the K-W post-hoc statistical test, revealing significant seasonal variations. The difference in the availability of seasonal food in Korea due to the country's distinctive four seasons may be responsible for the seasonal variation in the food waste characteristics, thereby leading to the quantity of food waste generated. It was found that the summer season contributed to the highest food waste generation rate as compared to autumn, winter, and spring. This can be attributed to the fact that the stored food items are rapidly degraded by microbes, which are finally wasted during these seasons (Sposob et al., 2020). However, in the winter season, the storage shelf-life of food items increased due to a decrease in the temperature. The variation in food waste generated among the sampled Korean households might probably be due to the lifestyle of the residences (Kim et al., 2010).

For the seasonal influence on food waste composition by food group, there is a slight change in variations of food groups across the four seasons. Animal products such as meat, fish, and egg

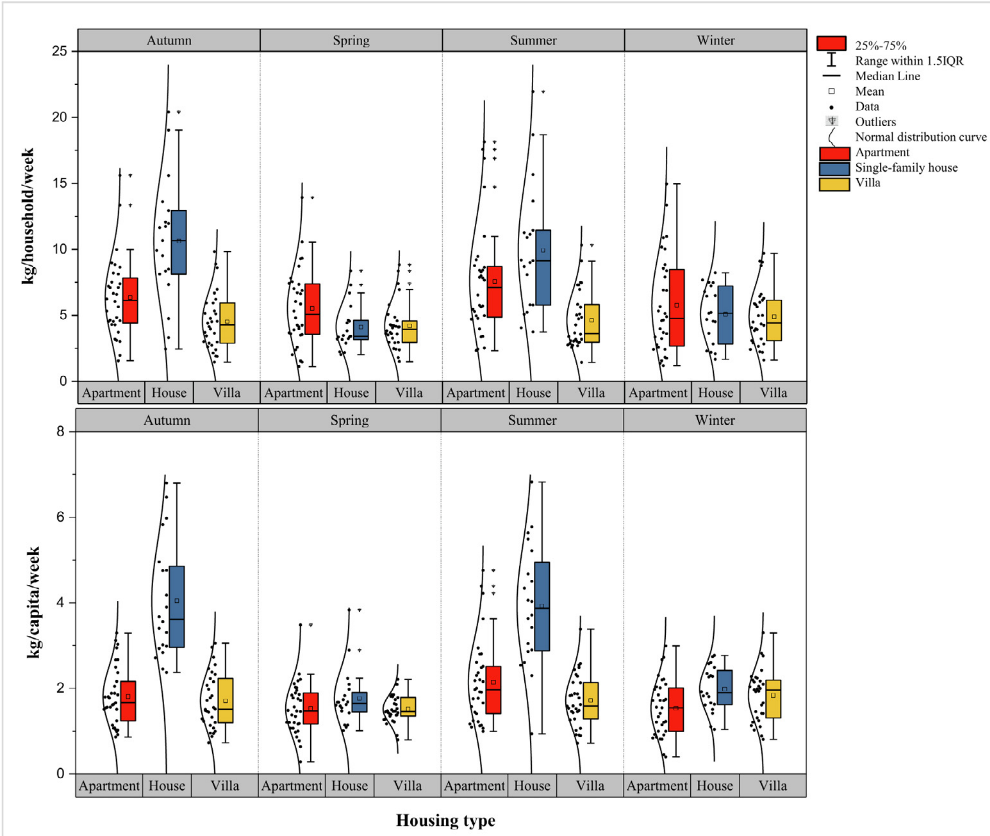

Fig. 3. Data distribution of the food waste generation as a function of seasons for the three housing types.

Table 3
Kruskal-Wallis post hoc test and ANOVA results for seasonal variation in food waste generated in different Korean housing types.

Housing type	Variable	Seasons			
		Summer	Autumn	Winter	Spring
Apartment	Mean rank	90.30	72.00	51.48	51.21
	H significance	<0.001			
	t-Statistics	23.15			
Villa	Mean rank	81.52	65.71	50.92	51.85
	H significance	0.002			
	t-Statistics	14.86			
Single-family house	Mean rank	104.15	91.35	46.82	57.40
	H significance	<0.001			
	t-Statistics	41.14			

had higher proportions of the waste percentage of 51, 39, and 36, respectively in the summer season. Similarly, the higher waste proportion of staple food group (30%) was observed during the autumn. The significant numbers of Korean holidays including the Chuseok (Thanksgiving Day in Korea) fall in the autumn season and the higher proportion of food waste, especially the staple foods cannot be entirely avoided. The least percentage proportions of staples (21%), vegetables (19%), meat (15%), fruits (18%), and fish (16%) were recorded during the spring season. Despite all the slight arithmetic differences of the food group among the four seasons, these differences are not statistically significant for the four seasons as indicated by the K-W post-hoc statistical test (Table A3).

3.3. Required management policy

South Korea is regarded as one of the few countries with a stringent policy for preventing food waste, especially at the consumption stage of the supply chain (OECD, 2017). Based on the results of this study, the following prevention/reduction measures that could be adopted to tackle food waste issues are, therefore, proposed. The campaign on food waste prevention/reduction should be targeted at food-specific items rather than adopting the same prevention strategy for all the food categories as food waste generation patterns of food items vary significantly. Also, the awareness of food waste's implications among households should be championed by the local authorities. The food waste prevention campaign requires institutional support to achieve the Sustainable Development Goals of the United Nations on food waste reduction and prevention.

Besides these propositions on food prevention measures, the source separation of food waste from other household waste, and volume-based pricing system have been the remarkable major policies on food waste reduction and management in Korea (Yoo and Yi, 2015). These were reported as the significant challenges

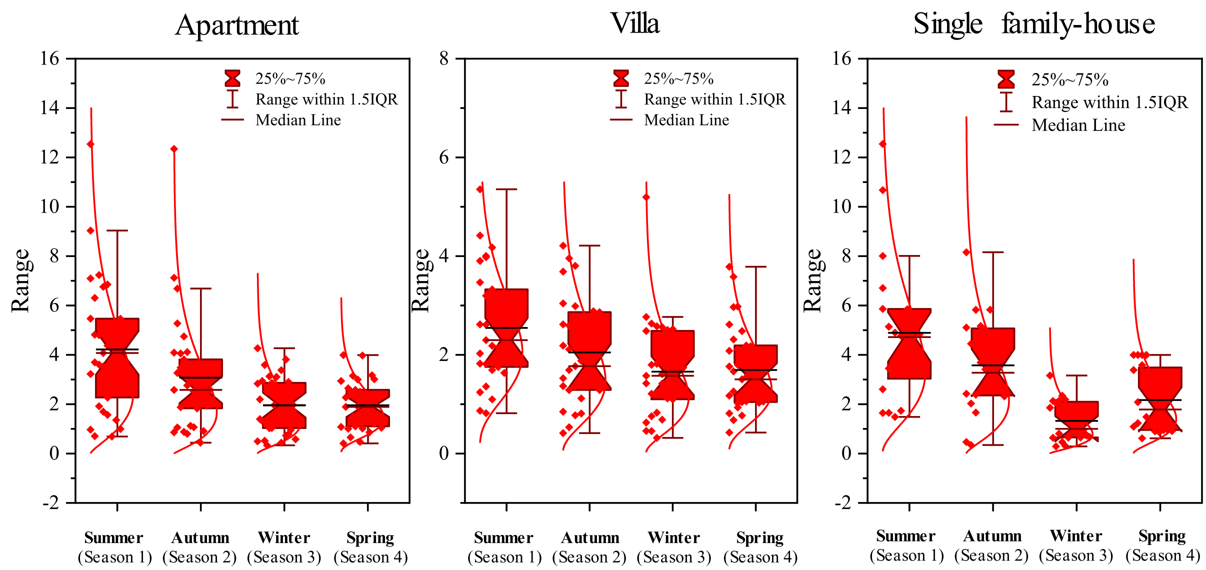

Fig. 4. Data distribution and comparison of the mean rank of seasonal food waste generation amount in different Korean housing types using Kruskal-Wallis post hoc test.

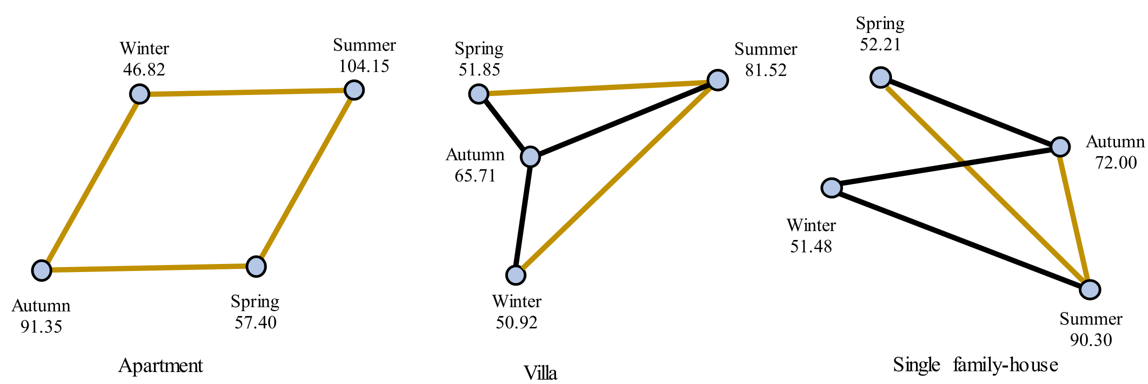

Fig. 5. Pairwise comparison of seasonal food waste generation amount in different Korean household systems using Kruskal-Wallis post hoc test (out of a total of six possible pairs, only those pairs were shown which had statistical significance below 0.05).

required to achieve food waste recycling and circular economy (Jamal et al., 2019) since food waste represents a significant percentage of the total municipal waste generation in Korea (Ju et al., 2016). The pay-as-you-waste policy implemented since 2014 and the subsequent integration of the Radio-frequency Identification (RFID) system in some selected regions to further monitor the consumers' food waste generation have been claimed to reduce the food waste generation rate (Lee and Jung, 2017). However, the age-long cultural eating pattern in Korean households cannot adequately prevent food waste. The inexhaustible side dishes called "bachan" that go with the main dishes for every eating cycle unavoidably promote food waste. (Lee, 2018) opined that the significant outcome of household food waste reduction may partially be attributed to some sharp practices such as toilet flushing, illegal dumping, and concealing in general waste. However, since our study only considered food waste that is linked to the known participant households that generated such food waste; therefore, we did not consider possible illegal dumping or other food waste streams of similar categories. However, there is a possibility of illegal dumping of food waste among some unknown households, as noted by Lee and Jung (2017), which are not captured in our study.

Notwithstanding, significant efforts have been made to convert food waste to useful products such as animal feeds, composts, biogas, and the likes using biological and other treatments. Since one of the major unresolved challenges facing the plants used for recycling and conversion of food waste in Korea is seasonal variations of the food waste materials (Sposob et al., 2020), the knowledge of the quantity of food waste generation rate and its compositions can further ensure efficient planning of these processes. Meanwhile, environmental impact issues regarding the food waste transportation to the distantly located few plants across the country have been reported (Adelodun and Choi, 2020; Kim et al., 2013). There is a need for the decentralization of food waste treatment plants in each of the districts to safeguard the environmental concerns and hygiene of waste management personnel and to ensure efficient treatment of the waste. While the initial set objective on food waste management in Korea is on the resources recovery from food waste (recycling, composting) due to shortage of land required for direct landfilling of food waste and the environmental concern of leaching problems from the landfill (Ju et al., 2016), the need to look towards food security and conservation of resources required for food production can further improve the drastic reduction of food waste generation rate, considering the low self-sufficiency in the country's food production and constraint of essential resources such as land and water for food production. Furthermore, the food waste management should also be geared towards achieving the desired circular economy in the country while championing the cause of 2030 Sustainable Development Goal target 12.3 of food waste reduction following the waste hierarchies of 3R's "reduce, reuse, and recycle" (Redlingshöfer et al., 2020).

3.4. Research limitations and further study

Our study is not, however, without limitations. Firstly, the food waste generation rate was based on a single metropolitan city, and upscaling the obtained results to national estimates could lead to slightly high variance, even though the sample characteristics were similar to that of the population (Kim et al., 2010). However, the granularity of the data obtained while considering the temporal variations in the food waste generation rates during the four seasons and three predominant housing types, and the high-quality food waste sampling methodology used improves the reliability and accuracy of the food waste data. Secondly, the distinction between avoidability and unavoidability or edibility and non-edibility of the food waste nature was not considered. Although these two important parameters are essential indicators for preventive measures of food waste (Corrado and Sala, 2018), their subjective nature based on the cultural perspective and political influence limited their considerations in our study (Nicholes et al., 2019; Chaboud and Daviron, 2017), as all the food wastes disposed into the designated food waste bins are considered avoidable and edible due to the circularity policy agenda in South Korea.

Further, the existing practice of source-separation of food waste from other household wastes, including food packages in the study area, specifically aid the sampling methodology used in this study. The applicability of this method in other settings where the source-separation of food waste is not in existence could be challenging to adopt. Nevertheless, the source-separation of household food wastes is getting popular with several countries, including Norway, Sweden, Germany, Spain, and Austria are already implementing it. We also considered only food waste that is linked to the known participant households that generated such food waste other than unknown food types. However, there is a possibility of illegal dumping of food waste among some unknown households, as noted by Lee and Jung (2017), which are not captured in our study. The exclusion of such households could alter the food waste generation patterns among the households reported in this study only if their population is significant and have different food waste generation patterns.

Further research on food waste quantification and composition should target more diverse geographical settings to address potential spatial variations. Furthermore, the present study tried to link the food waste generation rates to the food waste producers, thereby ignoring other food waste streams such as illegal dumping. Future research should take cognizance of other food waste streams that could potentially influence overall food waste generation patterns in households for an effective food waste prevention and intervention program.

4. Conclusions

The status and composition of food waste generated among the sampled Korean households were investigated by considering two important influencing factors of seasonality and housing types. The findings of this study indicated that 0.88 ± 0.37 kg/household/day (0.26 ± 0.11 kg/capita/day) of food waste was generated among the Korean households, which is similar to an average value of 85 kg/capita/year reported for an industrialized Asia. The study showed that the quantities of food waste generated significantly differ among the housing types and seasons. Among the three different housing types considered, the single-family housing type had the highest rate of food waste generation, closely followed by the apartment with villa housing type had the least mean value of food waste rates, which could be attributed to the household size and age group of household members. For the seasonality, the overall ranking of food waste generation rates in the four seasons was observed following the order of summer > autumn > spring > winter. The mean rank comparison method using the K-W post hoc statistical test helped understands the food waste generation trends. We found that the differences in the distribution of food waste groups among all the households in the different housing types were not statistically significant, thereby suggesting similar consumption patterns among the households irrespective of the housing types. Based on the statistical approaches provided in this paper, a defined methodology or policy targeting at developing intervention strategies to prevent the wastage of 46 identified food items can be implemented. Food waste management policies in Korea should be geared towards achieving the target 12.3 of the United Nations Sustainable Development Goals following the waste hierarchies of 3R's "reduce, reuse, and recycle".

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.wasman.2021.01.003.

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