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ORIGINAL PAPER

Quantitative and qualitative benefits of household efforts to dry food waste at source

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Abstract
Iran law makes municipalities responsible for recycling or disposing of household waste. Therefore, municipalities can use the geographical and cultural potential of each area as an opportunity to improve the situation. However, waste management would be impossible without people's participation. In Iran, neither has much effort been made to increase people's participation, nor have appropriate policies been implemented to increase the amount of recycling at source. In this study, an attempt was made to get citizens to participate voluntarily in household waste management for six months. They were encouraged to dry their food waste. The results of this study showed that due to the hot and arid climate of Iran and the pattern of Iranian food consumption, dehydration of food waste at the source of production can reduce their mass by a maximum of 80%, and as a result, the cost and frequency of collecting them will drop drastically. Moreover, implementing this method not only removed leachate but also increased people's responsibility for the produced waste. Therefore, one can conclude if people participated, Iran's geographical and climatic circumstances would allow food waste to dry at the source by imposing the lowest cost and energy consumption on households. In that case, the costs of collecting, disposing, managing of waste and leachate, as well as the environmental damage will reduce significantly. Also, waste separation will be done better because households have to separate their food waste from dry and recyclable waste.

Keywords Circular Economy · Municipal waste management · Cost–benefit analyses · Drying food waste · Waste leachate

Introduction

By 2050, generating 3.40 billion tons of worldwide waste is expected annually, soaring from the current 2.01 billion tons. From a global point of view, the average of generated waste per person is 0.74 kg each day, but it has a wide range from 0.11 to 4.54 kg (WB 2019). Nowadays, the average rate of municipal solid waste in Iran is about 0.745 kg per person each day, although it has not risen seriously in recent years, that could be due to the economic situation of Iran (Esmaeilizadeh et al. 2020). Fami et al. (2019) also stressed that the amount of food wasted in Iran is about 27 million tons, which has social, economic and environmental consequences for society.

Many argue that the reasons for food wastage vary in most developing and developed countries, and emphasize that the large amounts of food wastage are a feature of developing countries (Schmidt 2016). Nevertheless, according to FAO (2019) statistics, the amount of waste and loss of food products in Iran is almost twice as high as the global average. Organic materials and food waste, especially fruit and vegetable residues, constitute the bulk (68.42%) of municipal solid waste of this country (Esmaeilizadeh et al. 2020). Additionally, water is the predominant component of household food waste in source of production ranging from 75 to 95% by weight (Esmaeilizadeh et al. 2020; YPEKA 2012).

For decades, advanced approaches of disposal due to the extensive convenience and precise technical regulations in the field of waste management in most

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high-income countries are provided (Bruvoll et al. 2002). This is while there are usually no or less rational and purposeful strategies for this in developing countries. Bundhoo (2018) believes that the difficulty of municipal solid waste management in the developing countries consists deficiency of budget, infrastructure, laws, knowledge, learning, and awareness on solid waste problems. In Iran, positive efforts have been made in the field of waste management; however, major challenges for municipalities to improve waste management include the following: lack of funding, disregarding the investments that were made for improving cultural behavior in this matter, the ineffectiveness of the current educational approaches, imbalance in cost-efficiency of municipal waste management systems, the existence of major shortcomings in selection of the employees of the Municipal Waste Management Organization (MWMO), non-specialist manpower, inadequacy between the offenses of non-standard disposal of solid waste and their punishments, weakness of executive guarantees for the principled implementation of the laws, improper performance of organizations that are responsible for public education, and also lack of efficient cooperation between relevant institutions (Valizadeh and Hakimian 2019). These unsolved problems make waste management inefficient in Iran, for example, currently, 77.5 percent of the country's waste is sent to informal incineration sites near cities. According to the reports, more than 3 million square meters of northern forests have turned into landfills (Khayamabshi 2016). Furthermore, in Tehran, only about 15% of recyclable and compostable wastes are separated at the source, and about 4% are separated in waste processing units. On average, about 6000 tons of various wastes are daily sent to the centers for disposal, from various sources of production such as 22 districts, towns, and surrounding cities, health centers and other places. Nevertheless, only a small portion of the wastes in Tehran is managed by advanced technics, and open dumping and landfilling are still the main waste disposal methods in Iran, so that about 71% of municipal solid waste is landfilled in unsanitary landfills (Majlessi et al. 2019). According to studies conducted and statistics provided by the Department Of Environment of Iran (DOE) in 2018, mismanagement and lack of timely treatment of waste have caused the volume of the leachate of waste produced in Arad Kouh in Tehran to reach 400 m3 per day. This number is estimated based on the Landfill Water Balance Model (WBM), which has also announced that only 100 m3 of this leachate is treated. It should be mentioned that Arad Kouh Waste Processing and Recycling Complex is one of the household waste disposal and recycling facilities in Tehran. The increase in the capacity of this landfill site, as well as the high volume of waste sent to Arad Kouh, has caused many environmental problems for Tehran and its surroundings. That is while, according to Pantini et al. (2014) Municipal solid waste landfills can be one of the main sources of environmental pollution, which by emitting the leachate and the landfill gas potentially can not only pollute groundwater and soil, but also be one of the effective factors in global warming.

In Tehran, citing to researches of Islamic Parliament Research Center Of The Islamic Republic Of IRAN (2018), a huge amount of leachate of food waste has been absorbed by the earth. It is expected that the absorbed leachate will cause catastrophic pollution if it reaches the groundwater aquifers. Moreover, the daily influx of these wastes from Tehran to Arad Kouh has created many problems for the lives and health of the region residents. (IPRCOTIROI 2018). According to the data and pieces of information provided by the Department Of Environment of Iran and also the Tehran Waste Management Organization, one of the positive points is that in recent years, the infectious and hazardous waste of hospitals has been decontaminated by incinerators, and waste similar to their household waste goes to household waste disposal centers. In addition, industrial waste, construction and demolition waste (C&D waste), mineral waste, special waste of the agricultural sector, etc., are transferred to separate disposal centers. This means that the household wastes do not mix with other types of wastes. Therefore, in household waste disposal centers the leachate content is the same in origin.

Leachate of household waste contains heavy metals and hazardous substances such as Cu, Zn, Pb, Cd, and Hg (Kulikowska and Klimiuk2008). Many of these contaminants are difficult to control when excreted, and their heterogeneity causes that some of them are not treated well and adequately (Perazzini et al. 2016). The same authors wrote that the initial moisture of solid wastes contaminates their property and also prevents the use of different methods of recycling, reusing, and treatment. Perazzini et al. (2016), and Tun & Juchelková (2019) pointed out that the reduction of initial moisture content in the waste decreases the mass and volume of the substance and deters biochemical reactions as well. They noted that other benefits of trying to eliminate and reduce initial moisture include: the diminution of transportation and disposal expenditures, the deactivation of microbiological reactions of organic waste, the reduction greenhouse gas emissions, reduction of risk level, and increase different methods of reusing. Among drying methods, biodrying, biostabilization, thermal drying and solar drying are the most common (Tun & Juchelková 2019). Although these advantages have led to the development of drying techniques, there are still some difficulties. For instance, the use of biodrying method and solar drying may be expensive for less developed or poor countries. In addition, other disadvantages of these methods are that the stabilization periods of the process properties are slower and longer, which may adversely affect the final quality of the dried products (Perazzini et al. 2016). Furthermore, in all the methods of drying waste at the destination during the collection and remaining the waste in collection depots the possibility of chemical and bacterial reactions exist, which may reduce the quality of the final products rather than being dried at source. This means that some pathogens may not be eliminated by the drying process at destination. This has reduced the likelihood of reuse. For example, some countries, such as the United Kingdom, have banned the use of these dry products as animal feed (Tonini et al. 2018). That is while dry food waste is rich in essential nutrients for animal consumption. For instance, the average crude protein in this dry food waste (19.2%) is almost twice that of maize grain (10–8%), which is a primary feed source. So one ton of these wastes can be substituted the same amount of edible grains and meet the protein needs of a particular animal at the same time (National Research Council (NRC) 2012). Therefore, drying methods can be used as a way to treat food waste for reuse as animal feed. However, as mentioned, although centralized and controlled drying in a waste management facility can be considered as efficient method for treating food waste, there could be better approaches. Management of household waste at the source is one of these methods. Needless to say, moving in this direction requires the participation of citizens because according to Bruvoll et al. (2002), additional time and energy are imposed on households to manage and sort the waste at the source of generation. Kinuthia (2016) emphasized that due to the complex and multidimensional features of waste management processes, the citizens' participation is crucial to start organizing waste from the beginning of generation. It is important to note that the use of waste management methods without the cooperation of citizens, such as landfilling after consumption, misses the opportunity to involve households and young people in changing the cultural direction towards sustainable waste management in the future (Prescott et al. 2020). Besides, in Hage et al. (2018), Nyborg (2003), Andersson and Stage (2018), and Thøgersen (2003), their results indicated that waste management policy instruments can draw people's attention to the importance of recycling and increase their responsibility for the waste generated. In line with this, Bruvoll et al. (2002) examined the impact of these instruments and noted that by using these, households spend a considerable amount of time and energy on sorting waste (185 h per tonne, on average). Through a survey of 1132 Norwegian households, they found that 97% of respondents stated that they want to help the improvement of the environment by sorting out their waste. 73% admitted that their reason for sorting waste is that they want to imagine themselves as a responsible person, and 88% expressed their motivation as follows ''I should act according to the way I want others to act".

Therefore, it can be said that consumers react to the waste, based on their attitudes, feelings, and behavioral goals (Ghinea and Ghiuta 2019). The same authors wrote that analyzing consumer attitudes is critical to understanding their incentive and decision-making strategies because without understanding the purpose of consumer attitudes, change is not easily possible. Moreover, Fami et al. (2019) Moreover, Fami et al. (2019) emphasized that information usage, knowledge, ability, motivation, economic power, and demographic factors affect significantly food waste. They claim that focusing on household food management not only helps to manage household food consumption but can also reduce waste generation.

However, most of the methods used to manage waste at the source of its products are based on incentives and punitive economic policies. In fact, the assumption of the difficulty of changing consumer behavior has led to less awareness, education, and efforts to improve consumption patterns, especially in developing countries. Also, this has contributed to limited efforts to provide innovative ways to engage households in waste management, including food waste. Currently, the most common method introduced to food and other organic waste management is the production of household compost. In this regard, efforts have been made to encourage households to participate in the production of household compost, as the best way to treat perishable waste and household organic waste (Madrini et al. 2016). Anderson et al. (2012) concluded that waste compost in the source causes organic waste to be removed from the waste stream from the beginning, which in turn can reduce the amount of municipal waste. Even so, home composting has a time-consuming and complex stabilization process that needs knowledge, experience, equipment, and effort (Sikora 1998). Home composting has a few disadvantages, including that the final product may not be homogeneous after taking several weeks. Also, there could be odors, dust, and attraction of vermin if not correctly managed (Madrini et al. 2016; Sikora 1998). The same authors wrote that they are making households discouraged from practicing. Therefore, many studies have been done to improve the home composting process. Several studies have addressed the optimization of the composting process using various bulking agents. Also, other studies examined the effect of minerals in the composting of different organic waste substrates (Gabhane et al. 2012, Li et al. 2012, Kurola et al. 2011, Madrini et al.

2016, Li and Li 2015, Latifah et al. 2015). Even a study tried to improve the composting process with an innovative bioreactor (Margaritis et al. 2018). Nevertheless, few researchers have focused on other approaches such as drying waste at the source and encouraging households. And a little information is available on how to dry food waste at the source of generation.

In this study, citizens voluntarily participated in household waste management for six months. They were encouraged to dry their food waste. This study aimed to evaluate the cost–benefit of drying household food waste. Finally, in this survey, participants answer about the effect of this method on the amount of their waste, and also their attitude about the waste that they produce. In particular, this study examined how this approach affects the total amount of waste collected, as well as how it affects the waste streams and their masses heading for recycling, the elimination of leachate from food waste, the reduction in the use of plastic bags, and municipal waste management costs. This study was conducted in one of the towns in Tehran's 14th district, where employees of a government organization live. The sun-drying experiments were carried out from August 2019 to the end of January 2020 and were approximated the results of waste drying in three seasons.

In interpreting the following results, you should keep in mind that the interviewer's bias may be the source of a possible error in the polls. It means that respondents may exaggerate their drying and sorting efforts to satisfy the interviewer.

Materials and methods

Description of the case study area

In this study six 30-unit blocks were randomly selected, which had been accommodated a total of 180 families in them with a population of 736 people. All the families in these blocks were invited to participate in this study. The waste of this town was collected every day from 8:00 AM to 12:00 PM by the municipal sweepers, from the doors of the houses of the families, and was then transferred to the waste trucks. Of the 180 households surveyed, only 10 households separated food waste from other dry waste. But even these 10 families were throwing all the dry and recyclable waste, including glass, paper, newspaper, plastic, etc., together in a plastic bag. The waste in this town was separated by municipal sweepers after collection. Surveys showed that this separation was not done properly and accurately, and therefore, food waste could not be used for biological treatment. Much of the city's waste was incinerated or dumped at the landfill.

For this study, one of the six blocks was selected randomly so that their waste could be weighed together once they had been collected from their doors (Group 1). For 6 months, this routine was repeated every day of the week. From the 30 households in the block, one household was placing its waste in two separate bags containing food waste and other dry waste. The rest of the households were dumping all their waste in one bag during the process. The population of these 30 families was 118. The average waste production of each person in this group during one day and six months, and the related costs are given in Table 2. From the 150 households in the other five blocks, 138 households responded positively to do this study. The population of households willing to participate in the study was 572 people (Group 2). They cited that they made efforts to be responsible citizens and contribute voluntary to the study.

The background variables used in the analysis are the number of inhabitants in these blocks; average income in IRR '000 000; average age; the population of each household; the percentage of inhabitants with tertiary education. The results are shown in Table 1. Individuals have stated that they had not received any training in waste management. In this study, the data of the Tehran Waste Management Organization (TWMO) have also been used. The TWMO is one of the centers of the Tehran Municipality which is responsible for cleaning and clearing roads, collecting and transferring waste as well as disposing of it, and then constructing new waste processing units and providing statistics in the field of waste.

Table 1 Descriptive statistics of the background variables used in the data analysis

Socio-economic variables	Number	Average	Minimum	Maximum
Number of household in these three blocks	180	30	30	30
Number of inhabitants in these three blocks	736	122.6	118	126
The average income of a household in IRR '000 000	180	27	20	40
The average age of adults	380	36	21	50
The population of each household	180	4	3	5
Percentage of adults with tertiary education (%)	380	50	30	60

Training of the participating households

For this study, during a ceremony, the inefficient situation of waste management in Tehran and some other cities of Iran was taped and shown to these families, and was then compared with more developed countries such as Germany, Austria, and Sweden. In these videos, leachate flows and the poor health of the residents of the areas near the landfill were shown, and experts explained them in more details. Watching these videos, households realized what harm the non-separation of waste in Iran along with inefficient management would do to the environment and human health. Then the benefits of drying food waste at the source and the positive effects of waste management in the country were explained to them.

It was further explained to households that among the important factors in accelerating and facilitating the drying of food waste, in addition to sunlight and dry air, proper ventilation of the environment is considerable. This factor prevents the accumulation of moisture due to drying of waste and thus speeds up the working process. Another factor is the dispersion of the outer surface of the material, which means that a wider surface and a lower height increase the drying speed. The households then were taught how to dry household food and organic waste. In the first step, it was explained that they must first sort their recyclable waste from food waste. In the next step, they were taught to identify organic matter (food waste) that could be used as feedstock. In other words, households were asked to separate only waste of food, fruits and vegetables for drying that are not previously moldy. In addition, they were told not to include food waste composed of meat and fish and other cooked food which could create an unpleasant odor in the drying process. For the effective implementation and evaluation, at this stage and before the drying process begins, every household weighted using a weighing scale and recorded the produced non-dried food waste daily. At the end of each month, households calculated and reported the total weight of their non-dried waste, which they had recorded daily. The next step is to choose the right place to dry. The balcony or any other places in the house that receives the most sunlight during the day and communicates with the open air are suitable for this purpose. In this study, households were asked to do this on their balconies. It should be noted that if for any reasons there was no balcony or it is not suitable enough to dry the waste, the drying process could be done in any space of the building that is connected to the open air, such as a private yard or rooftop. A three-story steel basket was then presented as a gift to participants, and they were asked to move their food waste to the baskets instead of the trash (Fig. 1).

Fig. 1 Three-story steel basket, which was given as a gift to the participants for participation in the program. This basket was heavy enough not to be overturned by the wind. The appropriate height of each floor made sure that the waste was not thrown out due to the wind and did not pollute the surrounding environment. Also, its sliding rows made it possible for people to easily discharged waste on each floor separately

Dimensions of each floor in this basket are 30 * 35 and their height is 15 cm. In addition, 7 cm of empty space was designed between each floor so that not only does the air flow well, but also there is no problem in moving each floor and draining the dried material inside them. The appropriate height of each floor prevents the waste from being thrown out by the wind and polluting the surrounding environment. Also, its sliding rows made it possible for people to easily discharge waste on each floor separately. The approximate price of each basket was about 3000,000 in IRR. Although cheaper baskets could be used, the more expensive one was chosen so that it would not be overturned by the wind.

In the following, families were asked to cover the floor of each row with a piece of cardboard or paper in the home so that smaller debris of wastes would not come out of the container. Also, flooring can absorb excess sewage. It was decided that the families would move the source-segregated organic waste on the first day to the top row of the basket where the drying process takes place, the waste on the second day to the second row, and the waste on the third day at the bottom row. Only waste of one day enters each floor, and if it spreads well on the floor of each story, the rate of moisture removal will be faster, and the mold will stop to a large extent.

Participants followed the same process to make the waste dry enough. Visual observations of the participants were used to ensure that the mass and volume of the materials were sufficiently reduced and that their tissue resembled to that of dried fruits. According to the findings of this study, the final drying level varied for different types of food waste, and in the warm seasons it was found to be around 24 h to 72 h. For example, in hot seasons, watermelon skin takes the most time to dry and takes a little more than three days to lose its moisture, but for vegetables like basil, mint, lettuce, etc., this time was about 24 h. In the cold seasons, the waste dried up in the open air around 47 h to 125 h. However, since the food waste is usually a mixture, households were asked to allow the waste to dry completely and not to collect it earlier than scheduled.

After monthly collection of household data, the average daily and six-month waste production per person in this group was calculated. These calculations were repeated after collecting the dried wastes and weighing them. Reduction of food waste mass and moisture from the drying process was determined by weighing the products before and after the drying process. The weight of the initial non-dried waste ($M_{1,i}$) was determined by the households, and the weight of the dried material ($M_{2,i}$) was measured by the collection team after the final collection. The amount of moisture and weight lost was obtained by the following method:

$$\overline{M}_1 = \sum_{i=1}^{138} M_{1,i} \tag{1}$$

$$\overline{M}_2 = \sum_{i=1}^{138} M_{2,i} \tag{2}$$

$$100 * (\overline{M}_1 - \overline{M}_2)/\overline{M}_1 = MR \tag{3}$$

where MR is the percent moisture content, $M_{1,i}$ is total monthly weight of initial materials before dehydration for each family, $M_{2,i}$ is total monthly weight of materials after dehydration for each of them, and $\overline{M}_1$ and $\overline{M}_2$ are the total summation of these figures for all Group 2 households. Based on the pattern of Iranian food consumption, the results of this case study showed that the samples lost a maximum of 80% of their mass due to the removal of their moisture content after exposure to sunlight and open air during the period mentioned above.

After drying, each row could be moved to a separate bin or bag for storage. Then, households were asked to collect their recyclable waste and other wastes that are not recyclable or dryable in the same way that they used to be managed, but to put them out of apartment for weighing. After the daily collection of organic and inorganic waste of all these households by municipal officials, all of them were weighed and the average daily production of dry waste, both recyclable and non-recyclable, per person in these six months was calculated. In addition, households were asked to deliver their dried food waste to collectors on the first day of each month. Therefore, each month, 138 bags were collected and weighed altogether (138 bags is the total number of plastic bags that all of the households participating (households 138) in this project use to transport their food waste during each month. In other words, each household needs a plastic bag every month to transport their dried food waste). After one month, the families participating in the project were asked to stop if they did not want to continue, which none of the families did so. Then, based on the data provided by the Tehran Waste Management Organization (TWMO), the average cost of waste collection per person for each group for six months was calculated. Also, the amount of leachate that each person in group one produces in six months and the cost of refining it were estimated. Considering the initial cost of each method, the cost of each person's behavior towards their waste for the municipal management organization was finally evaluated. These results are shown in Table 4. In this estimate, due to the lack of accurate and transparent information, the cost of the destructive effects of greenhouse gases and damage to nature has not been calculated. For group 1, the statistical specifications used to follow the structure:

$$\sum_{i=1}^{180} x_{i,1} = X_1 \tag{4}$$

$$X_1/(180*118) = \overline{X}_1 \tag{5}$$

$$\overline{X}_1 * 180 = Y_1 \tag{6}$$

$$a*b*Y_1 = Z \tag{7}$$

$$c*Y_1 = T_1 \tag{8}$$

$$d_0 = initialcost = 0 \tag{9}$$

where $x_{i,1}$ is the amount of waste collected from the first block per day, X_1 is the total weight of the waste within 180 days, $\overline{X}_1$ is the average waste per person per day, Y_1 is the average waste per person in six months, a is the amount of leachate produced per kilogram of waste, b is the cost of treatment per liter of leachate for the waste organization in

2019, c is the cost of collecting each kilo of waste for the waste management organization in the same year, and t is the average cost of collecting waste for each person during the six months in this study. For Group 2, because recyclable waste was collected and weighed weekly (26 weeks) and dried waste per month (6 months), the statistical data followed this structure:

$$\sum_{z=1}^{6} \overline{M}_{2,z} + \sum_{j=1}^{26} x_{j,2} = X_2 \tag{10}$$

$$X_2/(180 * 572) = \overline{X}_2 \tag{11}$$

$$\overline{X}_2 * 180 = Y_2 \tag{12}$$

$$c * Y_2 = T_2 \tag{13}$$

$$d_0 = initialcost = 3 * 10^6 \tag{14}$$

where $\overline{M}_{2,z}$ is the amount of dried food waste collected from Group 2 per month and $x_{j,2}$ is the amount of recyclable waste collected from this group per week. X_2 is the total weight of the waste within 180 days. $\overline{X}_2$ is the average waste per person per day, Y_2 is the average waste per person in six months, c is the cost of collecting each kilo of waste for the waste management organization in 2019, and d_0 is the price of each basket which was bought for drying.

At the end of the study period, the respondents were asked through a questionnaire about the problems, costs, and benefits of the waste drying process over different months and days. In this study, face-to-face questionnaires were chosen to have the chance to explain any misunderstandings. The answers and results of the answers are given in Table 2.

Results and discussion

Climate change is increasing the degree of drought in arid regions. Drylands, which are highly sensitive to climate change, cover 41% of the Earth's surface and accommodate more than 38% of the world's population (Zhang et al. 2020). These areas cover large parts of North Africa, the Middle East, the northwestern parts of the Indian Subcontinent, interior Australia, and the smaller areas of the Southwestern United States, and Chile. In other words, hot deserts exist in all continents except for Europe and Antarctica; however, Almería in Southern Spain does have this climate. In summers that there is high sun, scorching and desiccating heat, the average temperature is ordinarily between 30 and 35 °C (84 and 95 °F), and midday readings are usually 43–46 °C (109–115 °F). In some desert places, even in winter, the temperature is very high. These places have the highest average annual temperature recorded on earth (peel et al. 2007). Due to scarce natural resources, land degradation, and frequent droughts, food production in these areas has faced crucial crises. Meanwhile, arid lands are home to more than 2.5 billion people that many of them are the poorest and least healthy residents of the world (Middleton et al. 2011). High population growth rates, weak governance, low intrinsic agricultural productivity, negligible investment, and soil degradation contribute to the poverty of the people of these lands (Reed & Stringer 2016). However, arid regions have worth wealth, such as abundant solar energy and 50% of the world's livestock (Mortimore et al. 2009; Stringer et al. 2012). Iran is one of these regions. This country is among the highest levels of solar energy reception and has more than 300 sunny days per year in more than two-thirds of its area. In this country the average solar

Table 2 Advantages and defect of food waste drying method

My family dries food waste because:	agree	disagree	No idea
The waste did not have an unpleasant odor during the drying process	132	6	–
The dried waste did not attract any vermin	138	0	–
The dried waste has no leachate	138	0	–
Drying waste does not take much time and energy	101	37	
There was Less volume	138	0	–
This led us to separate types of waste	138	0	–
This led us to study the state of the environment	82	–	56
This led us to evaluate the environment	138	0	–
It makes us produce less waste	112	–	26
It makes us feel more socially valuable	138	0	–
We continue drying waste in the future	138	0	–

Number of respondents: 138 households with 572 members and 286 adults radiation is 4.5 to 5.5 kWh/m2 per day. Thus, Iran has been introduced as one of the countries that has a great potential for the solar energy (Mirlohi et al. 2020). Accordingly, the waste management strategy described in this article can be implemented not only in Iran but also in other arid regions of the world. Although centralized and controlled drying in solar waste management facilities can be used to dry food waste, drying food waste at the source of its production can be introduced as a method that can be less expensive. Also it can significantly contribute to the health of the environment and the human food chain in line with the goals of the circular economy. It is necessary to explain that the drying of this waste in waste management facilities may not eliminate the contaminants caused by chemical and bacterial reactions, and eventually we will encounter products that do not have the necessary quality to be reused as compost or animal feed (Tonini et al. 2018). In this case, it will be necessary to spend more money and energy to reduce the level of pollution of dried waste.

In this study, drying and dehydration mean removing most of the food waste water. Sunlight causes water in organic and food waste to evaporate. Drying fruits and vegetables is one of the oldest and most common methods of food preservation in the world, which maintains the quality of food products. Indeed, if the dried matter is stored properly, it will be free of any unpleasant odors and mold, and vermins will not gather around them (Akpinar et al. 2006). From Table 2. it can be seen that the water content of foods varies widely from 90% in some fruits and vegetables to less than 5% in sweet snacks and pastries (Grandjean & Campbell 2004); however, recent investigations have confirmed that water is the principal component of food waste, ranging from 75 to 95% by weight (YPEKA 2012). Based on the pattern of Iranian food consumption, the results of this case study showed that the samples lost at most 80% of their weight after drying. This varied depending on the type of product, which corresponded to the findings Grandjean & Campbell (2004) to some extent requires. At the same time, it was possible to crush dried wastes to reduce their volume even more. The 80% weight loss of waste during the drying process means that the waste loses most of its water content after being exposed to direct sunlight and open air for three to five days. This study results showed that this causes food waste to lose about 80% of its weight after the mentioned period (three to five days). According to some researches, the pattern of Iranian food consumption and the type of materials they throw away as waste affects achieving around 80% weight loss. For instance, Fami et al. (2019) showed that most of the food wasted by Iranian households includes bread, cooked rice, fresh fruits, cooked pasta, fresh vegetables and salads, milk and dairy products, which make up more than 75% of the total food waste in Iran. Table 3 shows that most of these foods (except bread) have about 80% water content. Therefore, it is not strong to achieve around 80% weight loss by drying a mixture of food waste. In this study, the variability in weight loss of waste was not very significant for various households or at different times. It varied between 77 and 82%, which eventually averaged 80%. This number can change in another country with different food and waste production styles. Nevertheless, some studies have shown that this number will often be more than 70% because fruits and vegetables make up the bulk of food waste. These substances have more water content among the types of foods consumed (YPEKA 2012, Sotiropoulos et al. 2015, Esmaeilizadeh et al. 2020).

Table 3 Water content of commonly consumed foods and drinks

Food/drink	Water content (%)
Berries, melon, citrus fruits, pears, apples, salad vegetables, broccoli, carrots	90–95
Milk, soft drinks, fruit juice	85–90
Bananas, potatoes, sweetcorn	80–90
Fish and seafood	70–80
Rice and pasta	65–80
Soup	60–95
Stews, casseroles, etc.	60–80
Spirits (*e.g.,* gin, whisky)	60–70
Pizza	50–60
Meat	45–65
Cheese	40–50
Breads and biscuits	30–45
Breakfast cereals (without milk)	2–5

Source: Grandjean & Campbell (2004)

Since the rate of microbial growth in a food does not depend on the total amount of water present in it, but on the amount of bulk water present in a food (Finley et al. 2018), according to Akpinar et al. (2006), the main purpose of dehydration and drying agricultural productions are to decrease the moisture content so that they can be stored for a long time. In fact, if the amount of water can be decreased to less than 14%, the germs would be inactive. Moreover, bacteria stop at less than 15% and fungi at less than 10% moisture (Guine et al. 2007). In this study, the main purpose of drying is to diminish microbial and enzymatic activities and reduce the rate of chemical interactions, significantly, long-term storage of the product, lessen food waste weight and volume and eliminate leachate. Among these goals, raising product shelf life is a goal that not only has brilliant effect on deducting transportation, and storage costs, but also makes it possible to reuse these dried products as high quality compost or feed livestock. Indeed, with this method, food wastes that cannot be consumed by people or are not desirable to them, can be put back into the human food chain and used in the previous links as animal feed or compost and fertilizer suitable for soil. In this case, we are not dealing with waste that is expensive to collect and treat, but we are dealing with products that can meet the goals of a circular economy. For this reason, households were asked to refrain from including moldy, rotten and non-dryable waste, such as food waste composed of meat and fish and other cooked food, into the drying process. Therefore, during this study, as will be mentioned later, households did not complain of bad odor, accumulation of vermin, and even the space occupied by garbage.

As mentioned earlier, another goal of this method is to reduce the volume and mass of household food waste. Because the water in these materials has mass and volume, as a result of its removal, both the mass and the volume of the material are reduced. In addition, by reducing the mass and consequent volume of waste, it was possible for households to keep their waste at home for a month.

During these 180 days, there were 8 rainy days contributing to longer process than expected time for drying the waste. According to the findings of this study, the final drying level varied for different types of food waste and in the warm seasons it was found to be around 24 h to 72 h, but in the cold seasons, the waste dried up in the open air around 47 h to 125 h. Obviously, the greater the surface area of material exposed to the environment, the faster the rate of moisture removal will be.

For this study, the residents of this town were selected because the residents of this town did not have to put their waste in the big bins installed by the municipality in each neighborhood. Their waste was collected by municipal officials from the doors of their homes. Therefore, it was tried to test this method in an area where households did not make much effort to move their waste.

Economic evaluation

In the economic evaluation of the implementation of this method, according to studies provided Department of Environment of Iran (2018) and Tehran Waste Management Organization (2020), based on the Landfill Water Balance Model (WBM) each ton of waste in Tehran produces about 400–500 L of leachate in 2018 in landfills. In addition, according to statistics provided by TWMO (2020) the treatment of one liter of leachate in 2019 has imposed a cost of about 5,000,000 in IRR on the municipalities. On the other hand, the cost of waste collection in the same year was 2000 in IRR per kilo. In this estimate, due to the lack of accurate statistical information, the costs of the destruction caused by greenhouse effects and negative changes in nature have not been calculated. Moreover, the steady decline in the value of the national currency over the past three years has led to a steady rise in these costs.

The results of this project showed that the average amount of waste production per person in group 1 in per day was 0.445 kg and in 6 months 80.1 kg. These figures for the group 2 were, respectively, 0.08 kg (0.04 Recyclable waste + 0.005 non-dryable waste, etc., + 0.035 Dried food waste) and 14.4 kg. Because group 2 separated their waste well, the composition of the waste could be easily determined. According to the results, each person in group 2 produced an average of 0.035 kg dried food waste and 0.04 kg of recyclable waste per day. In fact, Table 4 shows that each person in group 2 initially produces an average of 0.221 kg of waste per day before the drying process. Of this amount of garbage, 0.175 kg is food waste that is dryable, and its weight reached 0.035 kg

Table 4 The average waste and leachate production of each person in each group during one day and six months, and the related costs

Variable	Average in per day(kg)	Average in 6 months(kg)	Leachate produced in 6 months(lit)	Initial cost (IRR'000)	The cost of leachate treatment in 6 months(IRR'000)	The cost of collection in 6 months(IRR'000)
Waste produced per person (Group 1)	0.445	80.1	32–40	0	160,000–20,000	160
Waste produced per person (Group 2) **before drying**	0.221 = 0.175 Non-dried food waste + 0.04 Recyclable waste + 0.005 non-dryable waste, etc.	8.1 = 7.2 Recyclable waste, + 0.9 non-dryable, etc.	_	_	_	16.2
Waste produced per person (Group 2) **after drying**	0.035 (Dried food waste)	6.3 (Dried food waste)	~0	3000	~0	12.6

after the drying process. A comparison between the two numbers (0.175 kg and 0.035 kg) shows that waste has lost 80% of its weight due to the evaporation of its water content. As a result, the average daily production waste per person in group 2 after dehydration decreases from 0.221 to 0.08. The food items wasted most at the household level were bread, cooked rice, fresh fruits, cooked pasta, fresh vegetables and salads, which was consistent with Fami et al. (2019) findings. Furthermore in this group, the amount of food waste composed of meat, fish and other cooked food waste that cannot be dried was very small and averaged only about 0.006 kg just per day for per person that after the initial dewatering next to the sink, its weight was reduced by 0.005. These figures were significantly different from the amount of waste produced in group one.

Group 1 wastes are often mixture, and while producing leachate, they could not be recycled easily and biologically treated. That is why in Tehran and other parts of Iran, only about 15% of recyclable and compostable wastes are separate at the source, and about 4% are sorted in waste processing units by advanced technics. Therefore, open dumping and landfilling are still the main methods of waste disposal in Iran. About 71% of municipal solid waste disposed of in unsanitary landfills or dumpsites (Majlessi et al. 2019).

Nevertheless, the waste of group 2 was separated and did not produce leachate. Based on the information and costs mentioned above, the cost of collecting waste from each person in group 1 in 6 months was 160 thousand in IRR. Besides, the waste of each member of this group produced an average of 32 to 40 L of leachate that its refining cost is 160 to 200 million in IRR.

This is while the cost of collecting waste from each person in group 2 was 28.8 thousand in IRR in 6 months. Also, the waste of this group did not produce leachate and there was no cost to the environment, the municipality, and the waste management organization. Another point is that the recyclable dry waste of this group could be recycled better due to better and more accurate separation. The dried food waste was also handed over to a rancher, who after confirming the quality of all of them, used them as animal feed; without leachate and the need for any method of treatment or disposal.

Quality evaluation

The respondents are 138 households participating in the study (Group 2) and all of them have two parents. In most households, women were responsible for drying the waste. For the first question in this questionnaire, these group respondents were asked if the waste had an unpleasant odor during the drying process. As predicted, 95 percent of respondents said the waste not only did not smell bad but often smelled a little like dried vegetables and fruit. Another 5% said the waste had a little bad smell, but not all the time. They explained that in winter and on cloudy or rainy days if food waste was not spread well, it dried out over a longer period and smelled a little bad. For the next question about attracting any vermin, all of them emphasized that during different seasons, this waste did not attract any vermin.

In the next section, 73% of households replied that in most cases this was not much different, in terms of time and energy, from the transfer of waste to the door to collect. Of course, 27% of them reported that they had to spend time collecting crumb waste, such as tea trash, which was spread by the wind and the birds ate some of the waste and that made the balcony dirty. However, they insisted, it did not prevent the implementation of this method of waste management. In the benefits section, all households reported that the amount of waste they collected in a month was almost equal to the amount of waste they collected in eight or nine days. They could even shred dry food waste to take up less space. Another important point was that the families stated that, by implementing this plan, they were subconsciously forced to separate their dry and wet waste. 19 families (14%) claimed to have increased the number of bins during this time so that they could separate plastic, glass, paper, cardboard, and metal waste, and e-waste such as batteries. This is consistent with Abbott et al. (2011) and Dijkgraaf & Gradus (2017) findings. Abbott et al. (2011) showed that there is evidence that a lower collection frequency of residual waste increases dry recycling rates. Also, the same households reported that they were more careful in producing food waste and their waste was reduced. In fact, they claimed that during this time they were careful not to spoil the food in the house as much as possible. In addition, they claimed that they were more careful about how they were cooked and the amount of food prepared for each meal to avoid wastage and reduce waste. In fact, they tried to modify their consumption pattern. However, because households were reluctant to have weighed their food waste separately, in this study it was refused to do so in order to preserve the dignity of households, and all the bags collected were weighed together each time. Therefore, it was not easy to prove the claim of these families.

On the other hand, a total of 82 families (about 59%) said, they had studied more about waste management during this time and had become more aware of this issue. Also, all of the families announced that implementing this method, caused them to look at the environment with a more open vision and value and appreciate it more.

81 percent of households (112 households) claimed that, during this time they focused more on food management and wasted less food. Therefore, as the results of Schmidt and Matthies (2018) studies show, effective interventions and identification of promising entry points can reduce food waste and improve the sustainability of the food system. Also, households emphasized that the scheme had subconsciously affected their demand for plastic bags and products that produced more waste and that they had tried to replace similar goods that cost less for the environment. It is worth mentioning each household in this study uses a plastic bag to transport their food waste during each month and maximum of two bags per week to transport their other waste that cannot be dried. However, other households take their garbage out of the house almost every day in plastic bags. Therefore, it can be said that the implementation of this method on a large scale and at the level of a city prevents the entry of a significant number of plastic bags into nature.

Finally, all households said that they felt more socially valued with the implementation of this project and that they talked to their friends and acquaintances about the implementation of this method and tried to persuade them to do so. All households stated that they would treat their waste in the same way in the future.

Conclusion

Food waste is the main type of waste generated by households. This study examined the effects of household waste food drying on the costs of municipal waste management and the environment. The concept of separating and drying food waste at source is a new approach that has never been used or recommended for household food waste management before. The results of this case study indicate that the drying of food waste at the household level may be considered as a waste management option that can be integrated into existing management plans by creating the necessary infrastructure. During the study, households admitted that they did not know much about the fate of waste, the cost of dealing with it, and its adverse effects on the environment before participating in the study. The results of this study showed that drying food waste at the source reduces the waste volume and mass, and eliminates food waste leachate. Moreover, for drying food waste, households are forced to separate food waste from other solid wastes. These benefits can drastically reduce waste management system costs and increase the attention and responsibility of the community to waste, which can ultimately lead to greater environmental protection. This study is a case study and has not been generalized. In fact, it aims to examine the initial idea and the prerequisites for its implementation. However, the results showed that there is the potential to expand its dimensions.

Recommendations

The final products of this method can be used as a renewable source of alternative and environmentally friendly methods to produce high value-added products (e.g., animal feed, thermal energy, ethanol and compost). Although it seem this method is more applicable to dry areas, development strategies for food waste drying could consider various stages from public awareness and consumption pattern improvement to the development of technological and institutional infrastructure. In order for this method to be extrapolated to other countries, it is possible to build household waste dryers that generate the heat needed for drying operations by converting solar energy into heat energy or recycling the heat energy wasted in homes. In this case, the difficulty of households dealing with food waste and even drying it will be significantly reduced. These devices can be used not only for home use but also on a larger scale and for the use in hotels, restaurants, rapid treatment of agricultural land waste, agricultural product processing workshops, etc. Using these devices, the method of drying waste at the source will be led to be extrapolated to other countries. Although similar devices have now been developed that treat food waste at the source of production (including homes, restaurants, etc.) and turn it into compost, all of these devices are powered by electricity. That is while, in countries like Iran, despite the existence of cleaner and cheaper energy such as sunlight and renewable energy than fossil fuels, electricity is still supplied using fossil fuels, which is both more expensive and more polluting. In the winter of 2020, for example, Iran had struggled with electricity generation and supply problems and used fuel oil to generate electricity, which had severely polluted the air in Iranian cities for consecutive days. Along with this issue besides, as explained in the introduction, the preparation and processing of compost is difficult for food waste generating units. Perhaps this is another reason why the use of household and semi-industrial compost production machines has not been widely welcomed all over the world. But the complexity of the method of drying food waste at the source of production is much less than the complexity of the method of composting. In addition, this method is applicable not only in large cities, but also in villages and smaller towns, because in these areas, households face less living restrictions in small apartments. Therefore, they have more access to the appropriate space to perform this method. Since most people's jobs in these areas are ranchman or farmer, maintenance and transportation costs can also be reduced.

On the other hand, as explained in the previous sections, one of the main objectives of this study is reuse some food waste that can be returned to the human food chain and be used as animal feed or products to produce high-quality compost. But to achieve this goal, households do not have to be involved in the reuse process and this part of the work will not be done by households, it is enough for them to dry their waste and have enough motivation to do so. To solve the problem of people's participation and encourage them to use drying method, it will be helpful to provide households with more positive attitudes and financial motivations to not only reduce food waste, but also drying them. Some mechanisms can be defined that make the use of this method economical and bring financial benefits for households. For example, the municipalities can be asked to cooperate in developing this method and provide financial incentives for households that dry their waste. Households can be rewarded by delivering their dried waste to garbage collectors or designated centers. The second solution is to try to set up a cooperatives whose members are households that dry their own waste. These cooperatives, after confirming the quality of their products by the responsible institutions, can sell their products as the feed of livestock or standard quality compost. The other solution is to involve the private sector to develop this method. These companies can offer more creative solutions to develop this method by receiving compensatory assistance from municipal waste management facilities. In addition, the waste management organization can provide a grant to purchase dryers. In this way, it is possible to provide dryers for consumers at a lower cost. In fact, urban management systems in these areas, with the help of these methods and the use of the mechanisms and tools mentioned, in addition to having significant savings in the field of municipal waste collection, will be able to reduce the adverse effects of household food waste on the environment. Thus, the development of a method of drying waste at the source of its production has many benefits that justifies the effort to develop and promote it.

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Declarations

Conflict of interest The authors declared that they had no conflict of interests.

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