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REVIEW
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Decentralized Composting of Food Waste: A Perspective on Scientific Knowledge

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Composting has been demonstrated to be an effective and sustainable technology to treat a wide variety of organic wastes. A particular aspect of composting is the number of technological options that can be used, from full-scale plants to small composters. In this sense, the interest in composting at home or on a community scale is exponentially growing in recent years, as it permits the self-management of organic wastes and obtaining compost that can be used by the same producer. However, some questions about the quality of the obtained compost or the environmental impact of home composting are still in an early stage of development and provide little knowledge. In this review, the main points related to home and community composting are analysed in detail according to the current scientific knowledge by highlighting their advantages and possible drawbacks. Particularly, the composting process performance is analysed, with temperature stratification being one of the main problems related to small amounts of organic matter. Simultaneously, compost quality is determined using parameters such as stability and/or maturity, concluding that home compost can be similar to industrial compost in both aspects. However, sanitisation of home compost is not always achieved. Regarding its environmental impact, gaseous emissions, especially greenhouse emissions, are the most studied category and are generally low. Finally, the effects of pandemics on home composting are also preliminary commented, concluding that this strategy can be a good alternative to have cities that are more resilient.

Keywords: composting, decentralized, organic fraction of municipal waste, compost quality, pandemics

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HIGHLIGHTS

Home and community composting is an alternative for the treatment of organic waste.
Home and industrial composting is of similar quality, especially in stability and maturity.
Environmental impact on home and community is mainly due to gaseous emissions.
Vermicomposting is a promising alternative with a high-quality end product.
Pandemics have increased the implementation of home composting programmes.

INTRODUCTION

Organic waste management is a relevant challenge in modern societies and developing countries, in particular the concerns associated with biodegradable waste, which can have important negative consequences such as greenhouse gas emissions (GHG) (Friedrich and Trois, 2013). Therefore, it is important to develop strategies that can, on the one hand, solve the problem of biodegradable organic waste management and, on the other hand, produce a quality product that may close the organic matter cycle in the framework of circular economy (Rashid and Shahzad, 2021).

Among municipal waste streams, food waste (FW) comprises the main fraction (45%) of the total municipal solid waste (MSW) in Europe (IPCC, 2006). This percentage can be increased up to 55% in developing countries (Troschinetz and Mihelcic, 2009). Some years ago, the final destination of FW was either disposal in controlled/uncontrolled landfills or incineration with/without energy recovery. Unfortunately, this situation persists in some countries, whereas in other parts of the world more sustainable methods for biodegradable waste management have been considered according to new stringent legislation.

FW treatment is usually performed by biological processes such as composting and anaerobic digestion, although new strategies are being developed to obtain valuable bioproducts from organic wastes (Cerda et al., 2019). Composting is based on the biological degradation of organic matter under aerobic conditions, with compost being the final product of the process. The process is considered a sustainable alternative for treating FW that is used worldwide (Cerda et al., 2018).

Composting is usually performed in full-scale facilities that normally collect the organic waste produced in several municipalities (Colón et al., 2017). In some cases, composting can be coupled with anaerobic digestion, as the environmental efficiency of these facilities is higher in terms of resource and energy recovery from waste due to the simultaneous production of compost and biogas (Colón et al., 2012).

In contrast to these facilities, an increasing number of initiatives such as home or community composting have appeared in different parts of the world, jointly with new regulations, consumers' attitudes, etc. In previous years, these activities were usually considered amateurish leading to sparse scientific evidence (Mayoral and Sánchez, 2005). Today, we have strong scientifically based information about home and community composting in different aspects such as performance of the process, the quality of home compost or even the environmental impact, and life cycle assessment (LCA).

To illustrate this, **Figure 1** presents the evolution of publications related to this topic according to the database Scopus® in the last few years.

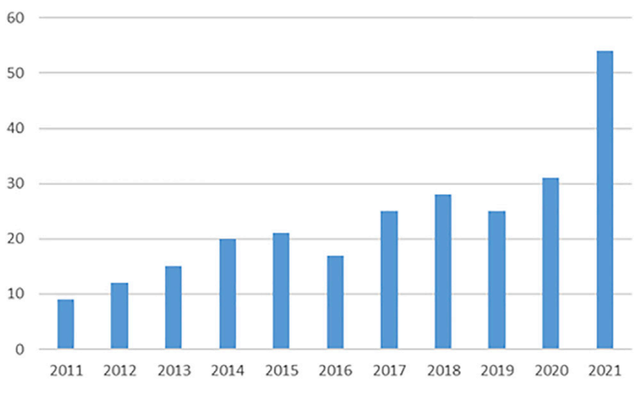

FIGURE 1 | Publications related to home or community composting in the last few years according to Scopus®. The words "home", "domestic", and "community" composting have been used in the search.

As observed in **Figure 1**, the increase in the number of scientific publications and the extraordinary peak in 2021 are evident, coinciding with the pandemic situation. It seems that this composting strategy can help in situations where the resilience and the self-sufficiency issues are critical, as those related to a situation of a global pandemic (lockdown, restrictions, etc.). Of course, this phenomenon should be confirmed in the next few years (with more composting programmes, publications, etc.).

The objective of this article is to present a general perspective of decentralized composting, especially in those studies with scientific information, to give information to the readers of this state-of-the-art technology. This includes home and community composting, although information on community composting, related to scientific aspects of composting process performance or compost quality, is scarce. Other points such as the effect of pandemics (still to be deeply analysed) and the possible role of vermicomposting are also commented.

METHODOLOGY

The international database Scopus® from Elsevier (Amsterdam, Netherlands) was used in this study. For the analysis of home and community composting, the words "home", "domestic", and "community" composting were searched in the title of the publication, which retrieved approximately 300 articles. The term "backyard" was discarded as it retrieved a short number of articles (less than ten), mainly book chapters of difficult access. These articles were used to build **Figure 1**.

The articles commented on and included in the text were selected on the basis that they should contain scientific information on two specific issues: composting process performance and/or compost quality. This resulted in approximately 60 articles. Most of them are included in the references of this review. Articles related to logistic, cultural, or social aspects of home or community composting were discarded.

In the case of vermicomposting, it was found that the number of articles was too high. Moreover, most of them were specifically related to the scientific aspects of the process and emerging advances in the use of vermicompost. Not being the main topic of this review and being scarcely implemented, a short selection of articles combining home composting and vermicomposting was used.

Finally, when analysing the pandemic's effect, it was evident that the main sources of information were related to rethinking waste management programmes for avoiding food waste, a topic that is presented in a short number of studies. However, information on, for instance, home compost quality before and after pandemics, to the best of the author's knowledge, was not found. It is evident that this section will improve in the coming years.

HOME COMPOSTING

Among the different strategies for composting, home composting (also known as domestic or backyard composting) can be defined as the process of composting performed in small-scale composters. Although the volume can vary, the range from 300 to 1000 L is the most common. In home composting, the operator is usually the waste producer, that is the waste is usually composed of food waste and garden leftovers. There are several scientific approaches to home composting, and the most significant are presented below.

Process Performance

Home composting performance is different from that of industrial full-scale composting. First, it is difficult to maintain the thermophilic conditions that allow the compost to be sanitized (Tatàno et al., 2015) or to avoid the presence of considerable stratification of the temperature in home composters (Arrigoni et al., 2018). These previous studies are especially interesting to comment. Tatàno et al. (2015) showed that, even though high moisture contents restricted the internal temperature pattern, classical compost indicators such as moisture, organic carbon, and C/N presented decreasing profiles versus composting time. Other parameters showed an increase in electrical conductivity and total nitrogen, which are related to a proper composting process (Cerda et al., 2018). Second, humification was also studied, and the authors finally concluded that 12–15 months is a suitable duration for the proper development of home composting. Arrigoni et al. (2018) presented a complete study showing how, in cold climates, it is difficult to reach long periods of thermophilic temperatures in decentralized small composters due to a lack of critical mass to retain heat. However, the results indicate that small-scale composting was viable since thermophilic sanitization temperatures (55°C) were maintained for three consecutive days in most of the composting mass. However, stability indicators showed a different pattern of the biodegradation rate of organic matter along with the compost bin's height, with the bottom layer requiring a longer period to be stable than the upper layers. The authors concluded that these phenomena can be important when designing commercial home composting reactors (Arrigoni et al., 2018). Other works studied some important aspects of home composting performance, such as mass balances (Andersen et al., 2011), which are very important for further studies related to Life Cycle Inventories and Life Cycle assessments (Colón et al., 2010). In the study of Andersen et al. (2011), it is stated that the loss of carbon during home composting was within 63–77%, whereas the total loss of nitrogen was within 51–68%, nitrous oxide being a 2.8–6.3% of this loss. Both carbon and nitrogen loss ranges are indicative of an active composting process.

Regarding the technical performance of the process, other aspects are considered in the recent literature, some of them being related to the industrial composting process and some other ones specific to home composting. Among them, the need for a bulking agent to provide porosity to the mixture is highlighted to have a strict aerobic process thus avoiding unpleasant odours and unwanted gaseous emissions in the form of greenhouse gases, especially methane and nitrous oxide. In this sense, Guidoni et al. (2018) investigated how different ratios of bulking agents and food waste can affect the progress of the composting process. Results showed that the ratio of the bulking agent has an important effect on the biodegradation of organic matter, nitrogen dynamics, and the toxicity of the end product. Specifically, a higher proportion of food waste presented better conditions for microbiological development and lesser time to obtain the typical parameters of mature compost. By contrast, a higher ratio of the bulking agent resulted in favourable conditions to have less undesirable gaseous emissions. It is evident that this ratio must be carefully studied in home composting to reach an equilibrium between biodegradation and environmental impact (Storino et al., 2016). About the fractions of food waste, there is some discussion on including meat and food waste of animal origin. Storino et al. (2016) studied home composting with and without the presence of meat in the initial mixture. The authors concluded that meat has several positive effects on the processing activity and an acceleration of the biodegradation of organic matter, without altering the main physicochemical characteristics (pH, salinity, or phytotoxicity) and a low pathogen level with proper handling of the home composters. However, no information on gaseous emissions expected from meat waste such as ammonia is provided. Other authors (Colón et al., 2010) showed low gaseous emissions when composting leftovers of raw fruits and vegetables without animal wastes. In the case of inoculation, home composting consists of active microorganisms to maintain a semicontinuous process. However, some authors pointed out that the presence of the so-called "effective microorganisms" is positive in particular aspects such as odour control and humification (Fan et al., 2018).

Finally, some authors pointed out that waste collection is a critical step in having a proper home composting process. Thus, Puyuelo et al. (2013) performed a comparison of several methods to collect FW before composting, showing that the use of perforated passively aerated bins jointly with compostable bags was superior to other conventional systems. For instance, this system did not imply more gaseous emissions and it was suitable for preparing the organic waste for further composting. Besides, in terms of weight loss, temperature, respiration index, and organic matter reduction, the best results were also achieved with the aerated system.

Of course, the question of bags transcends the collection of organic waste. Actually, one of the main problems of industrial composting is the presence of impurities. A significant part of these impurities are plastic bags (Martínez-Blanco et al., 2010). This implies that the designing capacity of a plant is not real (a percentage of it is occupied by impurities) and the quality of the compost decreases, both visually and chemically. Several recent studies have reported the problems caused by plastic bags in industrial composting. On the one hand, plastic bags can alter the critical properties of compost as the germination index (maturity), as reported by Balestri et al. (2019) using HDPE (high-density polyethylene) bags. On the other hand, these plastics can be converted into microplastics after the composting process, a topic that is now under investigation (Edo et al., 2021; Zhou et al., 2022). Anyway, it is evident that the fate of plastics in composting is one trending research area. In contrast, it is evident that home composting should not have any of these problems, as no bag or compostable bags are used. Today, several compostable bags can be found in any supermarket. Probably, one of the most popular certifications in Europe is "OK Compost" (TÜV Austria) adopted by many manufacturers. However, there are also studies that report the presence of biodegradable plastic microfibers in the compost (Unmar and Mohee, 2008; Accinelli et al., 2020). The question of impurities, especially plastics, is one of the main differences between home and industrial composting and it should be a topic of future research.

Home Compost Quality

Regarding the quality of compost obtained from home systems, there is a consensus in the sense that this quality is similar, if not better, than that of industrial facilities. The absence of impurities in the initial mixture is the main reason for this high quality of home composting. However, it is necessary to properly handle the composter to have good properties in the final product. The process must include manual turning, enough porosity, adequate moisture, and a proper location of the composter to achieve the levels of stability, maturity, and absence of pathogens required for a good organic amendment. There are several studies related to this topic. Vázquez and Soto (2017) presented a study including 880 experiences of home composting in rural areas, using household biowaste including meat and fish leftovers. Ninety home compost samples were analysed showing excellent properties: a low C/N ratio (10–15), no physical contaminant materials (less than 0.3% in dry matter), low heavy metal content, and high nutrient content (2.1% N, 0.6% P, 2.5% K, 0.7% Mg, and 3.7% Ca). The authors reported that home composting of household organic waste (including meat and fish leftovers) is a feasible practice. Other studies showed similar results of home compost quality in terms of physicochemical characterization (pH, moisture, carbon, nitrogen, and C/N ratio) (Papadopoulos et al., 2009; Kucbel et al., 2019). Regarding the presence of pathogenic microorganisms, they are usually not detected, even when thermophilic temperatures are not fully reached (Storino et al., 2016). An article by Mao et al. (2021) investigated advanced microbial techniques to determine the presence of several pathogenic microorganisms and antibiotic resistance genes in several samples of home compost. The conclusion of this study is that typical pathogens of composting such as *Salmonella enterica* and *Escherichia coli* were absent from all compost samples. In contrast, the genes of airborne opportunistic pathogens such as *Mycobacterium* spp., *Legionella pneumophila*, and *Pseudomonas aeruginosa* were detected in home and commercial composts.

Apart from these studies, the literature is scarce on the comparison of home and industrial composting. A special, interesting study is that of Barrena et al. (2014), where a large number of home and industrial composts were compared in terms of stability using respiration techniques. The main conclusion is that home composting, when properly managed, can reach high levels of stability, although industrial compost is often stable. In the case of industrial compost a high dispersion can be found in its quality and stability according to the composting technology used (aerated windrows, turned windrows, and in-vessel systems). If only physicochemical properties are compared, industrial and home composts are not significantly different.

Environmental Impact

Environmental impact of home composting has been largely studied in the literature. The reason for this is simple. On the one hand, the main advantage of home composting is the absence of waste transport and lower energy requirements, whereas a possible disadvantage is the lack of gaseous emissions control as in full-scale facilities, which is practically unavoidable (Colón et al., 2009). Therefore, some of these studies have presented detailed information about the environmental impact of home composting to have a reliable picture of this strategy and to let stakeholders decide about the convenience of using massive home composting. On the other hand, there is a need to compare home composting with industrial composting from the environmental point of view to have an experimentally based comparison. The preliminary studies on this topic were presented by Colón et al. (2010) and Andersen et al. (2012). Both articles performed a complete study on the environmental impact, which belongs to an LCA. It is very important that, although performed in very different locations (Spain and Denmark, respectively), the conclusions were similar: home composting performed better than other waste management technologies in most of the impact categories. Both studies also agree with the fact that gaseous emissions are the main contributors to negative environmental impact in different environmental categories, especially global warming potential. Colón et al. (2010) also reported that the construction of the composter can present negative impacts associated with abiotic depletion, ozone layer depletion, and cumulative energy demand, and home composters can be redesigned to avoid these negative impacts.

Further studies on the environmental impact have been focused on gaseous emissions during the home composting process (Quirós et al., 2014). For instance, Ermolaev et al. (2014) studied the GHG emissions of several home composters treating food waste and compared them with literature data from full-scale composting. In this case, home composting emitted less methane than large-scale composts but similar amounts of nitrous oxide. This study is important as it permits a comparison between home/industrial composting, at least with one environmental impact. Other works have focused on this comparison, in rigorous studies with the same initial mixture, season, and location, with more environmental categories studied, as in the case of Colón et al. (2012). In this study, four different full-scale facilities treating the source-selected organic fraction of municipal solid waste (OFMSW) were environmentally evaluated with an LCA, including composting technologies (in-vessel, turned piles, and home composting) and anaerobic digestion plus composting. In this case, home composting was better in terms of an environmental impact than the other composting technologies, although the plant including anaerobic digestion was, as expected, the only one that had a global warming positive (that is, negative numbers of impact in CO_2 equivalents per mass of waste treated). The study also presents the normalization of these impacts in relation to the stabilization of the final material, which is a novel functional unit in LCA studies related to waste management. In the previous work, Martínez-Blanco et al. (2010) directly compared home and industrial composting by means of a complete LCA. In summary, the results were as expected: ammonia and GHG emissions (methane and nitrous oxide) released from home composting were considerably higher than those of industrial composting. However, this latter option involved 2–53 times more need for transport, energy, water, and infrastructures.

Particular Situations

Home composting is sometimes related to specific situations, which are worthy to comment. For instance, added-value home compost can be obtained to gain biopesticide properties by inoculation with biopesticide producer microorganisms such as *Bacillus thuringiensis* (Ballardo et al., 2020). In this case, the authors inoculated *Bacillus thuringiensis* in a home composter bin, using proper controls without inoculation. The results exhibited a significant growth of this bacterium, and the processes resulted in final composts that were very similar in terms of physicochemical and microbiological properties, respiration, and germination indices with and without inoculation. In another study, de Bomfim et al. (2021) showed that it is possible for a sustainable application of recycled espresso coffee capsules, as some of them are mainly composed of natural composites for a home composter product, although the results correspond to a simulation. Other studies showed the biodegradation in a home composting environment of fully green composites produced by reinforcing bio-based and biodegradable matrices with success (Pantaloni et al., 2020) and compostable diapers as a first step prior to full-scale composting (Colón et al., 2013). In conclusion, it is evident that the changes in the current household biodegradable waste management introduced by home composting generate positive economic and environmental effects, this strategy being in accordance with circular economy principles (Sulewski et al., 2021).

COMMUNITY COMPOSTING

Although used extensively in many countries, especially in central Europe (Regions for Recycling, 2014), and having an extraordinary development in recent years, community composting has received less attention in the world of research. Thus, there are starting experiences in universities, hospitals, municipal markets, or just a group of households. However, the information found in the scientific literature is very scarce. **Table 1** collects several experiences in different parts of the world.

As seen in **Table 1**, most of the studies on community composting are related to economic feasibility. From these studies, it is evident that many entities can use community composting. In this case, universities can play an important role as the first stakeholders to impulse this strategy that can be easily extrapolated to other organic waste producers, such as hotels, hospitals, and schools. Community composting can have an important influence on two items: on the one hand, it can treat a significant amount of organic waste and, on the other hand, it can be a stimulus to promote home composting among citizens (Government of Catalonia, 2020).

VERMICOMPOSTING AS A COMPLEMENT OF HOME COMPOSTING

Vermicompost is the product of earthworm digestion and aerobic decomposition using the activities of micro- and macroorganisms. Vermicomposting, or worm composting, results in a rich organic soil amendment containing a diversity of plant nutrients and beneficial microorganisms. There are extensive studies of vermicomposting in aspects such as process performance, biology, type of reactors, etc. (Samal et al., 2019). In this sense, it is worthwhile to note that vermicomposting, which is usually performed at a low scale, is typically applied to agricultural waste and manure, rather than food waste (Ahmed and Deka, 2021; Hanc et al., 2021).

In fact, the articles dealing with food waste vermicomposting carried out at home or on community scales are scarce, and sometimes a mixture of wastes is used (Arancon et al., 2005; Katakula et al., 2021). Although these studies are of some interest, it is difficult to fit them in a decentralized home composting scheme. Another group of works is focused on the use of vermicompost as an organic amendment, usually being positive in terms of plant growth (Arancon et al., 2004; Arancon et al., 2005). Regarding the process, most of the studies coincide with the fact that vermicomposting results in a product that is an excellent organic amendment for agriculture, with a high content of nutrients (Garg et al., 2012). In the process, it is important to design reactors minimizing the self-heating of waste that can harm the earthworms, for instance, with low amounts of waste and moderate heights such as tray reactors (Ghorbani et al., 2021). Sometimes, vermicomposting and composting are coupled; however, the experiences combining vermicomposting and home composting are mostly carried out on a full scale, either using food waste or agricultural waste (Soobhany et al., 2015; Lim et al., 2016). Finally, an interesting study is the one presented by Lleó et al. (2013), where home composting and vermicomposting technologies were studied to determine the quality of the compost produced from FW. The authors concluded that both technologies were suitable alternatives to divert a fraction of the biowaste resulting in a good product, although gaseous emissions in home composting were higher.

TABLE 1 | Experiences of community composting published in the literature.

References	Community	Main Conclusion
Torrijos et al. (2021)	University waste (Spain)	Integration of food waste composting and vegetable gardens in a university. Temperature is the best monitoring parameter.
Marcello et al. (2021)	Domestic waste (Italy)	A cost-benefit analysis shows a net positive revenue for the community compost system.
Pai el al. (2019)	Domestic waste (the United States)	The results demonstrate the viability of decentralized composting to divert substantial volumes of food waste.
Lim et al. (2019)	Domestic waste (Malaysia)	27% of GHG reduction was achieved by avoiding transport.
Pankhurst et al. (2011)	Domestic waste (the United Kingdom)	Bioaerosols did not disperse in concentrations significantly higher than those measured at background locations.
Tai and He (2007)	Military waste (Taiwan)	Feasibility of the project to be implemented.
Zurbrügg et al. (2004)	Domestic waste (India)	Deficiencies in composting techniques, marketing, and municipal authority involvement.
Mu et al. (2017)	University waste (the United States)	A cost–benefit analysis showed that the composting system could generate a profit. When educational and environmental benefits were included, the revenue considerably increased.
Ghosh et al. (2000)	Cellulosic hospital solid waste (India)	Supplements were employed and cow manure-amended composting produced the best quality compost in the shortest time.

EFFECT OF PANDEMICS

In general press and reports from specific organisations, there are many articles showing how a home or community compost can help increase the self-sufficiency and resilience of modern societies (BBC, 2021; DownToEarth, 2021; The US Composting Council, 2021). However, it is still too early to determine if the pandemic situation is the reason why there is an increase in the implementation of home and composting programmes.

In the scientific literature, many initiatives to make a profit from the pandemic situation and to reformulate waste programmes to include home or community composting are presented and discussed. Adusei-Gyamfi et al. (2022) presented how COVID-19 pandemics can be used as an opportunity to implement sustainable waste management programmes in Africa, while Majewska et al. (2022) reported the possibilities of repairing Polish towns and cities during the COVID-19 pandemic. In another group of recent works, the attitude of the population towards food at home during the pandemic period has been studied. For instance, Babbitt et al. (2021) presented a study that surveyed U.S. consumers about food purchasing, use, and waste behaviours during the pandemic, which resulted in an increase in overall food purchases and a slight decrease in food waste generation. Other authors also confirmed this decrease in food waste generation due to more accurate planning of food shopping and the increase of unavoidable *vs* avoidable food waste (Bogevska et al., 2021; Laila et al., 2021) in several parts of the world. Anyway, the next few years will be critical to know if the COVID-19 pandemic has had a significant effect on home and community composting. Regarding the differences in compost quality, to the best of the author's knowledge, there are still no reports.

FUTURE PERSPECTIVES AND CHALLENGES

From this review, it is important to note that home and community composting has the potential to be an attractive alternative to typical centralized composting plants. The fact that home compost has similar or even better characteristics than commercial industrial compost is of relevance. Specifically, recent studies on home composting demonstrate that some critical parameters such as stability and maturity can be achieved as in full-scale composting. Other important issues, such as the presence of pathogenic microorganisms, have been studied with positive results (absence) although it is evident that more work is necessary. Another important advantage of home composting is the absence of impurities and their negative influence on the full-scale composting process.

Probably, the main challenge of home composting is the presence of uncontrolled gaseous emissions and the absence of a treatment system. It is evident that a future trend of eco-design and research is the inclusion of systems to avoid these negative gaseous emissions.

CONCLUSION

It can be concluded that home and community composting has a great potential to be a massively implemented strategy in organic waste management in developing national and regional programmes. One important reason for this expansion is the fact that home composting has passed from being a hobby to a scientifically based technology. From the environmental and economic points of view, home and community composting appears to be superior to industrial composting in most of the environmental categories, which again makes this strategy attractive to be included in waste management programmes.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor to this work and has approved it for publication.

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