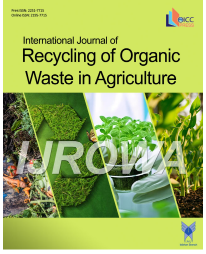

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Design and trial of a comprehensive home composting evaluation tool

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Abstract:

Purpose: In this study, a comprehensive home composting evaluation tool (HCET) was designed and trialled to support the analysis of empirical and quality assurance parameters of home composting systems.
Method: The proposed HCET was developed based on a review of relevant scientific literature, a range of 'how to'/'good practice' guidelines for home composting, and guiding principles from the New Zealand Compost Standard. It was then trialled within a research project examining home composting practices in Palmerston North, Aotearoa New Zealand.
Results: This research showed that whilst home composting is widely undertaken in Palmerston North and diverts a significant amount of organic waste from landfill, home composters often encounter technical challenges and have variable results. Critical reflection on the practical experience of trialling the draft HCET in the context of the broader findings from the research project enabled the HCET to be refined and finalised.
Conclusion: A growing body of literature demonstrates that home composting is a popular and cost-effective opportunity to divert municipal organic waste from landfill, reduce greenhouse gas emissions and enhance local soils and home gardening. As such, effective and systematic evaluation of the various home composting technologies, practices and outputs is a critical opportunity to accelerate the development of a more sustainable, low emission circular bioeconomy. The proposed HCET provides a quick, accurate and effective way to undertake data collection and system analysis, which will support future research further developing and optimising home composting technologies and practices.

Keywords: Composting; Home composting; Organic waste; Recycling; Circular bioeconomy

1. Introduction

Organic waste constitutes more than 50% of municipal solid waste globally, including approximately 60% of municipal solid waste in low and middle-income countries and 30 – 45% of municipal solid waste in high income countries (UNEP, 2024). It is estimated that approximately 20% of anthropogenic methane emissions are caused by the anaerobic decomposition of organic waste (UNEP and CCAC, 2021). In this context, there is growing interest in utilising technologies to recycle and divert organic waste from landfill thereby reducing greenhouse gas emissions (De Boni et al., 2022; Sulewski et al., 2021). Common methods for recycling organic waste include systems for anaerobic digestion, composting and vermicomposting (Cheng et al., 2022; Pirsaheb et al., 2013; Sánchez, 2022).

Composting involves the biological decomposition of organic matter under mainly aerobic conditions via various types of system control to form a stable, humus-like finished product (Ermolaev et al., 2014; Sulewski et al., 2021). Although emissions of nitrous oxide (N_2O) and methane (CH_4) occur during the composting process, carbon dioxide (CO_2) is the main gaseous emission (Ermolaev et al., 2014) and studies have shown that the quantities of CH_4 and N_2O are negligible when compared with those generated by landfilling (Chan et al., 2010; Sánchez, 2022). It has been estimated that decentralised composting systems are able to accommodate up to 50% of organic waste in the municipal waste stream, with the potential to reduce greenhouse gas emissions by 15 – 40% (Vázquez et al., 2015; Wilson et al., 2023). The organic recycling of macro and micro-nutrients via composting systems, also represents an important opportunity to enhance soil biology and provides an inexpensive and environmentally sound alternative to inorganic fertilisers to support plant growth (Gómez-Brandón and Domínguez, 2014; Hoornweg and Bhada-Tata, 2012; Zhou et al., 2022).

Composting can be undertaken on a large commercial scale, on-farm, or at an individual household scale. Both large and small-scale composting processes require the same general parameters, such as adequate moisture content, aeration, carbon-nitrogen ratio and suitable temperature ranges (Vázquez et al., 2015; Wang et al., 2015). In commercial composting, large-scale facilities and processes are employed to control composting process parameters, such as temperature, moisture and oxygen content to enable rapid, healthy decomposition and ensure high value, quality assured end products (Adhikari et al., 2010; Fernández et al., 2016; Martínez-Blanco et al., 2010). However, life cycle assessment studies of the environmental impact of commercial composting have revealed that poorly managed operations may contribute to environmental issues such as odour, eutrophication, greenhouse gas emissions and ozone depletion (Andersen et al., 2012; Barrena and Sánchez, 2022; Rizki et al., 2015). Commercial composting may also involve an additional expense with respect to the collection and transportation of organic waste, alongside associated increases in noise pollution and traffic volume (Adhikari et al., 2010; Pembrokeshire County Council, 2007).

Home composting can be defined as "the self-composting of organic waste and the application of the finished compost in a garden owned by private householders" (Martínez-Blanco et al., 2010). In home composting, the householder can therefore be recognised as the waste producer, the recycler and the end user of the finished compost products (Andersen et al., 2011). Encouraging and expanding participation in home composting can provide a cost-effective and sustainable approach to municipal organic waste diversion and recycling for beneficial use (Sayara et al., 2022; Smith and Jasim, 2009). Knowledgeable and skilful home composting practices enable effective home composting process management, which provides quality assurance of the end-products and environmental protection for home garden soils receiving applications of compost (Mihai and Ingrao, 2016; Wait and Rankin, 2022).

If source separation of any contaminants of organic waste is performed and critical parameters such as temperature and moisture content are properly managed, home composting can be a practical and technically feasible alternative to commercial composting (Mihai and Ingrao, 2016). Lleó et al. (2013) also highlight that the transport energy needs for commercial composting are many times those required for home composting. Relative to commercial composting, home composting can therefore, pragmatically be considered as a relatively successful and economically feasible option for the management of municipal organic waste (Barrena and Sánchez, 2022; Hoornweg and Bhada-Tata, 2012).

Compost produced in both home and commercial composting processes need to be high-quality in order to impart the full spectrum of potential benefits as a soil amendment (Barrena et al., 2014; Kohli et al., 2022). A means of systematic evaluation of the quality of both the composting process and finished products is therefore essential. Commercial compost standards and guidelines for carrying out composting have been developed to aid composting operators to ensure a good quality process as well as to produce high-quality finished compost. These guidelines and standards have been developed to protect both the consumers of compost products and to maintain a profitable market basis for driving organic waste diversion to beneficial use (Compost New Zealand, 2007b).

Commercial composting standards are not designed to be applied to home composting (Compost New Zealand, 2007a; Standards Australia, 2003; Standards New Zealand, 2005). There is a lack of applicable standards or guidelines, by which home composting systems can be evaluated on the basis of production process and finished product quality assurance. However, as noted above, the biophysical basis of the 'decomposition' occurring in both commercial and home composting contexts, has generic similarities. Therefore, commercial composting standards offer a starting point in guiding the operational processes and evaluating home composting finished product quality. Commercial and home composting processes remain significantly different in critical areas. However, a carefully considered application and adaptation of some of the key principles and practices outlined in commercial composting standards provide a scientific and technical basis for evaluating the quality assurance of the home composting processes and finished compost.

The aim of this research was to develop a comprehensive new home composting evaluation tool (HCET) to support the evaluation of home composting processes and finished product quality assurance. It is hoped that the proposed HCET will contribute to promoting more effective home composting practices which in turn will support the social and environmental objective of increasing organic waste diversion.

2. Materials and method

This study employed a range of methods to develop the proposed HCET. As illustrated in Fig. 1, this was an iterative process. First, a comprehensive online search was undertaken to identify relevant scientific literature about home composting, 'how to'/'best practice' guidelines for home composting, and commercial composting standards. Collectively these sources informed the first iteration of a draft HCET which was initially piloted and then trialled in a survey of 19 households undertaking composting in Palmerston North, Aotearoa New Zealand. The pilot testing and field trial, together with further engagement with the literature informed the development of the final HCET.

Identification and analysis of literature employed in the development of the proposed HCET

Three forms of literature were identified, reviewed and analysed as critical sources of information for developing the proposed HCET:

- Scientific literature about home composting.
- International and New Zealand 'how to'/'best practice' guidelines for home composting (typically produced

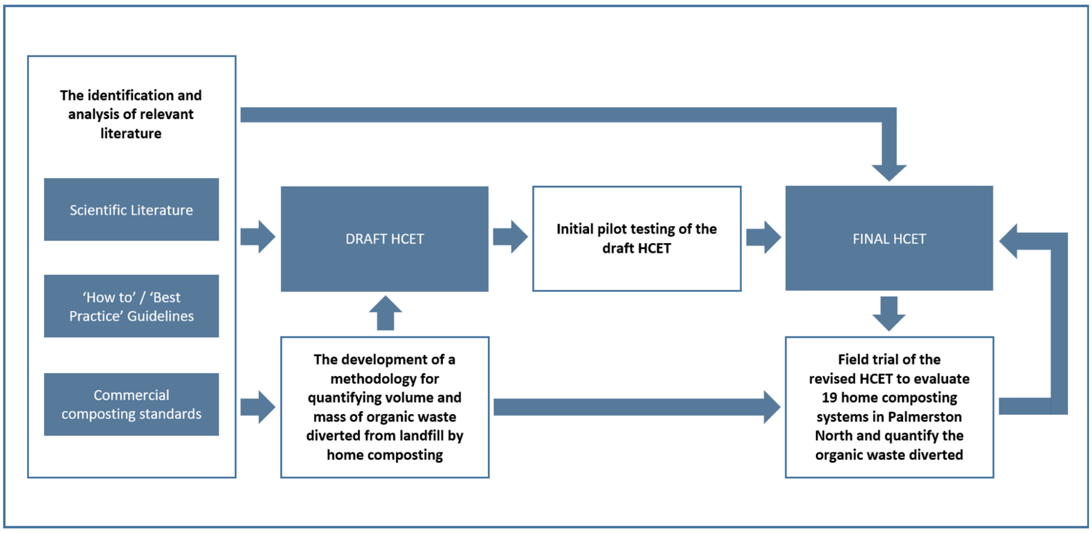

Figure 1. An overview of the process used to develop the HCET.

by municipal authorities to advise households on good home composting practices).

- Commercial composting standards, particularly NZS 4454:2005.

Relevant scientific literature about home composting

The keyword search strategy used to identify relevant scientific literature on home composting sought to encompass the broad spectrum of terminology used internationally. This included: 'home composting', 'backyard composting', 'decentralised composting', 'small-scale composting', and 'amateur composting', in combination with the terms 'organic waste', 'household organic waste', 'bio-waste' and 'biodegradable waste'. Once a reasonable body of literature was identified, the studies were classified based upon a simple typology which ensured that the selected literature most aligned with and informed the objectives of the research, namely those that:

- Examined and quantified the amount of organic waste diverted from landfills via home composting.
- Explored home composting systems, practices, awareness, attitudes, and issues.
- Investigated home composting processes and compost quality assurance parameters.

'How to'/'best practice' guidelines for home composting

A review of international and New Zealand 'how to'/'best practice' guidelines for home composting published by local government, municipal authorities and non-government organisations was then conducted. The selected 'how to'/'best practice' home composting guidelines were arranged and analysed according to the commonality of recurring themes (as summarised in Table 1). A simple coding system based upon the number of occurrences under the common pragmatic advisory construct of key dos and don'ts of home composting practices (indicated by the source number codes in Table 1) was employed. This approach enabled the level of consensus around what represents successful home composting practices to be identified and illustrated from amongst the selected best practice guidelines.

Commercial composting standards

Although there are a growing number of ISO standards specifically relating to a range of compostable plastics (e.g. (ISO, 2021, 2022, 2023) there is currently no agreed international composting standard. In Aotearoa New Zealand, the key provisions of *New Zealand Standard for Composts, Soil Conditioners and Mulches* NZS 4454:2005 (as summarised in Fig. 2) guide commercial composting operators in achieving successful management practices for their composting operations, which will result in quality assured compost end-products. This, like composting standards such as the Australian and European Compost Standards, identify essential finished compost quality assurance parameters which ensure that the compost does not represent an environmental or public health hazard and will achieve a positive outcome when applied to agricultural or garden soils.
In the New Zealand context, considering, and where appropriate including, some of the guidelines from the NZS 4454:2005 in the proposed HCET, provides an opportunity to improve the evaluation of the process and final products from home composting practices. Various methodologies provided in the NZS 4454:2005 (and the associated documents developed to support accreditation) for: obtaining a representative physical sample (i.e., by systematically sampling from locations representative of the entire compost pile) and accurately determining the temperature, and the moisture content of the compost process and finished compost were included in the proposed HCET.

Methodology for quantifying the volume and mass of organic waste diverted from landfill by various types of home composting systems

The development of the HCET was a critical element and outcome of the overall research project which included quantifying the amount of organic waste diverted from landfill by home composting in Palmerston North City, Aotearoa

Table 1. International and New Zealand 'how to' / 'best practice' guidelines for home composting. Sources: (1) Auckland City Council (2011), (2) Asia-Pacific Cultural Centre for UNESCO (1994) (3) University of Illinois Extension (2016) (4) Chartered Institute of Environmental Health (2009) (5) Chen et al. (2012) (6) Christchurch City Council (2014) (7) City of Casey (n.d.) (8) Dundee City Council (2016) (9) Palmerston North City Council (n.d.) (10) Pembrokeshire County Council (2007) (11) Pears (2009).

International and New Zealand 'how to' / 'best practice' guidelines for home composting		Sources (as listed above)
Dos	The optimum moisture content for the compost pile should be between 50 and 60%. Water can be added to the pile when needed.	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
	Mixing/turning of the compost pile is crucial for aeration, rapid decomposition, removal of excess heat and addition of moisture.	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
	A C/N ratio of 25 – 30 to 1 (25 – 30 parts carbon to 1 part nitrogen) or more green materials and less brown materials is essential.	1, 3, 4, 6, 7, 8, 9, 10, 11
	Feedstock should be layered thinly and uniformly when starting a new pile.	1, 3, 6, 7, 8, 10, 11
	It is important to have a sturdy and enclosed home composting system, or cover compost piles on the ground with underfelt, a tarpaulin or a plastic sheet.	1, 3, 6, 7, 9, 10, 11
	Physical characteristics of good quality finished home compost include dark brown to black colour, earthy smell and crumbly texture.	1, 2, 6, 7, 10, 11
	Shredding/size reduction of large feedstock (that is to make partial size distribution more uniform) before home composting is vital for rapid and sustained decomposition.	1, 3, 4, 8, 10, 11
	It can take between 2 – 18 months to obtain finished compost depending on the operational scheme, turning rate, type of feedstock, and time of the year. Decomposition is more rapid in summer as heat accelerates decomposition.	1, 6, 7, 8, 9, 10
	Home composting systems should be located on a sheltered, level site with good drainage and easy access to the house and a water source.	1, 2, 3, 6, 8, 9
	Bulking agents (dry brown materials) can be added to improve the porosity of saturated, smelly or slimy piles.	1, 3, 5, 8, 10
	The home compost pile formation should be started with a dry base of twigs to support good aeration and drainage.	1, 6, 7, 9, 10,
	It may be necessary to raise enclosed home composting systems on a few bricks, wire mesh or chicken wire.	1, 3, 4, 6, 7
	The recommended pile dimension is at least 1m high x 1m wide x 1m deep. This helps to form the critical mass to retain moisture content and temperature.	1, 3, 5, 6, 7
	A small amount of soil can be added halfway through the layers to encourage microbial activities and prevent insects.	3, 6, 8, 11
	The optimum compost pile temperature should be in the range of 30 to 60 °C.	1, 3, 7, 9
	More green materials can be added to a slow or ineffective compost pile, to revitalise the process.	1, 3, 10
	Food waste is to be buried in the centre of the pile, during turning or covered with more brown materials in case to reduce the likelihood of attracting insects or rodents.	1, 3, 6
	Only small quantities of lawn clippings should be added as large amounts can prevent the pile from composting well.	1, 6, 7
	Compost activators or accelerators can be added to the compost pile to speed up the natural breakdown process.	1, 8
	Lime and untreated wood ash can be sprinkled on the pile to balance pH, reduce smell and prevent fruit flies.	1
	Coarse finished compost should be sieved through chicken netting before use and the coarse material returned to the pile for further composting.	6
Don'ts	Input: Meat, fish and bones should not be added because they may not break down in the composting time frame and may attract rodents.	1, 3, 4, 7, 8, 9, 10, 11
	Input: Human and pet faeces should not be added as they can generate odour and may contain and transmit parasites and diseases.	1, 4, 7, 8, 9, 10, 11
	Input: Diseased plants, large pieces of woods treated wood, invasive weeds, fertilisers and toxic materials should not be added.	1, 6, 7, 8, 9, 10, 11
	Input: Baked and processed foods, beer and sugary or carbonated drinks should not be added as they attract rodents and insects.	4, 6, 7, 9, 10, 11
	Input: Oils, fats and dairy should be avoided as they smother bacteria and are unable to break down.	1, 4, 6, 9, 10, 11
	Input: Coal ash, disposable nappies, used tissues and bamboo should not be added to the pile.	1, 4, 10, 11
	Home composting systems should not be sited in an area where water will pool and risk becoming stagnant causing bad odour.	3, 5, 8, 11
	Home composting systems should not be sited under direct sunlight or exposed to strong winds to prevent drying and cooling.	3, 9
	Input: Citrus, onions and garlic should not be composted due to their strong smell inhibiting the bacteria around it.	7

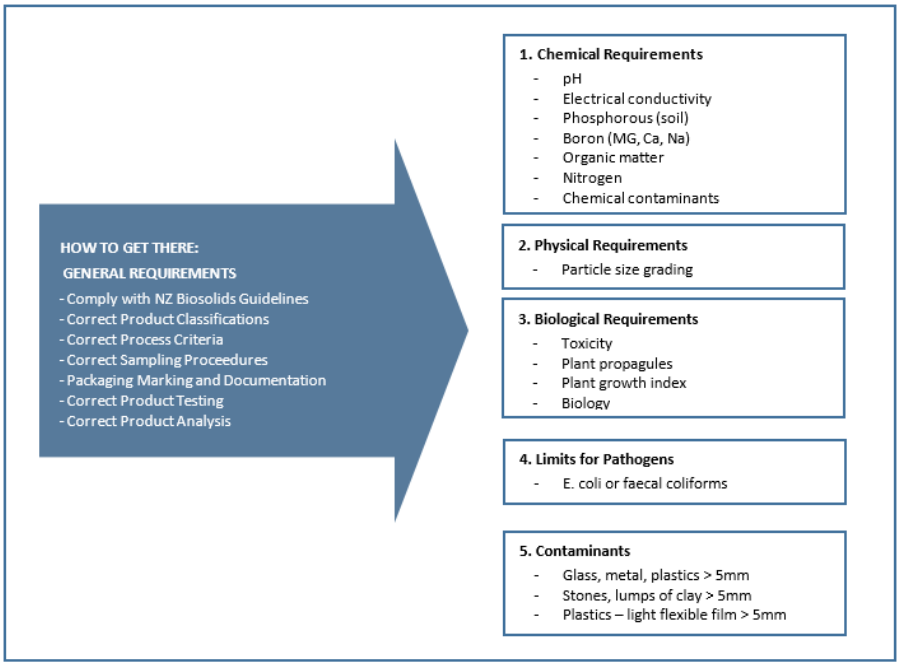

Figure 2. An overview of the key provisions of NZS 4454:2005. Source: Compost New Zealand (2007a).

New Zealand. Within this mixed methods research an initial draft and then finalised HCET was developed as a compact comprehensive rubric for data collection in the field (Mensah, 2017). The step-by-step method which was employed for quantifying volume and mass is illustrated in Fig. 3. This procedure was based on reviewing the spectrum of types and shapes of home composting bins/systems (including single or multi-bin systems) currently utilised in Aotearoa New Zealand. These included cuboid, frustum, trapezoidal prism, cylinder, cone and pyramids. This review of the types and shapes of home composting bins/systems provided the relevant range of necessary volume calculation formulas by which, any given home composting system likely to be encountered, could be measured. The necessary parameters (i.e., width, height, length and radius) required to perform the corresponding volume calculation appropriate to the identified range of types and shapes of home composting system were then included in the HCET.

The findings from the selected scientific literature, best practice guidelines for home composting, the NZS 4454:2005 composting standard and the proposed methodology for quantifying the amount of organic waste diverted from landfills via home composting were compiled into a streamlined draft HCET for trialling and use within in the overarching research project.

Pilot-testing and field trial of the draft HCET

A key stage in the development of the proposed HCET was the initial pilot-testing of the draft HCET. Following initial pilot-testing, the revised HCET was utilised to collect data evaluating the home composting process and finished compost products of 19 composting households in Palmerston North. Table 2 outlines the step-by-step methodology employed during the site visits. This procedure was de-

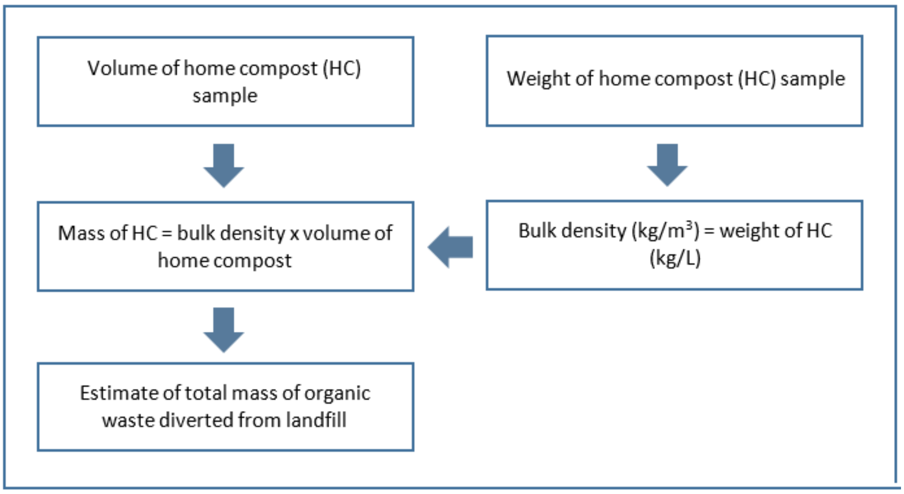

Figure 3. Step-by-step methodology for the quantification of the volume and mass of organic waste diverted from landfill via home composting.

Table 2. The standard operational procedure designed and trialled in this mixed-methods home composting evaluation research, to support consistency in data collection.

Step	Procedure undertaken by researcher
A.	The start time was recorded.
B.	A board labelled with the sample identification number was placed in front of the compost bin/open pile and a photograph of the system was taken.
C.	The type and shape of the compost system was identified, and the corresponding specific volume measurements of the compost bin or open pile were recorded.
D.	The temperature readings were taken and recorded by following the procedure provided in NZS 4454:2005.
E.	The home composting system, process and finished product were visually observed and evaluated using a five-point rating scale ranging from 1 ("very poor") to 5 ("very good") provided on the proposed HCET (reference was made to the accompanying guidelines where necessary.
F.	With the aid of a digging fork, the compost pile was opened up in order to extract a representative series of samples from different sections of the pile to form a two-litre compost sample. The sample was then poured into a zip lock bag and was sealed and labelled.
G.	The smell of the compost pile was examined, evaluated and recorded on the HCET.
H.	A sub-sample of partly decomposed or finished compost was placed in the palm.
I.	The palm was closed, and the sample was squeezed firmly.
J.	The structure of the sample was then evaluated and recorded on the HCET; samples which crumbled with light pressure indicated the availability of adequate moisture while those which either got deformed, stuck together when the pressure was applied, or released water, showed high moisture content.
K.	The end time was recorded.
L.	The compost pile and work area were tidied up and a checklist of the apparatus was conducted to ensure that none was left behind.

signed in conjunction with the proposed HCET itself as a set of operational instructions to ensure consistency in data collection.

3. Results and discussion

This section describes and discusses the key findings from the HCET development process outlined above.

Findings from literature review examining home composting processes and final product quality assurance

The key themes that emerged from the literature and formed the parameters of this review process were: the type of home composting study (e.g. environmental impact assessment, quality assurance, system operational performance, user awareness/attitude etc.), the location of the research (which included Australia, Canada, Denmark, France, Greece, Guadeloupe, India, Italy, New Zealand, Palestine, Poland, Spain, Sweden, Thailand, the United Kingdom, the United States and Vietnam) and the research objective (e.g. investigating commercial vs home composting, greenhouse gas emissions, centralised vs de-centralised approaches, the rationale for uptake/ongoing participation and exploring system performance) and the key findings of each study. The most relevant sources' quality assurance parameters are summarised in Table 3. pH, moisture content, carbon-nitrogen ratio and temperature were the most common parameters analysed in the selected studies and with the exception of pH were therefore included in the proposed HCET. Although pH was identified as a key parameter in the cited studies, unfortunately a cost-effective method for determining the pH of the samples was not available within the financial constraints of this study. In future home composting studies, this parameter should be assessed if resources for determining the pH of the compost are available.

Findings from the review of home composting 'how to'/'best practice' guidelines

The commonly recognised priority parameters identified through the analysis of the levels of consensus amongst the selection of international and New Zealand home composting 'how to'/'best practice' guidelines for home composting

Table 3. Parameters analysed in selected compost quality assurance studies.

Study	Moisture content	Organic matter content	Heavy metals contents	C/N ratio	Temp.	pH	Electrical conductivity
Alexander (2007)				✓	✓	✓	✓
Barrena et al. (2014)	✓	✓	✓	✓		✓	✓
Cristoforetti et al. (1998)	✓		✓	✓		✓	
Colón et al. (2010)	✓	✓				✓	
Dhankorkar et al. (2022)	✓			✓		✓	✓
Ermolaev et al. (2014)	✓				✓	✓	
Karnchanawong and Suriyanon (2011)				✓	✓		
Margaritis et al. (2023)	✓	✓	✓	✓	✓	✓	✓
Phu et al. (2021)	✓	✓	✓				
Vázquez and Soto (2017)	✓		✓	✓	✓		

(summarised in Table 1), are outlined in Table 4. These detailed observations were synthesised and informed the technical detail and arrangement of the proposed HCET and accompanying guidelines.

Summary of parameters considered essential for undertaking a home composting quality assurance evaluation

Based on the findings outlined in the previous sections, the following parameters were ultimately considered essential and included in the HCET as a framework for undertaking a home composting process and finished compost quality assurance evaluation:

- Siting, design and construction of the home composting system.
- Process management - inputs/feedstock, shredding, blending/amendment, mixing/turning.
- Physicochemical properties - temperature, moisture content and pH.
- Physical characteristics - colour, smell and texture of finished compost.

This compilation of findings was the result of the staged analytic process which informed the iterative formation of the proposed HCET (Appendix 1). This process drew upon the wide range of sources described above while also taking into consideration practical issues which emerged in the pilot-testing and field trial phases, such as what equipment was affordable in this research context. For example, expensive multi-function equipment for in-situ measurement of pH, moisture content and temperature was not an option for this study, and it was decided that a simple temperature probe and moisture content 'squeeze test' were an acceptable alternative.

Including affordability as a design parameter makes the proposed HCET more relevant to the context of low-income countries, where home composting and small-scale distributed composting represents a significant environmental opportunity and cost may be an important consideration for researchers and practitioners. The final design parameter was making the proposed HCET a simple, concise field data collection tool, which would efficiently capture the most relevant data in a user-friendly and legible format. Guidelines, based on the applied experience of this research procedure, around how the proposed HCET can be practically utilised were also developed (Appendix 2).

The approach to evaluation employed in the proposed HCET

The HCET employs a five-point rating scale ranging from 1 ("very poor") to 5 ("very good") to evaluate the home composting process and finished compost. The score for each key parameter is calculated by averaging the scores for the relevant sub-parameters. The "final home composting evaluation score", is then calculated by averaging the scores for the 14 key parameters. Key parameters and final scores can be compared within and between home composting systems to identify key strengths and challenges. The guidelines for implementation support effective implementation of the HCET and ensure that if two or more people are using the tool, they can achieve a consistent level of scientific rigor.

4. Conclusion

This research demonstrates that the proposed HCET provides a quick, easy, accurate and efficient model for mixed methods data collection to evaluate home composting systems and other small-scale composting systems. More broadly, the proposed HCET contributes to methodological discussion relevant to home composting quantification and evaluation in Aotearoa New Zealand and internationally. Given the environmental and social importance of home composting, there is a need for more research into how composting processes and outcomes can be optimised. If an internationally agreed HCET can be developed, home and small-scale composting practices can be better compared with each other, with commercial contexts, and between cities and countries, which will in turn provide more robust and comparable data on this important aspect of municipal waste management.

Table 4. Key parameters and observations collated from the review of international and New Zealand ‘how to’ / ‘best practice’ guidelines for home composting.

Parameters	**Key observations**
Location/siting of the home composting system	Important considerations include: • Proximity to the house, neighbours, back door, kitchen and garden • Proximity to a water source • Visual appeal • Accessibility during various weather conditions • No evidence of stagnant water and water pooling • Location on a level area with good drainage • Shelter from direct sunlight and wind
Design/construction of the home composting system	The home composting system should be sturdy, have a cover or be elevated on bricks/wire mesh
Essential management practices	• Shredding increases the surface area of feedstock for effective microbial decomposition • Layering helps to achieve the required proportions of green and brown materials (thereby producing the required C/N ratio) • Mixing/turning promotes aeration • The addition of bulking agents or amendments enables the adjustment of the porosity and smell of the pile • Covering of food waste prevents the attraction of pests, and reduces the smell
Process parameters	Control and monitoring of process parameters are necessary to ensure an effective process and good quality compost. These parameters include: • Moisture content ($50-60\%$) • C/N ratio ($25-30$ to 1) • Temperature ($30-60$ °C) • Pile dimension (1m high × 1m wide × 1m deep) • Timeframe (>2 <18 months)
Materials that should be excluded from the compost system	The addition of the following materials to the compost pile may result in home composting problems: • Baked, cooked and processed foods • Beer and carbonated drinks • Cat, dog and human faeces • Oils, fats and dairy products • Meat, fish and bones • Diseased plants, large and/or treated wood • Tins, glass and plastics • Invasive weeds, fertilisers and toxic material • Coal ash, disposable nappies, used tissues • Bamboo, flax and cabbage tree leaves • Large amounts of lawn clippings

Continue of Table 4.

Parameters	Key observations
Common home composting problems	Common home composting problems associated with the inclusion of the wrong feedstock types and/or poor monitoring and control of essential home composting paramters include: • Non-decomposing pile • Smelly pile • Slimy pile due to high moisture content • Saturated or dry pile • The presence of insects, rodents or pests • Overheated or under-heated pile
Physical characteristics of the finished compost	A matured compost should have a dark brown to black colour, an earthy smell, and a crumbly texture with no recognisable feedstock.

Local councils and municipal authorities often spend considerable sums of money to promote home composting practices and educate people on how to most effectively undertake home composting. The proposed HCET can be used by local councils and municipal authorities to effectively measure and report on the return on investment of such programmes by enabling funders to capture 'before' and 'after' quantitative and other quality assurance measures to determine whether promotional and educational programmes are effective and well targeted.

It is hoped that the proposed HCET will assist further research seeking to quantify and evaluate home composting practices in other research contexts and contribute to increasing understanding around home and small-scale composting as a critical waste management practice. Internationally, home and small-scale composting is recognised as an important opportunity to circularise biological nutrient flows within the construct of circular bioeconomy strategies. This novel HCET seeks to contribute to improving the collective understanding of home and small-scale composting practices through better data in order to enhance the effectiveness of home composting and maximise the social and environmental benefits it generates.

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Authors contributions

Sabina Mensah undertook the original research project and wrote the first draft of the manuscript. Jonathon Hannon supervised the original research project and wrote and revised the final manuscript. Karen Hytten supported the original research project and wrote and revised the final manuscript.

Availability of data and materials

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Conflict of interests

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 1 Proposed Home Composting Evaluation Tool (HCET).

Questionnaire #	Telephone #	Date: / /	Photographic	YES/NO	Start time (mins):		Visit Duration (mins):
Suburb	Sample ID		Observations		End time (mins):		

Parameters	Observations/Discussion		Evaluation Yes	No	1	2	3	4	5	Av	Identify Shape of Compost Bin	Volume M3
EVALUATION OF COMPOST PROCESS QUALITY ASSURANCE *[where poor =1 → good =5]*											**Shape # 1 (Cuboid/Cube) i.e. 2 or multi -bin option**	
Location/Siting	Appropriate proximity to house relates to the visual, odour & nuisance impacts										Bin one: (l= w= h=)	
	Usable, all-weather access, good drainage - avoids water pooling										Bin two: (l= w= h=)	
	Access to water source adequate shade/shelter										Bin three: (l= w= h=)	
Design & Construction	Fitness for purpose cover system/containment (i.e. balancing aeration vs moisture content retention)										Bin four: (l= w= h=)	
	Adequate ventilation (included at base) to support aerobic conditions/O_2 porosity										**TOTAL**	
	Safety - any obvious hazards or ergonomic issues											
Feedstock/Inputs	Appropriate input types (no obvious exclusions via reference lists)										**Shape # 2 (Frustum)**	
	Indicators of inorganic contamination i.e. plastics, bones, glass, other										(h= R= r=)	
	Indicators of oversized inputs vs shredding as required										**TOTAL**	
Blending/Amendment	Balanced/blended proportions of 'green & brown' materials (ref: C: N ratio aim @ >30:1)											
	Appropriate mix layering of inputs to support O2 porosity of compost										**Shape # 3 (Trapezoid prism)**	
	Appropriate range of particle sizes to support O_2 porosity of compost										(h = H= b_1= b_2=)	
Bulk Density	**One litre sample nett weight (g)**	**Bulk Density (kg/m^3)**									**TOTAL**	
	NB: ref: NZS 4454:2005 & community composting guidelines aiming for 200 – 300 **kg.m^3**											
Process Management	Indicators of/ability for turning/mixing (i.e. by hand or other method)										**Shape # 4 (Cylinder)**	
	Watering to optimise moisture content (50 – 60% ref hand squeeze test)										(r= h=)	
	Covering to reduce evaporation/dry and or pest access to food scraps										**TOTAL**	
	Indicators of leakage excess leachate generated & uncontained											
Temperature	**Recorded ambient temp**	**Recorded compost temp**									**Shape # 4 (Sphere)**	
	NZS 4454:2005 referenced against community composting guidelines (1= ambient or below → 5= 45 to 65°C)										(r=)	
Moisture Content	Onsite moisture content observation	Follow up moisture content recorded in lab									**TOTAL**	
	NZS 4454:2005 referenced against community composting guidelines aiming for 50 – 60% ref hand squeeze test and criteria											
Biology	Observable presence of positive biological activity i.e. worms and other vertebrate decomposers										**Shape # 5 (Cone)**	
Issue Management	*Ammonia - NH_4 (pungent odour)*	*NB b/c this group is a negative parameter, ratings are reversed: poor = 1 = lots of bad smell & good = 5 = no smell*									(r= h=)	
	Hydrogen sulphide - H_2S (rotten egg)										**TOTAL**	
Odour/Smell	*Putrid/Manure characteristic of Methane*											
Issue Management	Insects, flies & or the precursor, maggots										**Shape # 6 (Pyramid)**	
	Indicators of birds, rodent (rats & mice) or cats/dogs scavenging										(l= w= h=)	
Parameters **EVALUATION OF FINAL PRODUCT QUALITY ASSURANCE**											**TOTAL**	
Colour	Colour on spectrum from light to dark brown - which indicates the formation of humus											
Maturity	Cool (near ambient) and stable temperature										**FINAL HC EVALUATION**	
	Absence of evidence of any fresh inputs (i.e. introducing seeds)											
Texture	Friable/crumbly vs slimy/soggy i.e. breaks down to small particles in hand											
	Lumpy heterogeneous vs uniform homogenous range of particle sizes											
Notes												

Appendix 2 Guidelines for implementing the proposed HCET.

Parameters	Observations/Discussions		Evaluation				
			1-Very Poor	2-Poor	3-Average	4-Good	5-Very Good
Location/Siting	**Proximity**	Visually appealing, distance from households, neighbours, back door kitchen and garden	None present	Any one present	Any two present	Any three present	All present
	Usability	Usable/all-weather access (especially during rainfall)/no evidence of stagnant water and (potential) water pooling	None present	Any one present	Any two present	Any three present	All present
	Moisture content management	Graded section/easy access to water source/not directly exposed to sunlight, rainfall or strong winds	None present	Any one present	Any two present	Any three present	All present
Design & Construction	**Fitness for purpose**	Sturdy/no rotting of structure/not too much rust/sufficient size or volume (and section with respect to piles on the ground)/contained	None present	Any one present	Any two present	Any three present	All present
	Ventilation	Evidence of e.g. raised on bricks, wire mesh, poles, sticks (some materials are naturally porous)	No ventilation	Fairly ventilated	Moderately ventilated	Ventilated	Well ventilated
	Safety	No obvious ergonomic issues such as tripping hazards, height related to lifting, width related to leaning over, sharp edges, presence of dirtiness	More than four present	Any four present	Any three present	Any one present	None present
Feedstock/inputs	**Appropriate inputs**	Presence of 'more compostable' than 'less compostable' materials	More than five 'less compostable'	Any four 'less compostable'	Any three 'less compostable'	Any two 'less compostable'	None present
	Contamination	No visible contamination	More than four present	Any four present	Any three present	Any one present	None present
	Shredding	Free from large materials which may require shredding	Very large	Large	Fairly large	Fairly small	None present
Blending/Amendment	**Blending**	Evidence of blended proportions of greens and browns	Excess greens	Excess browns vs greens	Fairly balanced greens and browns	Moderately balanced greens and browns	Balanced greens and browns
	Layering	Evidence of layering (i.e. uniform and thin layers)	No layering	Fairly-layered	Thin but not uniform	Uniform and thin	Dry base, uniform and thin
Process Management	**Turning**	Evidence of turning for e.g. appropriate height of compost bin and large top opening for inserting garden/digging fork or shovel for turning/mixing	None present	Any one present	Any two present	Any three present	All present
	Moisture content	Onsite squeeze-test	More than two drops	Two drops	A drop of water	Moist and undeformed	Crumbles
		Lab test	10% or less	Below 25%	Between 30 – 35%	Between 40 – 50%	50-60%
	Covering	Cover or lid/covered pile/buried food waste/no likely access to pests	None present	Any one present	Any two present	Any three present	Buried food waste
	Leachate	Thick/thin/light brown/dark brown/odourless liquid	Colourless/pale yellow with offensive smell	Colourless/pale yellow with fruity smell	Colourless/pale yellow with no smell	Thick/thin/light brown/dark brown but smelly	Any present/no leachate
Temperature	**Process tempearture**	Compost pile/finished compost	Below ambient	Ambient	Ambient +1-5°C	Ambient +6-10°C	Ambient +>10°C
Biology	**Biological activity**	Presence of earthworms, mites and other decomposers	None present	Any one present	Any two present	Any three present	More than three present
Issue Management	**Odour/smell**	Presence of earthy or no odour/smell	Very bad smell	Bad smell	Moderate smell	Slightly earthy smell	Earthy/no smell
	Pests	Insects (e.g. flies and maggots), rodents, cats/dogs	All present	Any three present	Any two present	Any one present	None present
Colour	**Humification**	Light-dark brown	Very light brown	Light brown	Dark brown	Light black	Dark black
Maturity	**Product temperature**	Cool (near ambient) and stable temperature	Ambient +>10°C	Ambient +6-10°C	Ambient +1-5°C	Below ambient	Ambient
	Unrecognised input	Absence of fresh feedstock	Undecomposed	Mostly partly decomposed	Less partly decomposed	Small pieces of leaves and feedstock	Fully decomposed
Texture	**Friability**	Evidence of breakdown to small particles in hand	Very slimy and soggy	Slimy and soggy	Soggy	Damp but not slimy	Crumbly
	Particle size	No evidence of e.g. lumpy, heterogeneous, sticky/powdery particles	None present	Any three present	Any two present	Any one present	Homogenous