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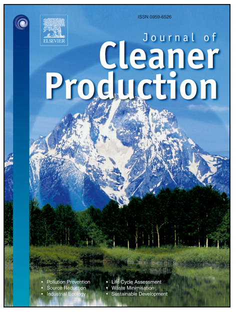

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Ex-ante demand assessment and willingness to pay for human excreta derived co-compost: Empirical evidence from rural South Africa.

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Abstract

Recovering plant nutrients from human excreta streams through circular bioeconomy initiatives like co-composting may offer a cross-sectoral solution to waste management, sanitation, and agriculture. However, the failure of composting innovations is attributed to a lack of a ready market for the compost produced. The current study hypothesizes that improving the desirable attributes of compost to the market through pelletization, fortification, packaging (with labelling), and certification of co-compost could enhance the market demand for co-compost. Socioeconomic variables such as income, religiosity, and environmental attitudes as measured by the new ecological paradigm, were also hypothesized to influence the willingness to pay for co-compost. Based on Lancaster's characteristics demand theory, the efficient Bayesian design, and the discrete choice experiment, we administered a mobile-based survey to 341 rural farmers. The conditional logit, random parameters, and latent class models show that the rural farmers were willing to pay for all the attributes included, especially certification by relevant authorities (ZAR1.70/kg) and fortification with inorganic mineral fertilizers (ZAR1.49/kg). The findings also indicate the influence of income, religiosity, and environmental attitudes on farmers' willingness to pay for co-compost. The results demonstrate the importance of addressing perceived and actual health risk through certification and the complementary role of co-compost in enhancing the agronomic efficiency of chemical fertilizers through fortification in farming systems. Redesigning compost to include the identified attributes could enhance its market appeal. Mainstreaming dissemination strategies and targeting customer segments could improve social acceptance of human excreta-derived compost in agriculture.

Keywords: Human excreta; efficient design; choice experiment; co-compost; willingness to pay; demand assessment

1. Introduction

High-input agricultural intensification and high per-capita consumption continue to deplete farming land, which calls for alternative and sustainable methods of restoring productive land (Kopittke et al., 2017; Sasmal and Weikard, 2013; van den Born et al., 2000). The challenges associated with using organic soil inputs include high labor demand, variable product quality, low agronomic response, and limited availability of sufficient quantities (Janssen, 1993). There is also a growing narrative in the integrated soil fertility management literature suggesting the failure of alternative ways of improving soil health and recommending the use of chemical fertilizers as an important element to meeting the growing demand for food (Vanlauwe et al., 2014). However, there are bottlenecks in the adoption of chemical fertilizers by poor farmers, especially in Africa, where annual nutrient depletion rates exceed 60kgNPK/ha (Noble, 2012). In such contexts, the yearly average fertilizer application rates cannot meet the soil nutrient mining rates or the plant requirements for crop production (Mwangi, 1996; Drechsel et al. 2001a; 2001b; Devkota et al. 2016;). The use of inorganic fertilizer is often associated with low agronomic response due to poor soil quality associated with low soil organic carbon, and rainfall variability (McIntire and Gryseels, 1987). The low usage of chemical fertilizers is also associated with high transaction costs, and low farmgate prices reducing the return on investment (Mwangi, 1996; Holden, 2018). There are also of negative environmental externalities associated with the excessive use of chemical fertilizers (Han et al., 2015; Lin et al., 2019; Savci, 2012) and external inputs (Foley, 2005; Tilman et al., 2011)..

Long-term fertility trials in sub-Saharan Africa (SSA) show that longstanding yield benefits can be achieved by combining organic and inorganic soil inputs using integrated soil fertility management (Byerlee and Heisey, 1996; McIntire and Gryseels, 1987). More recent studies demonstrate the long-term benefits of the combined use of organic and inorganic fertilizers in SSA (Chivenge et al., 2009; Sileshi et al., 2022, 2019). On average, an annual per capita production of 520kg of human excreta containing 7.5kg of plant available macronutrients (NPK) and other micronutrients, if captured and valorised into agricultural fertilizer, could organically produce 250kg of cereal (Wolgast 1993). Globally, full resource recovery and reuse of waste-based streams could help to recover approximately 41 million tons of nutrients, making up 28% of the present annual nitrogen (N), phosphorus (P), and potassium (K) utilization (Otoo et al., 2018). Closing the nutrient loop through the circular bioeconomy approaches can help to mitigate the challenges of resource scarcity, nutrient depletion, and promote sustainable economic growth based on waste resources (Burlakovs et al., 2017; Ellen MacArthur Foundation, 2015; Korhonen et al., 2018).

Using co-compost produced by mixing human fecal matter or wastewater treatment sludge with compostable organic matter such as food and green waste has climate change mitigating effects through the sequestrating or sinking and storage of stable organic carbon into the soil. There are also reported soil health benefits that can be realized by incorporating soil organic carbon (Adamtey et al., 2010; Cofie et al., 2009; Nikiema et al., 2014, 2012; Wang et al., 2019). The free carbon makes weak bonds with nutrients in the soil and prevent nutrient loss while making them available to crops (Chivenge et al., 2009; Sileshi et al., 2019, 2022, Vanlauwe et al., 2011). Incubation studies and field experiments shows significant benefits of applying human excreta-derived plant nutrients on soil health and crop productivity (Odindo et al., 2016; Glæsner et al., 2019; Lemming et al., 2019; Simha and Ganesapillai, 2017). The excreta-based waste streams including green waste, food waste, non-sewered and sewerage-based waste streams, may present potential cross-sectorial benefits to the sanitation, waste management, health, environmental, and agricultural sectors (Cofie and Koné, 2009; Khadra et al., 2019; Koné et al., 2007).

Technically, the low calorific value (high moisture content), of waste streams in most developing countries favor biological treatment compared to thermal treatment alternatives (Pandyaswargo et al., 2012). The benefits of composting are also related to the high level of degradation of organic materials, simplicity, low set-up costs, and the creation of economic value-added agricultural products from waste streams (Sabkia et al., 2018; Saer et al., 2013). In addition, the composting technology is a mature innovation in terms of technology readiness level and wide-scale applicability (Egle et al., 2016; Harder et al., 2019). As a nutrient recovery technology, the thermophilic composting technology can inactivate pathogens to the World Health Organization (WHO) acceptable levels for agricultural use (Khadra et al., 2019; Koné et al., 2007). When compared to alternative disposal methods, such as incineration and landfilling, the co-composting system could be a more sustainable waste management option in terms of environmental performance (Cleary, 2009; Rahman et al., 2019; Recycled Organics Unit, 2003; Saer et al., 2013).

Despite the stated benefits, the failure of most composting initiatives to scale up is primarily due to lack of technical feasibility and economic viability (Pandyaswargo and Premakumara, 2014). The typical economic failure of composting technologies is attributed to the lack of a ready market for the compost produced (Pandyaswargo et al. 2012),suggest that high investments in compost marketing is critical to the viability of the composting system. Research evidence indicate potential institutional, financial, market, technological, and behavioral barriers to its wide-scale acceptance (Viaene et al., 2016). Pathogen detection, low product value, and slow mineralization have been reported to reduce the market acceptance of compost (Ayilara et al., 2020). Preceding the current study and following the recommendations by (Arksey and O'Malley, 2007) and (Colquhoun et al., 2014; Levac et al., 2010), two scoping reviews of literature were conducted to clarify the key concepts, examine research methodologies, and identify the critical attributes of compost that would enhance its social acceptance and willingness to pay. The findings of the first scoping review on social acceptance indicated paucity of published research evidence, inconclusive and contextualized effect of demographic, sociological, and socioeconomic farmer characteristics on willingness to use human excreta in agriculture (Gwara et al. 2021). A follow up empirical study on the social acceptance of human excreta in South Africa shows that there is high social acceptance and willingness to recycle human excreta derived co-compost in agriculture by rural farmers. The results also indicated lack of awareness and perceived health risk as the potential barriers for recycling human excreta in agriculture (Gwara et al. 2022).

The second scoping review of literature focused on the willingness to pay for human excreta in agriculture, and the results indicated that the area is a nascent area of research with limited published research (only four published studies globally) on the market demand for co-compost (Gwara et al., 2021). The findings demonstrated that there is limited scientific knowledge to conclude what attributes co-composted human excreta and organic waste (garden waste and food waste) need to have to be accepted and purchased by farmers. In fact, out of the four existing studies, only two studies endeavored to elicit the willingness to pay for the attributes that would improve the market demand for co-compost. This is paradoxical considering the magnitude of scientific research efforts that has been put in identifying pathways and processes for safe recovery of human excreta for agricultural use (Harder et al., 2019). The current study addressed the research gap and improved from the previous studies in four main ways. First, the study synthesized the co-compost attributes from previous studies and elicited the willingness to pay for pelletized, fortified, and certified co-compost, while packaging was combined with labeling. Second, the study followed the recommendations of the contemporary guidance for stated preference studies (Johnson et al., 2017) and implemented the Bayesian efficient optimal experimental design to improve the shortcomings of the orthogonal designs that were implemented in all previous studies in terms of task complexity and response efficiency, utility and attribute balance, and unrealistic model assumptions. Implementing the Bayesian efficient optimal design, used in this study improves the reliability and statistical efficiency of the willingness to pay estimates as shall be explained in the methods section.

Third, the study contributed to the nascent field of study by offering a unique and different context and study participants by eliciting the willingness to pay for human excreta recycling by South African rural farmers. To attract investment in circular bioeconomy businesses such as faecal sludge treatment technologies and innovations, it is imperative to solicit, ex-ante, the market feasibility, especially focusing on the product attributes or characteristics that would make it appeal to the target consumers and to demonstrate financial returns (Malele et al., 2019). Providing the compost to farmers in its suitable form requires funding, and potential consumers should be willing to pay for the cost of delivering the compost in its acceptable attributes (Gulbrandsen, 2009). Spending effort on finding ways of improving the market appeal of compost averts possible outcome of producing costly waste-based products with no demand in agricultural systems (Rouse et al., 2008). The aim of the current study is therefore to estimate the willingness to pay for co-compost among rural farmers in South Africa. The findings of the study may help to inform faecal sludge management businesses and commercialization of co-compost in agriculture.

2. Methodology

2.1. Theoretical foundations of the choice experiment approach

The current study takes a choice-based approach by assuming that the respondent's choice decisions truthfully reveal their preferences and are based on the utility or social benefit associated with different alternatives in each choice set. The choice-based model follows Lancaster's theory, which argues that the value of a good (hedonic or implicit price) can be decomposed to its observed characteristics or attributes (Lancaster, 1966). The willingness to pay is an estimate of the societal benefit, preference or desirability of a product attribute technology or innovation. The analytical foundations for discrete choice experiment approach are based on the random utility theory, which decomposes the demand or utility U of a good into the observable vector V of deterministic product attributes, the individual-specific idiosyncrasies i, and the unobservable and stochastic error component ε, for the j alternatives in a choice set (McFadden, 1998, 1974) as illustrated in **Equation 1.**

$$U_{ij} = V_{ij} + \varepsilon_{ij} \quad (1)$$

Two methods are used in the evaluation of the willingness to pay for non-marketed goods, namely the choice experiment and the contingent valuation approaches. The literature in health, environmental, and agricultural economics suggests the popularity of choice experiments compared to other stated preference approaches (Mahieu et al., 2014, Lloyd-Smith et al., 2022). The advantage of the choice experiment approach is in the theoretical simulation of the consumer purchasing decisions (Danso et al., 2017; Hanley et al., 1998). The choice experiment method also reduces ethical protesting and strategic responses and provides an in-depth knowledge of how decision-makers trade-off between attributes (Adamowicz et al., 1995). Empirical evidence suggests that the choice experiment methodology provides more precise estimates than alternative approaches (Adamowicz et al., 1995). Although the choice experiment approach may suffer from hypothetical bias and incentive compatibility (Lusk and Schroeder, 2004), correct framing of questions, pretesting, certainty scales, and cheap talk scripts may improve the accuracy of choice experiments (Johnston et al., 2017). The current study endeavoured to implement the best practices following the recommendations from the contemporary guidance for implementing stated preference studies (Johnston et al., 2017).

2.2. Data

The current study targets the rural farmers as potential customers for fecal sludge treatment products. The rural communities in South Africa currently facing the challenge of emptying full ventilated improved pit latrines that were previously constructed by the government in response to the millennium development goals (Harrison and Wilson, 2012). The responsible public utilities face challenges of budgetary constraints, mismanagement of public funds, and lack of legislative and regulatory mandate. The farmers with full pits often resort to inferior sanitation facilities, such as makeshift toilets and open defecation, risking exposure to known health risks and loss of dignity (Lüthi et al., 2011). The rural farming community may seem like a curious market for fecal sludge treatment businesses to target as it requires a lot of small rural farmers with relatively smaller land sizes to be targeted. Alternatively, targeting large scale farmers, where businesses need to persuade only a small number of customers to buy the large quantities of co-compost from a treatment plant may seem like a better sample for the current study. However, unless they are focusing on organic farming, most large scale farmers can afford inorganic fertilizers and may want to capitalize on readily available nutrients. In addition, historically most of the rural farmers were dispersed to barren lands, largely not suitable for crop production. The smallholder farmers contribute more that 70% of the food calorific requirements in sub-Saharan Africa (Fanzo, 2017). Public support may need to be put in place to support the uptake of co-compost through subsidies and other form of incentives that targets either the farmers or the fecal sludge management businesses. Capturing the soil nutrients that are continuously mined as food from the depleted soils, and returning them back as soil amendments, in this case co-compost, will help to resuscitate soil health while building the resilience of the local food systems. Coupled with the previously noted challenges of soil nutrient mining and low fertilizer use resulting from low fertilizer agronomic response, the rural farmers could benefit from the recovery and reuse of human excreta in agriculture. It is against this background that the study area in Vulindlela Traditional Council was selected.

A cross-sectional study design was implemented using a household survey tool to elicit the farmers' preferences and willingness to pay for the various attributes of co-compost. The data were gathered from 341 rural farmers in Vulindlela Traditional Council, located (28.8583°S, 31.8378°E) in the KwaZulu-Natal province of South Africa. The Vulindlela Traditional Council consists of nine wards under the sole trustee of the King (Kharsany et al., 2015; Msunduzi Municipality, 2016). The area occupies 40% of the Msunduzi Local Municipality, covering approximately 25 000 hectares with more than 85 000 households and about 150 000 people (Kharsany et al., 2015). Humanities and Social Sciences Research Ethics Committee (H.S.S.R.E.C./00001499/2020) ethical clearance and verbal consent were obtained from the university research office. The ethics approval provided study participants with the study purpose, confidentiality clause, and the freedom to withdraw from the study. The survey instrument is readily available at the following link https://enketo.ona.io/x/#EkSVyazm.

The household survey (preparation, training, and interviews) was administered from 10 to 26 November 2021 during a national lockdown and university Covid-19 window, where household surveys were temporarily allowed. The enumerators were always encouraged to adhere to the country's Covid-19 lockdown level 1 regulation. Power tests were performed using the G*Power software $\alpha = 5\%$, and seven variables, power of 95% and Cohen's *d* effect size =15% (Cohen, 2013, 1992; Daly and Cohen, 1978; Kang, 2021). The sample size was estimated to be 153 participants although additional participants were added to incorporate other studies integrated in the survey tool. The sampling unit was defined as a household practising farming consisting of people living together and eating from the same pot and making important livelihood or food security decisions. The household head was the primary decision-maker on most farming activities. The sample population consisted of rural farmers who mostly depend on agriculture for food production. Details of the study area description, detailed study design, survey training and budget, survey questions, sampling strategy, sampling information, fertilizer types, reasons for use, and sources including measures of validity and reliability of the instrument are provided in the supplementary information of a preceding study on social acceptance (Gwara et al. 2022).

The study implemented a multi-stage sampling procedure to avert the challenges inherent in simple random sampling, including the unavailability of a complete list of all members of the population and budgetary constraints. First, two wards (ward 8 and 9) were purposively selected based on the maximum distance (about 40 km) from the Pietermaritzburg city. Using systematic random sampling technique, the sampling interval, or the space between each selected household - was calculated by dividing the total number of households in each ward by the sample size. The weighted sample size in each ward was calculated based on the number of households in each ward (ward 8 = 2 145 and ward 9 = 2 971), to get a total predetermined sample size of 341 farmers. Weighted or proportional sample sizes of 143 farmers in ward 8 and 198 farmers in ward 9, and the respective sampling interval of 15 households were calculated in both wards. Based on the sampling interval, non-response (not measured), and a mixture of disperse and clustered settlement patterns in the area, large distances between the sampled households were created rising the cost of the survey. As a result, a field sketch map of the ward was co-developed with the support of respective ward councillors and was used to assign enumerators into representative clusters. For instance, if a cluster was estimated to constitute a fifth of the size of the ward, a sampling interval of three (15 divide 5) was used to systematically select households which helped to reduce the walking distance per enumerator. There were few unrecorded cases where the selected household may not have been occupied at the time of the visit because of attending weddings, funerals or visits to friends and relatives. In those instances, and based on the field visitation log sheet, the household was either revisited later that day or on another day. If the selected household was permanently vacant or an adult was unavailable, a neighbouring household was visited. No reports were made by enumerators on refusal to participate in the survey. It should be acknowledged that the estimation of the proportion of the agglomerate or cluster may have created an unequal probability for some households to be selected, although efforts were made in the study to sample households selected in dispersed settlements. While the simple random sampling is not entirely free from bias, and because the current study was implemented ex-ante (low selection bias), this was found to be the best method to minimise sampling error based on the practicality of implementation and the available resources.

The survey tool incorporated cheap talk scripts and certainty scales to improve the incentive compatibility and consequentiality of the value elicitation approach (Arrow et al., 1993;

Johnston et al., 2017). Incentive compatibility and consequentiality were also reinforced by emphasizing the implications of the farmers' response to designing current and ongoing projects in the area, which was assumed to reveal their preferences truthfully. The survey instrument was checked for construct validity by being subjected to expert evaluation from scientists within the RUNRES project (Taherdoost, 2016). The survey tool provided some information cues to enhance the accurate framing of attributes (Kragt and Bennetta, 2010) to improve the instrument's incentive compatibility (Zawojska and Czajkowski, 2017). The survey instrument was additionally piloted on 25 rural farmers to test for face validity before being subjected to the study participants (Taherdoost, 2016). More details of the survey methodology and instrument can be found in the supplementary information of a related published study on social acceptance of human excreta reuse in agriculture (Gwara et al., 2022).

2.3. Product attributes

The five attributes for improving the market appeal for co-compost were identified through the scoping review of literature include pelletization, fortification, packaging, certification, and price (**Table 1**). Pelletization is an attribute that improves the co-compost product structure, reducing bulkiness, and transportation costs, while lowering handling costs during application (Danso et al., 2017; Kuwornu et al., 2017; Nikiema et al., 2014). Locally available materials such as pre-gelatinized starch and clay may increase the pellet structure and may help to reduce volatilization of nutrients when used as binders (Adamtey et al., 2009; Nikiema et al., 2013). Fortification of co-compost with inorganic fertilizers adds value and reduces the bulkiness of co-compost and transportation costs per nutrient mass while enhancing the applicability to various crops (Danso et al., 2017). Fortification with ammonium nitrate has a liming effect and increases the temperature in the co-composting thermophilic stage, which is important for killing pathogens in the co-compost (Adamtey et al., 2009; Vinnerås, 2007; Vinnerås et al., 2003). Packaging of co-compost allows for easy handling and specification of nutrient information, branding, and application instructions if correctly labelled (Agyekum et al., 2014; Rouse et al., 2008). The certification by the relevant authorities can reduce the perceived and actual health risks associated with co-compost use, enhancing social acceptance (Danso et al., 2017) and improve the product appeal through quality assurance (Rouse et al., 2008). The price attribute representing the lowest through to the choke price was decided based on the scoping review, expert opinion, and current local market prices of other types of fertilizers in the city-region of Msunduzi municipality.

Table 1. Description of attributes and levels

Attribute	Levels	Description
Price (Rands/kg)	5	1.5; 2.0; 2.5; 3.0;3.5
Packaging (Labelled)	2	Yes (packaged with application instructions), No
Fortification	2	1=Yes (fortified with inorganic fertilizer), No
Pelletization	2	Yes (pelletized), No (powder form)
Certification	2	Yes (certified), No (not certified)

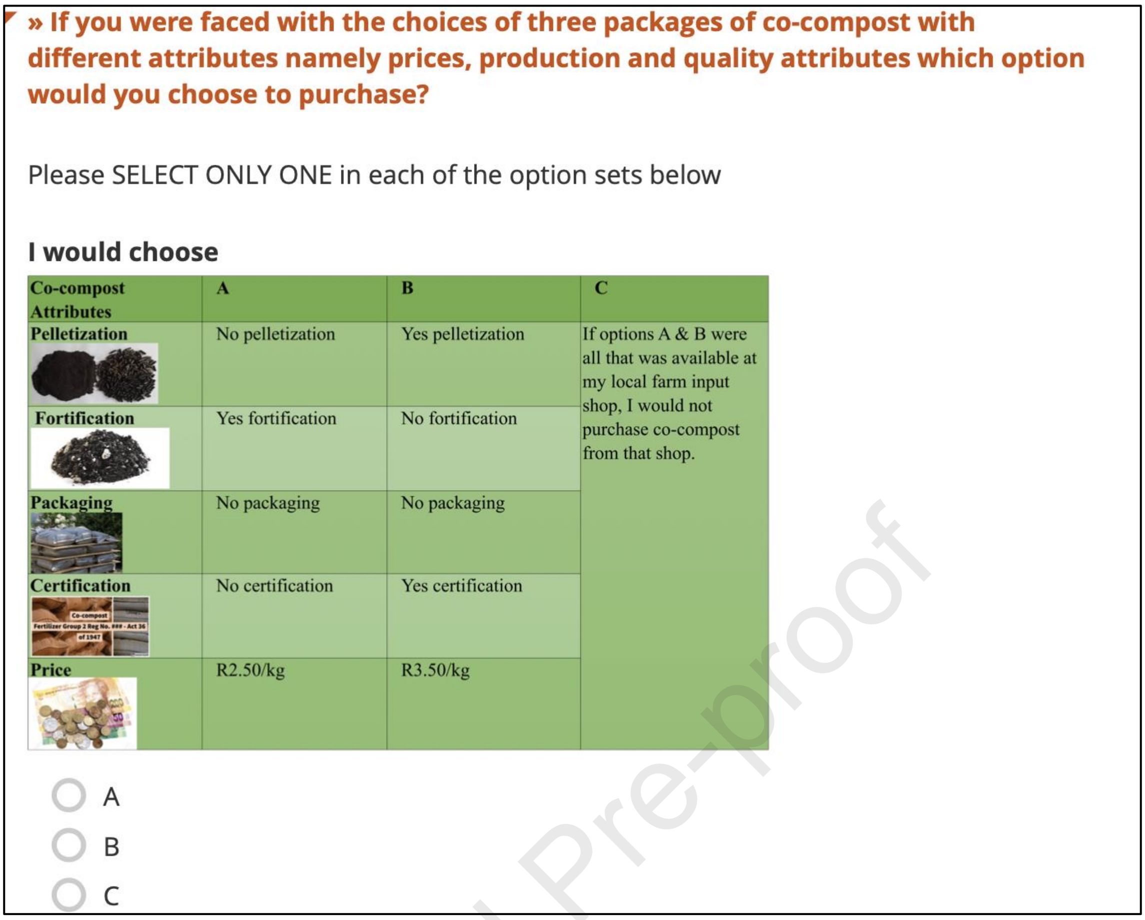
2.4 Choice experiment design

The study used the **idefix** package in **R** software and applied the modified Fedorov algorithm to estimate a Bayesian efficient design (Kessels et al., 2011, 2006). The approach resulted in the eight choice sets, where an example is shown in

Table 2 and **Fig 1**. The efficient Bayesian design applies the common experimental design principles such as orthogonality, level balance, minimal overlap, and utility balance (Huber and Zwerina, 1996). The efficient design helps to produce robust estimates at smaller sample sizes and choice tasks compared to orthogonal designs (Bliemer and Rose, 2010; Rose and Bliemer, 2009). Although the modified Fedorov algorithm is much slower than the coordinate exchange algorithm due to computational burden, it allows the user to put some restrictions on the design through specification of priors to improve the efficiency of the design (Traets et al., 2020). The modified Fedorov algorithm help to minimize the D(B)-error following a multinomial logit model by looping through every profile from the start of design and evaluating the D(B)-error for every profile until the maximum iteration is reached or when no additional information is obtained. The DB-error of the retained design, calculated as the mean of the D-errors, was estimated to be 2.86.

Table 2. An example of the choice task of the eight tasks presented to the farmers

Co-compost Attributes	A	B	C
Pelletization	No pelletization	Yes pelletization	If options A & B were all that were available at my local farm input shop, I would not purchase co-compost from that shop.
Fortification	Yes fortification	No fortification	
Packaging	No packaging	No packaging	
Certification	No certification	Yes certification	
Price	R2.50/kg	R3.50/kg	



» If you were faced with the choices of three packages of co-compost with different attributes namely prices, production and quality attributes which option would you choose to purchase?

Please SELECT ONLY ONE in each of the option sets below

I would choose

Co-compost Attributes	A	B	C
Pelletization	No pelletization	Yes pelletization	If options A & B were all that was available at my local farm input shop, I would not purchase co-compost from that shop.
Fortification	Yes fortification	No fortification	
Packaging	No packaging	No packaging	
Certification	No certification	Yes certification	
Price	R2.50/kg	R3.50/kg	

A

B

C

Fig. 1. An excerpt of a choice task from the survey instrument

2.5. Empirical model

To estimate the empirical model, the farmer i presented with the j alternatives in a choice set, the model assumes that the farmer always selects the option that provides the highest utility. The study initially assumed a linear random utility function with additive error, as presented in **Equation 2.**

$$U_{ij} = \beta_0 + \beta_p Pellet_{ij} + \beta_f Fort_{ij} + \beta_k Package_{ij} + \beta_c Cert_{ij} + \beta_r Price_{ij} + \varepsilon_{ij} \quad (2)$$

The random utility model was used to specify different models based on assumptions of the distribution of the error terms. The conditional logit (CL) model assumes that tastes are homogeneous, and the idiosyncratic errors are independently and identically Gumbel extreme value type 1 distributed (IID) across individuals and choices, and that the probability of choosing an alternative *j* is given by **Equation 3** (Louviere et al., 2000).

$$P_{ij} = \frac{\exp(\beta' X_j)}{\Sigma_{j'=1}^{J} (\beta' X_{j'})} \quad (3)$$

The IID assumption leads to further independence of irrelevant alternatives (IIA) assumption, which assumes that the probability of choosing the choices depend exclusively on the utility of the options and that the main effects can be stochastically and independently determined (Kassie et al., 2017; Morrison et al., 1998). The random parameters logit (RPL) model relaxes the IIA property by allowing preference heterogeneity across the observed attributes (Kassie et al., 2017). The model results in the attribute utility function expressed as a vector of; a) the population mean attribute utility weights and b) the variance of the individual taste parameters (diagonal matrix), and c) the unobserved individual idiosyncratic error component with 0 mean and unit variance (Kassie et al., 2017). Mixed logit models can accurately estimate any preference distribution because it does not impose any theoretical restrictions on the choice model and allows for all sources of correlation (Hess and Train, 2017). The alternative specific constants can be used to review the effect of unobserved but systematic factors influencing the individual's choices (Bahamonde-Birke et al., 2017). The constants technically reflect the mean of the differences in the idiosyncratic error terms (Prashker, 1988; Uncles et al., 1987).

The empirical models were estimated as CL, RPL, and the latent class (LC) models. The individual-specific variables included religiosity, annual household income, and environmental attitudes. Following numerous iterations, the simple CL model was estimated, assuming that the preferences are IID across individuals and alternatives illustrated in **Equation 3.**

$$U_{ij} = ASC_0 + \beta_p Price_{ij} + \beta_k Packaging_{ij} + \beta_f Fortification_{ij} + \beta_c Certification_{ij} + \beta_r Pelletization_{ij} + \beta_r Polytheism_i + \beta_y Income_i + \beta_k NEPscore_i + \varepsilon_{ij} \quad \ldots\ldots (3)$$

The RPL and the latent class (LC) models were estimated to account for preference heterogeneity. The empirical model for the RPL assumed normal distribution for inter-individual draws . The RPL incorporated population mean attribute utility weights, the variance (sigma) of the individual taste parameters, and three observed individual-specific variables that interacted with alternative specific constants. Following several iterations, the best model in terms of parsimony and fit was estimated as illustrated in **Equation 4.**

$$U_{ij} = ASC_0 + \beta_p Price_{ij} + \beta_k Packaging_{ij} + \beta_f Fortification_{ij} + \beta_c Certification_{ij} + \beta_r Pelletization_{ij} + \delta_{fk} Fortification\_Pelletization_{ij} + \delta_{ck} Pelletization\_Packaging_{ij} +$$

$$\beta_r\, Polytheism_i + \beta_y\, Income_i + \beta_k\, NEPscore_i + \varepsilon_{ij} \qquad (4)$$

The RPL model assumes continuous preferences distribution across the population, making it challenging to identify class heterogeneity. Therefore, a latent class model was estimated to determine the presence of different homogeneous classes of preferences. Unlike the RPL, where you must create interactions with the alternative specific constants, in the LC model, the sociodemographic variables were incorporated in the Apollo package as 'gammas' to influence the probabilities of belonging to the different classes. For identification of the probability model, one class was fixed to zero. The LC model with three classes was estimated, where the delta _Δ represents the latent class components for the three classes as illustrated in **Equation 5**.

$$U_{ij} = ASC_i + \beta_p\, Price\_\Delta_{ij} + \beta_k\, Packaging\_\Delta_{ij} + \beta_f\, Fortification\_\Delta_{ij} + \beta_c\, Certification\_\Delta_{ij} + \beta_r\, Pelletization\_\Delta_{ij} + \beta_r\, Polytheism\_\Delta_i + \beta_y\, Income\_\Delta_i + \beta_k\, NEPscore\_\Delta_i + \varepsilon_{ij} \qquad (5)$$

2.6. Sociodemographic variables

The sociodemographic variables may not be directly incorporated into the utility functions as they do not vary across the alternatives in a choice set. Therefore, they can only be incorporated as interaction terms with the alternative specific constants (Morrison et al., 1998). Income, religiosity, and environmental attitudes were incorporated to estimate their influence on willingness to pay for compost. The rationale came from the impact of these factors on social acceptance from the literature review (Gwara et al., 2021, 2020) and the initial study performed on the social acceptance of human excreta in agriculture (Gwara et al., 2022). Therefore, testing their influence may inform whether marketing decisions should be sensitive to such factors and how? The coding structure followed a continuous income and environmental attitudes scale and a dummy coding for religiosity. The descriptive results indicate that almost half of the respondents were Christians and were coded as 1, while non-Christians were coded as 0. The coding structure was chosen over the individual dummy coding for identification. The environmental attitudes were measured using the 15-item new or revised ecological paradigm (NEP) scale, with the overall rating ($1 \leq \boldsymbol{\mu} \leq 5$) indicating the mean scores of all responses (Ogunbode, 2013). The mean score of 3 represents neutrality, while 1 represent extreme environmentally unfriendly, and 5 extreme eco-friendly worldviews (Van Petegem and Blieck, 2006). The descriptive results show a mean distribution of 3.2, representing moderately environmentally-conscious farmers.

2.7. Marginal willingness to pay calculations

The implicit price, defined as the marginal rate of substitution between the non-price and the price attribute, reflects the willingness to pay for a marginal improvement in the co-compost attribute, holding all other attributes constant. The study used the Delta method to calculate marginal willingness-to-pay estimates by taking the ratio of each attribute to the price coefficient. The Delta method provides an approximation of the true standard errors following (Daly et al., 2012), who demonstrated that parameters estimated using maximum likelihood are also maximum likelihood estimates. The Delta method can accurately estimate the standard errors of any maximum likelihood functions as it does not depend on the model used to estimate the parameters (Daly et al., 2012). The inverse of the Hessian matrix of second derivatives of the estimated likelihood functions forms the Cramér-Rao lower bound of the minimum variance of the estimates and is therefore consistent following the Slutsky theorem. For model comparison, unconditionals were estimated in the LC model by estimating the average willingness to pay that considers the multivariate nature of the individual-specific parameters across classes (Hess and Palma, 2021).

3. Results

3.1. Characteristics of rural farmers in Vulindlela

Out of the 341 interviewed rural farmers, about 68.2% were female, while 31.8% were male **Appendix A: Extra Tables**. The average age of the farmers was 54 (14.2) years, with on average years 8 (4.1) years of education. The experience in farming was, on average, 23.2 (3.3) years. The average household size was 6.3 members (**Table 3**). On average, 43.7% of the interviewed farmers were married, while others were single (32.0%), widowed (22.3%), or divorced 2.1%. The most popular religion was Christianity (50.1%, while others were polytheism (23.4%), traditionalism (12.6%), Nazarene (7.9%), or atheism (5%). The data showed that 34.6% earn less than R12 000 per year, while 31.4% earn R12 000-R60 000, with 18.2% earning R60 000-R100 000, while 15% earn above R150 000 per annum (exchange rate 1USD ≈ R16). The sources of income were social grants (60.7%), formal salary work (10.9%), casual work (7.6%), remittances (6.2%), wages (4.4%), agricultural sales (3.8%), formal business (3.7%), informal trading (2.6%), and gifts (0.6%). About 77.4% of the farmers owned less than one hectare of farming land. In terms of the level of organization, about 8.5% of the rural farmers were a member of a farming association, while about 6% had ever interacted with an agricultural extension officer.

Table 3. Characteristics of survey respondents.

Household characteristic	Mean	Median	Max	Min	Standard Dev
Age (years)	54	57	88	20	14.2
Years of education	7.9	8	19	0	4.1
Farming experience	23.2	20	70	1	15.6
Farming Household size	6.3	6.0	17	1	3.3

3.2. Current agricultural practices

The primary type of fertilizer used by the respondents in their production systems was cow manure (59.3%), followed by inorganic fertilizers (19.5%), poultry manure (6.5%), compost (5.3%), and farm residues (2.9%). Approximately 6.5% of the farmers used other fertilizers or did not use fertilizers at all in their farming systems (**Table *4***). The use of cow manure and compost by most rural farmers in their agricultural production systems means that it is easy for farmers to evaluate co-compost whose physical attributes are like the available fertilizers in their farming systems. The questions on the proportion of land applied to each stated fertilizer types would have provided pertinent information on the size of the market. However, although this information was not collected from the study, based on the authors' knowledge of the area, only, a small portion of land is allocated to fertilizers of any kind.

Table 4. Driving forces for co-compost recycling intentions

Fertilizer type	Frequency	Percentage (%)
Cow manure	201	59.3
Inorganic fertilizer	66	19.5
Poultry manure	22	6.5
Others	22	6.5
Organic compost	13	3.8
Farm residues	10	2.9
Co-compost	5	1.5
Total	339	100

Of the farmers using some form of fertilizers or soil amendment, about 80% of the farmers chose their dominant fertilizer based on availability (

Table *5*). Other reasons include improving soil health (14.8%), price or affordability (3.6%), and environmental benefits (2.1%). The primary source of these fertilizers was free, making up 48.6% of the respondents, while 41.4% were producing it on the farm (

Table *5*). From our investigations, the free fertilizers are usually animal manure freely obtained from neighboring farmers who own livestock, as it is uncommon to sell animal-based fertilizers in the community. The farming systems are such that farmers only use the manure for vegetables, and the size of these plots is usually small, therefore, farmers do not make use of this excess manure. The rest of the farmers bought their fertilizers (8.6%).

Table 5. Reasons for the dominance and sources of fertilizers

Reasons for the type of fertilizer use	Percentage (%)	Frequency
Availability	79.6	269
Soil health	14.8	50
Price	3.6	12
Environmentally friendly	2.1	7
Total	100	140
Fertilizer sources		
Produce it on the farm	58	41.4
Produce it elsewhere	2	1.4
Buy it	12	8.6
Get it for free	68	48.6
Total	140	100.0

3.3. Driving forces and potential barriers to using human excreta in agriculture

More than 77.4% of the respondents were willing to recycle human excreta in agriculture. The farmers were asked what would drive the recycling of co-compost in their agricultural systems. In terms of the production factors, 87.6% of the farmers agreed that the organic matter content and safety were the most important driving factors for the use of co-compost. Farmers also put importance on the source of information and certification, which shows the importance of the perceived health risk in using human excreta-based co-compost. The price of co-compost was considered the most critical marketing variable, followed by a convenient location. The nutrient value, credit facility, and pelletization were also important driving forces for co-compost recycling. Packaging was among the least important variables driving force for co-compost recycling.

Table *6* shows the driving forces ranked from the most crucial variable to the least as ranked by the farmers.

Table 6. Driving forces for co-compost recycling

Statement	Level of agreement %

Desirable characteristic	Strongly Disagree	Disagree	Don't know	Agree	Strongly Agree	Total Agree
Organic matter	1.8	1.8	8.8	53.1	34.5	87.6
Safety	1.8	1.8	8.8	53.1	34.5	87.6
Trusted sources	6.2	7.7	10.3	45.7	30.1	75.8
Certification	5.6	7.6	14.1	38.8	33.8	72.6
Price	10.6	9.1	8.2	39.4	32.6	72
Location	5	10	12.9	48.2	23.8	72
NPK content	2.4	4.4	22.6	41.5	29.1	70.6
Credit offer	7.1	15.7	24.6	39.6	13	52.6
Pelletization	8.3	17.1	22.7	26.5	25.4	51.9
Packaging	8.9	22.6	19.6	33.2	15.7	48.9

462

3.3. Preferences and willingness to pay for the attributes

The RPL model performed better than the CL model, both in terms of the loglikelihood and the model parsimony (AIC). The CL and RPL models show that the price coefficient is negative and significant ($p \le 0.05$) as expected), indicating that as the price of compost increases, the utility decreases. The results of both the conditional logit (CL) and the random parameters logit (RPL) model indicate farmer preferences ($p \le 0.05$) for the pelletized, fortified and certified co-compost (

Table *7*). The results of the CL show the positive influence of the sociological (religiosity), socioeconomic status (income), and ecological dispositions on willingness to pay for co-compost. The results indicate that farmers who were non-Christians expressed a higher willingness to pay for co-compost. The results also show positive income elasticity of demand for co-compost where farmers may aspire to pay more as income rises. Pro-environmental attitudes and higher annual income positively influenced the willingness to pay for co-compost. The packaging appears not to affect the farmers' preferences for co-compost in both models as the estimated parameters were insignificant.

Table 7. Estimates of conditional logit and random parameters logit models

Model	Conditional logit	Random parameters logit
Parameter	Coefficient (standard error)	Coefficient (standard error)
Opt-out	3.30 (0.49) ***	-5.03 (0.75) ***
Price	-0.49 (0.05) ***	-0.96 (0.08) ***
Packaging	0.09 (0.06)	0.10 (0.10)
Pelletization	0.30 (0.05) ***	0.45 (0.17) ***
Fortification	0.82 (0.05) ***	1.63 (0.16) ***
Certification	0.72 (0.05) ***	1.34 (0.14) ***
Certification_Packaging		-0.40 (0.00)
Sigma (Packaging)		0.50 (0.17) ***
Sigma (Pelletization)		2.25 (0.17) ***
Sigma (Fortification)		2.04 (0.17) ***
Sigma (Certification)		1.87 (0.16) ***
Sigma (Certification_Packaging)		0.52 (0.13) ***
Religion (1 = Polytheism)	0.68 (0.13) ***	0.63 (0.21) ***
Income	0.15 (0.06) **	0.21 (0.10) **
Environmental attitude score	0.35 (0.13) ***	0.54 (0.21) ***
McFadden Rho-square	0.23	0.35
Loglikelihood	-2,190	-1,858
Akaike information criterion	4,398	3,746
Number of individuals	323	323
Number of observations	2,584	2,584

Notes: ** means significant at 5% and *** means significant at 1% level

The LC model with three classes was chosen as the best model to disentangle class heterogeneity (**Table 8**). The class allocation results show that the respondents had an 84% probability of belonging to class A, 7% probability of belonging to class B, and 9% probability of belonging to class C. Class A farmers preferred all the co-compost attributes, including packaging, which was insignificant in both the CL and the RPL model. The class B segment revealed positive preferences for fortification and negative preferences for packaging, pelletization, and certification. Farmers in Class C showed positive preferences for certification. Higher income increased the probability of belonging to class A and decreased the probability of belonging to class B but had no significant impact on the probability of belonging to class C. The positive sign for income in class A represents income as a probability shifter of belonging to class A.

Table 8. Latent class model results with three classes

Classes	Class A	Class B	Class C
Parameter	Coefficient (standard error)	Coefficient (standard error)	Coefficient (standard error)
ASC	2.60 (0.27) ***	- 2.65 (0.27) ***	0.00 (fixed)
Price	- 0.63 (0.06) ***	- 1.06 (0.21) ***	- 1.84 (0.87) **
Packaging	0.25 (0.06) ***	- 0.31 (0.11) **	- 3.54 (1.94)
Pelletization	0.50 (0.08) ***	- 12.62 (2.30) ***	-0.98 (4.52)
Fortification	1.03 (0.10) ***	0.78 (0.20) ***	1.25 (2.91)
Certification	0.56 (0.06) ***	- 0.45 (0.09) ***	7.78 (2.61) ***
Income	0.26 (0.18)	0.56 (0.26) **	0.00 (fixed)
Environmental attitude score	0.02 (0.50)	- 0.19 (0.65)	0.00 (fixed)
Religiosity (1=non-religious)	-0.08 (0.56)	1.00 (0.68)	0.00 (fixed)
Delta	-0.08 (0.56)	-1.39 (2.29)	0.00 (fixed)
Class probability	0.84	0.07	0.09
McFadden Rho-square		0.34	
Log-likelihood		-1870	
Akaike information criterion		3788	
Number of individuals		323	
Number of observations		2,584	

Notes: ** means significant at 5%, and *** means significant at 1%

3.4. Marginal willingness to pay estimates

The implicit price, defined as the marginal rate of substitution between the non-price and the price attribute, reflects the willingness to pay for a marginal improvement in the co-compost attribute, holding all other attributes constant. The estimates from the CL and RPL models were comparable with a downward preference pattern where the preferable attributes were fortification, certification, and pelletization, with packaging as the least preferred attribute, in line with the descriptive results of co-composting driving forces. Comparing the implicit prices from the two models, the heterogeneity in farmer preferences showed a negligible effect on the implicit price estimates (Wu et al., 2015). The RPL model results showed the highest willingness to pay an estimate of R1.70/kg[1] of fortified co-compost. At the same time, the second preferred attribute was certification, with a willingness to pay an estimate of R1.40/kg for certified co-compost. Farmers were willing to pay about R0.45/kg for pelletized co-compost. Based on the RPL results, the willingness to pay for packaging (R0.10/kg) was insignificant (**Error! Reference source not found.**).

Table 9. Comparison of the willingness to pay estimates (ZAR/kg) for different models

Variables	Conditional Logit Model estimate (standard error)	Random Parameters Logit Model estimate (standard error)
Fortification	1.67 (0.26) ***	1.70 (0.25) ***
Certification	1.49 (0.24) ***	1.40 (0.23) ***
Pelletization	0.61 (0.15) ***	0.45 (0.17) ***
Packaging	ns	ns

Notes: ** means significant at 5%, *** means significant at 1%, and ns means insignificant

The results of the LC model reveal that class A was willing to pay a positive price for all attributes with utility ranking like both the CL and RPL models (**Table 10**). In customer segment A, farmers were willing to pay more for packaging (R0.40/kg) and pelletization (R0.82/kg), certification (R1.65/kg), and fortification (R0.91/kg) when compared to the CL and RPL models. Farmers in class B expected compensation for packaging (R0.23/kg) and pelletization (R5.63/kg) but were willing to pay more for fortification (R0.83/kg) and certification (R1.65/kg). Class C farmers were willing to pay, above all classes, for certification (R4.31/kg). Class B farmers indicate risk aversion where more value is placed on the certification attribute. Unconditional post-estimation of the LC model was calculated to generate a comparison with the CL and RPL. Comparing the willingness to pay estimates of the three models (CL, RPL, and LC), a similar utility pattern is observed (**Table 10**). However, the LC model produced more precise estimates with smaller standard errors than the CL and the RPL models.

Table 10. Marginal willingness to pay (ZAR/kg) estimates latent class with three classes

[1] 1 USD is equivalent to approximately 15 South African Rands

Variables	Class A estimate (standard error)	Class B estimate (standard error)	Latent Class Unconditionals estimate (standard error)
Certification	0.89 (0.15) ***	1.42 (0.03) ***	1.50 (0.00) ***
Fortification	1.64 (0.24) ***	0.73 (0.10) ***	1.12 (0.01) ***
Pelletization	0.78 (0.15) ***	- 11.91 (3.90) ***	0.21 (0.03) ***
Packaging	0.40 (0.10) ***	- 0.30 (0.10) ***	0.13 (0.04) ***

Notes: ** means significant at 5%, and *** means significant at 1%

Comparing the current study with a related study shows relatively similar results in terms of the magnitude of the marginal willingness to pay estimates. A market feasibility study of co-compost in Uganda indicated marginal willingness to pay of USD0.40/kg for certification, USD0.13/kg for pelletization, and compensation of USD0.09/kg for fortification (Danso et al., 2017). However, the current study demonstrates that the farmers investigated were willing to pay for fortified co-compost, although they required compensation for the same attribute in Uganda (**Table 11**). After converting the current result to the same currency, the marginal willingness to pay for certified co-compost was higher in Uganda than in South Africa. Certification is a preferred attribute in both countries, and this has implications for health risks, as will be discussed in the next section.

Table 11. Comparison of the marginal willingness to pay estimates for two related studies

Author (Year)	Attributes	Conditional Logit Model (USD/kg) estimate (standard error)	Random Parameters Logit Model (USD/kg) estimate (standard error)	Latent Class Unconditionals estimate (standard error)
Current study (2021)	Certification	0.10 (0.02) ***	0.09 (0.02) ***	0.10 (0.00) ***
	Fortification	0.11 (0.02) ***	0.11 (0.02) ***	0.08 (0.00) ***
	Pelletization	0.04 (0.01) ***	0.03 (0.01) ***	0.01 (0.00) ***
(Danso et al., 2017)	Certification	0.42 (0.05) ***	0.40 (0.06) ***	nr
	Fortification	-0.01 (0.05) ***	- 0.09 (0.04) ***	nr
	Pelletization	0.08 (0.03) ***	0.13 (0.03) ***	nr

Notes: ** means significant at 5%, *** means significant at 1%, and nr means not reported

4. Discussion

The findings of this study show that there is indeed a high demand for co-compost in the rural farming areas of South Africa. The results indicate a willingness to pay for all the selected attributes with greater demand for fortification and certification. Correct pricing of compost should reflect the willingness to pay by the market segment, in this case, rural farmers. If the price that farmers are willing to pay does not cover the production cost or the ability to pay, various strategies should be in place. These may include credit terms, ash discounts, trade discounts, payment periods, subsidies, and other allowances to enhance market demand (Rouse et al., 2008). It is essential to separate the willingness to pay from the ability to pay as the two concepts are different. The ability to pay reflects the budget position-a function of financial flows and the income streams of consumers and is usually fixed. The willingness to pay depends on the preferences and perceptions of the farmers and reflects the appreciation for compost instead of the actual market price (Rouse et al., 2008). Therefore, willingness to pay can be increased through raising awareness, education, branding, and advertising.

The attributes selected for this study namely packaging (Klaiman et al., 2016; Kojima and Ishikawa, 2017), pelletization (Hettiarachchi et al., 2016; Kuwornu et al., 2017; Nikiema et al., 2014, 2013, 2012), fortification (Adetunji et al., 2019; Nikiema et al., 2012; Opoku, 2015), and certification (Husted et al., 2014; Keraita and Drechsel, 2015; Moya et al., 2019) could also increase the market viability of compost. The findings also reflect significant demand for fortification, which could mean that farmers do not consider chemical fertilizers a substitute but rather a complementary input that could improve agronomic efficiency. Compost application increases the agronomic response to chemical fertilizers and is used either as livestock manure or compost for garden use in rural farming areas. Because compost contains soil organic matter, the carbon is responsible for withholding nutrient loss in the soil by making weak bonds while making them available to crops (Chivenge et al., 2009; Sileshi et al., 2022, 2019; Vanlauwe et al., 2011). Therefore, compost should not be considered as substituting chemical fertilizer as it cannot supply the same amount of nutrients but instead augment the chemical fertilizer use efficiency. Farmers should be well informed of what constitutes the benefits of compost to avoid the inaccurate perception that compost can have a similar effect on crops (Rouse et al., 2008).

The higher willingness to pay for certification indicates the influence of the perceived health risk associated with the reuse of co-compost. Compost certification by relevant regulating authorities could enhance product standardization and quality assurance to farmers. Certification ensures compost is free of pathogens, heavy metals, and other emerging chemicals of human health and environmental concern often present in human excreta waste streams (Bartrons and Peñuelas, 2017; Bischel et al., 2015; Carter et al., 2014; Schürmann et al., 2012; X. Wu et al., 2015). The use of the World Health Organization sanitation safety plan (Winkler et al., 2017; World Health Organization, 2015), careful selection of crops with minimum contamination, and proper handling of co-compost by farmers could also improve the demand for co-compost (Okem and Odindo, 2020).

The willingness to pay for a pelletized compost could help address the challenges of bulkiness (transportation), difficulty in handling, and ease of use (Kuwornu et al., 2017; Nikiema et al., 2013, 2012; Pampuro et al., 2018). Pelletized compost could be achieved using low-cost technologies and locally available materials such as clay as starch binders to increase the pellet strength and reduce the disintegration of the pellet structure (Hettiarachchi et al., 2016; Nikiema et al., 2014). Pelleted compost has reduced bulkiness and associated storage and transport while making it easier to apply due to a lower dust generation (Nikiema et al., 2013). Consequently, providing compost in pelleted form may enhance the market appeal of co-compost, social acceptance, and willingness to pay by farmers.

The findings of the study indicated the influence of the sociological (religiosity), socioeconomic status (income), and ecological dispositions on willingness to pay for co-compost. The findings suggest significant cultural and religious taboos that may prevent farmers from using compost and reduce their willingness to pay. For instance, Christians presented a negative willingness to pay for compost, and therefore essential to consider this when formulating awareness campaigns and dissemination material to target market segments. When promoting co-compost, the mainstreaming of dissemination plans could ensure sensitivity to religious and cultural beliefs. Research evidence in construction industries shows that the knowledge of circular economy may have the highest effect on the willingness to pay for recycled products (Véliz et al., 2022). Sensitivity to religious beliefs helps focus resources on behavior change communication in certain groups. The positive income elasticity of demand for co-compost and the pro-environmental attitudes could inform the segmentation and targeting of the farmers or customers. The more accepting market segments are also used to champion the benefits of the co-composting technologies, for instance, through the implementation of the lead farmer approach (Kiniso, 2022; Ragasa, 2020).

The class allocation probability from the latent class model indicates that the utility preferences of 84% of the farmers preferred all the attributes included in the model, including packaging. There were, however, a smaller segment of farmers in class B and C results who were not willing to pay for pelletization and packaging. The findings for the two classes indicate that low-income customer segments may need to be compensated through public support or government subsidies. Another approach could be to sell unpackaged and unpelleted co-compost to the two customer segments. Training farmers in the segments on the importance of pelletization and packaging may improve the demand for the compost while increasing resource efficiency by targeting the low-income and the Christian segments. Ensuring that the dissemination materials are sensitive to different religious groups could enhance social acceptance while averting unnecessary and costly backlash.

The positive influence of environmental dispositions on willingness to pay may also provide a basis for marketing co-compost as an environmentally sustainable product. With the increasing global interest in protecting the environment, it could be a good marketing strategy to brand co-compost as a sustainable product that helps diverting organic waste from landfills while providing sanitation through the emptying of full pit latrines and protecting the environment through reduced emissions and resource efficiency. Thus, going beyond the nutrient value of compost to include this sustainability dimension could enhance the demand for co-compost by farmers while allowing for public support from the various stakeholders in the composting value chain. Branding using catch-phrasing and logos, training, and awareness campaigns to reflect the co-compost sustainability component may help enhance its willingness to pay and social acceptance (Rouse et al., 2008). Implementing stringent environmental policies and regulations could promote nutrient recovery from waste streams (Otoo et al., 2015).

5. Conclusions

This study shows a great opportunity for co-compost as an alternative and sustainable soil input with significant benefits to farmers and new businesses in the waste recovery and reuse value chain. The benefits may extend far beyond its agricultural use to include benefits to the environment, waste management, human health, and sanitation sectors. However, enhancing the co-compost market feasibility may require an analysis beyond the demand elements investigated in this study. One potential opportunity could be to advance circular bioeconomy initiatives in the policy sphere. The potential competition from chemical fertilizers could be easily mitigated through fair government co-compost subsidy programs and viability gap financing for co-composting business models to boost their revenue streams. While chemical fertilizer use in most developing countries is generally low, public support may present an opportunity for alternative business cases in waste recovery and reuse that complement existing practices. More studies are also required to validate the willingness to pay for waste-based soil inputs in different contexts, as the current study results may be context-specific.

CRediT authorship contribution statement

SG: Conceptualization, Data collection, Software, Data analysis, Manuscript drafting. **EW:** Data and manuscript curation, Validation, Supervision, Manuscript drafting- review and editing. **TL:** Data and manuscript curation, Formal analysis, Validation, Manuscript drafting-review, and editing. **DJ:** Data and manuscript curation, Formal analysis, Validation, Manuscript drafting-review, and editing. **AO**: Supervision, Manuscript drafting- review and editing.

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Conflicts of Interest

The authors declare no conflict of interest.

Appendix A: Extra Tables

Table A.1. Characteristics of survey respondents.

Household characteristic	Percentage (%)	Frequency
Gender	*100%*	*341*
Female	68.6	234
Male	31.4	107
Marital Status	*100%*	*341*
Married	43.7	149
Single	32.0	109
Widowed	22.3	76
Divorced	2.1	7
Religious affiliation/practice?	*100%*	*341*
Christianity	50.1	171
Polytheism	23.4	83
Traditionalism	12.6	43
Shembe/Nazarene	7.9	27
Others	5	17
Annual Income	*100%*	*341*
< R12 000	34.6	118
R12 000≤ Y< R60 000	31.4	107
R60 000≤ Y<R100 000	18.2	62
Greater than R150 000	15.8	54
Source of Income	*341*	*100*
Social grant	60.7	207
Formal salary work	10.9	37
Casual labour	7.6	26
Remittances	6.2	21
Wage work	4.4	15
Sale of farm produce	3.8	13
Formal business	3.7	11
Informal economy	2.6	9
Gifts	0.6	
Farm Size	*100%*	*341*
≤ 1 ha	77.4	264
1–2 ha	19.6	67
3–4 ha	1.8	6
> 4 ha	1.2	4
Membership	*100%*	*341*
Yes	8.5	29
No	91.5	312
Extension officer interaction	*100%*	*341*
Never	93.8	320
Less than once a year	2.6	9
Once a year	2.3	8
At least twice a year	0.3	1
More than twice a year	0.9	3

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Declaration 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.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: