energies

Article

Consumer Preferences and Willingness to Pay for Potting Mix with Biochar

McKenzie Thomas [1], Kimberly L. Jensen [1,*], Dayton M. Lambert [2], Burton C. English [1], Christopher D. Clark [1] and Forbes R. Walker [3]

1 Department of Agricultural and Resource Economics, The University of Tennessee, Knoxville, TN 37996, USA; mthoma77@vols.utk.edu (M.T.); benglish@utk.edu (B.C.E.); cclark3@utk.edu (C.D.C.)
2 Department of Agricultural Economics, Oklahoma State University, Stillwater, OK 74078, USA; dayton.lambert@okstate.edu
3 Department of Biosystems Engineering and Soil Sciences, The University of Tennessee, Knoxville, TN 37996, USA; frwalker@utk.edu
* Correspondence: kjensen@utk.edu

Abstract: Biochar is a co-product of advanced biofuels production from feedstocks including food, agricultural, wood wastes, or dedicated energy crops. Markets for soil amendments using biochar are emerging, but little is known about consumer preferences and willingness to pay (WTP) for these products or the depth of the products' market potential for this product. This research provides WTP estimates for potting mix amended with 25% biochar, conditioned on consumer demographics and attitudes about product information labeling. Data were collected with an online survey of 577 Tennessee home gardeners. WTP was elicited through a referendum contingent valuation. Consumer WTP for an 8.81 L bag of 25% biochar potting mix is $8.52; a premium of $3.53 over conventional potting mix. Demographics and attitudes toward biofuels and the environment influence WTP. Biochar amounts demanded are projected for the study area's potential market. Optimal prices, profits, and market shares are estimated across different marginal costs of producing biochar potting mix.

Keywords: biochar; consumer preferences; potting mix; biofuels; feedstock

Citation: Thomas, M.; Jensen, K.L.; Lambert, D.M.; English, B.C.; Clark, C.D.; Walker, F.R. Consumer Preferences and Willingness to Pay for Potting Mix with Biochar. *Energies* **2021**, *14*, 3432. https://doi.org/10.3390/en14123432

Academic Editors: David Borge-Diez and Ricardo J. Bessa

Received: 29 April 2021
Accepted: 8 June 2021
Published: 10 June 2021

1. Introduction

1.1. Biochar as a Co-Product of Biofuels and a Soil Amendment

Biochar is a charcoal-like material produced by the thermal decomposition of organic material in an oxygen-limited environment at relatively low temperatures. Biochar can be produced from a variety of feedstocks, including wood wastes, agricultural wastes (e.g., wheat straw and rice hulls), dedicated crops (e.g., switchgrass and miscanthus), and food wastes. Biochar can be produced when pyrolysis is used to convert lignocellulose into bio-oil, an advanced biofuel precursor [1]. Depending on the technology used, between 15 and 50 percent of the co-product produced from pyrolysis is biochar [2].

The amount of biochar co-product [3] and breakeven prices [4] has been estimated for model pyrolysis facilities, but research that evaluates the market potential of biochar-based products is needed. Developing viable markets for biochar could improve the overall profitability of advanced biofuels production. Lack of high-value co-products is a leading barrier to industry-scale production of biofuels [5] and contributes to the failure of advanced biofuel production to keep pace with targets established under the Renewable Fuel Standard (RFS) [6]. Markets for the co-product that provide sufficient scale to utilize a significant portion of the biochar from a biofuels facility at a price above breakeven need to be identified.

A variety of products can be derived from biochar (for example, animal feed additives, filters, paints and colorings, and humidity regulation in building materials) [7]. Biochar stores carbon when used as a soil amendment. Biochar's chemical properties are stable, meaning that it remains in the ground and serves as a carbon sink for many years [8,9]. Applying biochar to soil in order to conserve or improve soil quality was brought to the forefront when Terra Preta de Indio soils containing high amounts of charcoal were discovered in the Amazon basin [10]. Biochar's porosity also reduces soil density, increases the aeration of the soil, and enhances soil microbial habitat [11]. Biochar also encourages plant growth, with associated increases in belowground biomass through root growth [11]. The use of biochar also reduces nitrous oxide emissions from soils treated with nitrogen fertilizers [12,13] and increases pH in acidic soils [14]. The composition of biochar and other soil affects the material's effectiveness in increasing crop yields and providing other soil benefits [15–22]. Effectiveness of biochar as a substitute for *Sphagnum* peat moss has been examined [23] in nursery and greenhouse production [24]. Substitutes for *Sphagnum* peat moss are being examined due to the potential long-term unsustainability of *Sphagnum* peat moss extraction [24].

Biochar could have applications to commercial agriculture and the home gardening industry as a soil amendment. The United States Department of Agriculture (USDA) has certified 13 gardening products that contain biochar under their USDA Certified Biobased program [25]. These products include 100% biochar and compost, soil enhancers, and soil conditioners containing biochar. Given the potential environmental benefits associated with the use of biochar as a soil amendment, biochar could find a niche market comprised of home gardeners, particularly individuals whose environmental motivations influence their gardening practices [26,27]. However, research is lacking that investigates consumers' WTP for retail co-product applications of biochar in home gardening.

Potting mix could provide a market for biochar because it is a retail gardening input commonly used by both indoor and outdoor gardeners. Potting mix could also represent a relatively high value-added retail application for biochar compared with commercial agriculture. Mason et al. [28] note that sales of products related to container gardening have been one of the fastest-growing lawn and garden categories. A potting mix/biochar blend would provide consumers with a convenient pre-mixed product. Notably, a 25% blend of biochar would be at or near the effective maximum blend for optimal plant growth [29]. Research focusing on the potential market for a 25% biochar-blended potting mix would be helpful in better understanding the potential viability of this co-product. Findings from prior studies of breakeven biochar price from a pyrolysis facility could be compared with estimates of the prices consumers would pay for a 25% biochar-blended potting mix. Furthermore, the production of biochar by a pyrolysis biofuels-biochar co-product facility could be compared with potential demands for biochar in a 25% biochar-blended potting mix application.

1.2. Study Objectives

This study aims to fill the information gap regarding consumer preferences and WTP for biochar in a retail gardening application. The novelty of this research is that it is one of the first studies to gauge consumer willingness to purchase a retail home gardening product amended with biochar. The analysis estimates the premium home gardeners would be willing to pay for a potting mix that includes biochar (25% biochar-blended potting mix). As a point of reference, the biochar demands in potting mix for the study region and consumer WTP for biochar in the potting mix blend are compared with biochar co-product amounts from an example biofuel-biochar pyrolysis conversion facility. Breakeven prices for biochar are identified from prior research.

In addition to providing an overall estimate of consumer WTP and the potential quantity of biochar-amended potting soil demanded, the study also provides measures of the effects of demographics, expenditures, and attitudes towards the environment and biofuels development on WTP. Findings are useful for identifying target markets of home gardeners most likely to purchase a biochar-blended potting mix. Optimal prices tailored to market segments are determined over a range of marginal production costs. Optimal prices are those that maximize the biochar-amended potting mix producer's profit, subject to a consumer profile. This sensitivity analysis illustrates how the marginal costs of the biochar production could affect pricing, profitability, and market shares, and how these outcomes may be magnified for certain market segments.

1.3. Prior Studies of Consumer Preferences for Eco-Friendly Gardening Products

Choi et al. [30] examined Tennessee consumers' attitudes toward biochar attributes using best/worst scaling (BWS). The attributes examined included whether the biochar was produced in Tennessee, certified as biobased, a coproduct of biofuel production, and produced from food waste, wood waste, agricultural by-product, or a non-food energy crop feedstock. They found that the attributes most likely viewed as favorable were if the product was produced from agricultural by-products or wood wastes. Attributes least preferred were if the biochar was produced in Tennessee or if it was made from renewable fuel co-products. Consumer demographics and attitudes influenced product attribute rankings. Respondents who frequently purchased potting mix were more likely to rank highly the biochar potting mix made from food waste. Older individuals were less likely to rank USDA bio-based certification as a desirable attribute. Politically conservative respondents were less likely to rank USDA Certified Biobased as an attractive biochar attribute. Respondents expressing concern about climate change and the nation's future energy needs and who were also gardening enthusiasts were more likely to rank certification as a less attractive product trait. Choi et al.'s analysis provides valuable information about consumer attitudes toward biochar attributes, but the study did not estimate WTP for biochar products.

Studies of consumer preferences for biochar are lacking, but research on consumer preferences for eco-friendly gardening products may provide additional insight into how consumers might perceive a potting mix with biochar. Dahlin et al. [31] examined German home gardener preferences for potting mix by varying attribute combinations in a discrete choice experiment. The attributes examined included peat-free soil, organic, soil contain guano, material source (renewable resources, fermented residues, or bio-gas), and price. Resource sensitive consumers indicated organic status, peat-free, and renewable resources were important product attributes. The resource sensitive group tended to report higher incomes, were more educated, and placed less importance on product price. These results suggest gardeners may be sensitive to the price of potting mix with biochar, but they may also value a product being derived from renewable resources.

Getter et al. [32] used a conjoint analysis of U.S. consumer preferences for floriculture products. They found that consumers would pay about $0.10 more for these products if they were grown in a sustainably produced potting mix. Of the eco-friendly plant production practices, plants grown using recaptured and recycled water in a sustainable potting mix were preferred over plants grown in pots made from recycled materials. Traditional production methods were least preferred among the practices. In terms of impacts on WTP, use of pollinator-friendly practices garnered higher premiums as did plants grown using best insect management practices. The results from their study suggest that home gardeners value environmental attributes of gardening products such as biochar in potting mix. Getter et al. collected information about demographics, but the effects of demographic variables on WTP for these attributes were not measured.

Other studies examined the effect of consumer demographics and attitudes on WTP for eco-friendly gardening products. Female gender correlates positively with preferences for eco-friendly packaging [27,33,34]. Their study results suggest that females would be more likely to prefer a potting mix-biochar blend compared with males. Findings from several studies suggest that age is positively correlated with preferences for environmentally friendly gardening products [27,34–36]. Studies also find that educational attainment is positively correlated with consumers exhibiting environmentally friendly gardening behaviors and using eco-friendly gardening practices [27,34,35,37]. Education is therefore expected to be positively correlated with preferences for a potting mix-biochar blend. Income has also been found to be positively correlated with environmentally friendly behavior, such as composting or recycling [37], and purchasing eco-friendly products [34,38]. Given findings from prior studies regarding the impacts of income, it is expected that the WTP for a potting mix-biochar blend will be positively correlated with income. Previous research also finds that consumers who express greater concern for the environment exhibit positive preferences for eco-friendly gardening supplies [27,33–36,39,40]. These studies may provide helpful insights into demographic profiles for consumers who may be more likely to purchase eco-friendly gardening products, but they did not directly address consumer preferences or WTP for biochar-based gardening products, nor how consumer' attitudes toward the environment or biofuels development may influence these preferences.

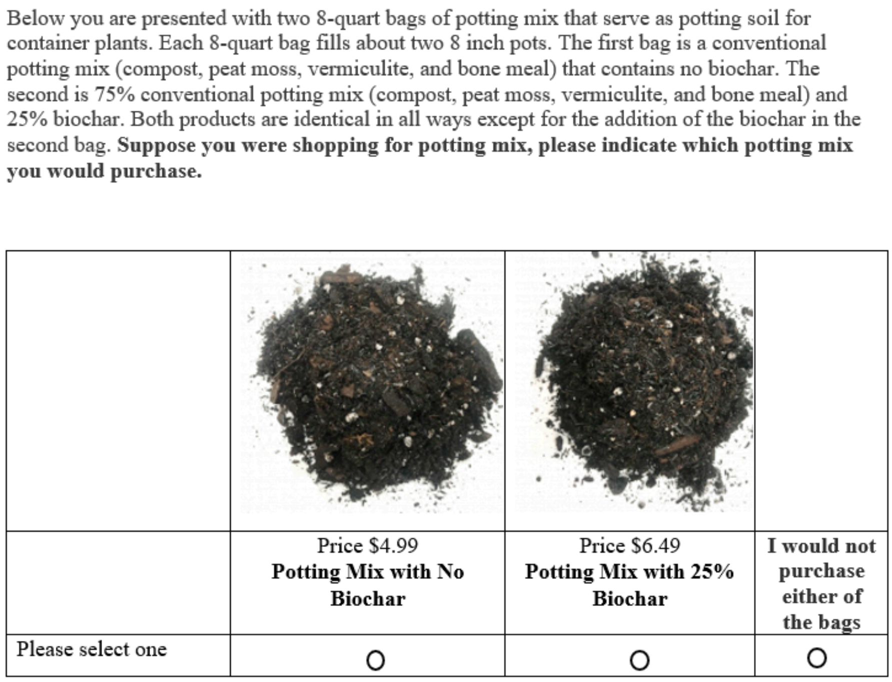
1.4. Studies of Biochar as a Co-Product of Biofuels Conversion

In the International Biochar Initiative (IBI) published survey of prices by biochar makers, biochar prices ranged widely internationally with wholesale prices averaging about \$2060 t^{-1} or \$3.40 L^{-1} [41]. For the U.S., the wholesale price of biochar was lower, at about \$1050 t^{-1} or about \$1.30 L^{-1}. Breakeven prices and financial feasibility of pyrolysis pathways across differing systems have been examined in prior research performing techno-economic analyses [4]. However, a recent study by Frank et al. [42] examined carbon prices and the economic feasibility of the slow-pyrolysis pathway for biochar production compared with a fast-pyrolysis pathway for biochar and biofuel production. Their results showed that fast pyrolysis to fuels and biochar achieved the lowest baseline minimum carbon price needed for economic feasibility. Brown et al. also found fast-pyrolysis had a higher internal rate of return for fast pyrolysis compared with slow-pyrolysis [43]. Campbell et al. [44] analyzed the financial feasibility of two thermochemical conversion pathways using a forest biomass feedstock. In their study, a 6.8 × 106 L biofuels-biochar co-product pyrolysis facility was estimated to produce about 17,700 t of biochar [44]. The breakeven price of biochar, dependent on a biofuel price of \$.66 L^{-1}, was estimated at \$1504 t^{-1} [44] or using the average density of biochar [45], the breakeven biochar price is about \$2.48 L^{-1}. The breakeven price they estimated was within the range of global and U.S. wholesale average prices reported by IBI from their 2014 survey [41]. Forest biomass is a likely feedstock candidate for a Tennessee pyrolysis facility given the state's forest resources [46]. We use findings by Campbell et al. [44] regarding biochar co-product amounts and breakeven prices from their techno-economic analysis of a pyrolysis facility to compare with our estimates of biochar amounts demanded at the market-level and prices consumers would pay.

2. Materials and Methods

2.1. Potting Mix Purchase Choice and WTP Estimates

Closed-ended questions are more reliable than posing open-ended questions, which ask consumers to state what value they would attribute to a hypothetical product [47]. Types of close-ended contingent valuation (CV) questions include single-bounded, double-bounded, and one-and-one-half bounded formats [47]. This research used a single-bounded CV method to estimate consumers' WTP for the biochar-amended potting mix. This is considered a referendum-style CV choice experiment [48]. A non-hypothetical experiment would avoid many of the concerns associated with stated preference data, but the collection of revealed preference data was deemed infeasible due to the limited availability of biochar-supplemented gardening products and the cost of conducting such a study. We elected to use a referendum-style CV method because we believed it would more closely mimic the context in which most home gardeners would have the opportunity to select a product with biochar-supplemented potting mix, a conventional potting mix, or neither product. The CV question presented respondents with a choice between a conventional potting mix, the 25% biochar-blended potting mix, or neither [49] (Figure 1). The photos in Figure 1 present two samples of potting mix, one was conventional and the other was a conventional potting mix with the addition of 25% biochar. Respondents who chose neither product are not included in the statistical modeling because these respondents were unwilling to participate in the market even at the conventional product price. The CV question was followed by a series of debriefing questions designed to further explore respondent motivations for their choice.



Below you are presented with two 8-quart bags of potting mix that serve as potting soil for container plants. Each 8-quart bag fills about two 8 inch pots. The first bag is a conventional potting mix (compost, peat moss, vermiculite, and bone meal) that contains no biochar. The second is 75% conventional potting mix (compost, peat moss, vermiculite, and bone meal) and 25% biochar. Both products are identical in all ways except for the addition of the biochar in the second bag. **Suppose you were shopping for potting mix, please indicate which potting mix you would purchase.**

	Price $4.99 **Potting Mix with No Biochar**	Price $6.49 **Potting Mix with 25% Biochar**	**I would not purchase either of the bags**
Please select one	O	O	O

Figure 1. Example choice set for potting mix.

An important issue to consider in measuring the accuracy of WTP estimates is whether the question asked of respondents is incentive-compatible [50]. There are several approaches used to address this issue [51,52]. We include a follow-up question asking respondents if they believed the survey would change product offerings (i.e., if the survey would have consequential impact) by including a dummy variable in the logit regression of WTP).

Using McFadden's [53] random utility framework, it is assumed that if the 25% biochar potting mix product provides greater utility than the product with no biochar, then the biochar product will be preferred. Let V_{i0} represent the ith consumer's indirect utility from choosing the potting mix with no biochar ($PM0$) and V_{i25} represent the ith consumer's utility from choosing the potting mix with 25% biochar ($PM25$). If consumer preferences are influenced by demographic and other non-price factors ($\boldsymbol{X}_i$) as well as price (P), then the i-th consumer prefers the potting mix with biochar if:

$$V_{i25}(\boldsymbol{X}_i,\ y,\ P_{25i})\ >\ V_{i0}(\boldsymbol{X}_i,\ y,\ P_{0i}), \tag{1}$$

where y is income. The probability a consumer prefers the product with 25% biochar is:

$$\Pr\,[PM25_i = 1]\ =\ \Pr[V_{i25}(\boldsymbol{X}_i,\ y,\ P_{25i})\ >\ V_{i0}(\boldsymbol{X}_i,\ y,\ P_{0i})]. \tag{2}$$

This probability is modeled using the logistic distribution [54]:

$$\Pr\,[PM25_i = 1] = \frac{\exp(\alpha + \boldsymbol{\beta}'\boldsymbol{X}_i + \beta_p P_{25i})}{1 + \exp\,(\alpha + \boldsymbol{\beta}'\boldsymbol{X}_i + \beta_p P_{25i})}\ . \tag{3}$$

where α is a constant, β_P is the price parameter, $\boldsymbol{\beta}$ is a vector of parameters on non-price variables, $\boldsymbol{X}_i$ is a matrix of demographic and other non-price variables including demographic characteristics, expenditure patterns, and attitudes toward biofuels and the environment. Table 1 provides a list of the variables included in $\boldsymbol{X}_i$ along with the variable definitions, means and standard deviations. The percentage of respondents that were willing to purchase the hypothetical biochar potting mix is also provided in Table 1.

Table 1. Names, definitions, and means and standard deviations for variables used in the logit model of WTP for biochar.

Variable Name	Definition	(N = 577) Mean	Std. Dev.
PM25	1 if chose the 25% biochar potting mix, 0 if chose the conventional potting mix	0.544	0.498
P_{25}	Price of the 1.1 L (8-quart) bag of 25% biochar potting mix ($4.99, $6.49, $7.99, $9.49, or $10.99)	$8.029	2.122
Age	Age of respondent in years	43.808	14.936
Female	1 if female, 0 otherwise	0.790	0.407
CollGrad	1 if college graduate (4 year), 0 otherwise	0.409	0.492
Rural	1 if reside in rural area, 0 otherwise	0.334	0.472
PctIncGard [a]	Percent of income spent on gardening supplies	0.491	0.523
PctIncGardSq	Percent of income spent on gardening supplies squared	0.514	1.875
PottingMixAmt	Amount potting mix used in a year (L)	48.731 (44.251 qts)	33.969 (30.846 qts)
Outdoor	1 if primarily outdoor gardener, 0 otherwise	0.716	0.451
Organic	1 if use organic gardening practices, 0 otherwise	0.308	0.462
InfoMed	1 if obtain gardening information from TV and/or magazines, 0 otherwise	0.393	0.489
InfoExt	1 if obtain gardening information from Extension or Master Gardener programs, 0 otherwise	0.239	0.427
InfoSocInter	1 if obtain gardening information from social media or internet, 0 otherwise	0.574	0.495
GardenCntr	1 if purchase potting mix from garden centers	0.114	0.318
BioFuel	Extent to which agree that- biofuels are important to meeting the nation's future energy needs [b]	4.054	0.865
DecInput [c]	Extent to which agree that it's important that gardening products purchased have decreased need for water or fertilizers [a,b]	3.860	0.855
RespFutGen	Extent to which agree that we have a responsibility to future generations to protect the environment [a]	4.555	0.737
NoUrgentNeed	Extent to which agree that there is no urgent need to take measures to prevent climate change [a]	2.166	1.303
Consequentiality	Extent to which agree that responses to this survey could cause potting mix manufacturers to change the characteristics of the mixes they sell [a]	3.799	0.923

[a] Household income before taxes in 2017 was collected as a categorical level variable and mid-points of the categories were used. Respondents were also asked their estimate of total dollar value of 2017 household annual spending on gardening supplies (for example: plants, seeds, fertilizer, potting or garden soils, seedlings, etc.). This information was also collected through a categorical variable and mid-points were used. The PctIncGard = 100 * (2017 garden supplies expenditures/2017 household income). [b] Likert scale with 1 = strongly disagree, . . . , 5 = strongly agree. [c] Two variables had a high correlation (0.602), these were preferences for gardening products that decrease water and those that decrease fertilizer use. Cronbach's Alpha was used to test for suitability of creating the linear (average) index of the two variables (DecInput) [55].

The prices of the conventional and 25% biochar potting mixes were provided to respondents, who were free to select either or neither product [56]. The WTP of the i-th individual for the potting mix with 25% biochar is:

$$\widehat{WTP}_{PM25i} = -\left(\widehat{\alpha} + \widehat{\boldsymbol{\beta}}'\mathbf{X}_i\right)/\widehat{\beta}_p. \tag{4}$$

where the "$\widehat{\ }$" indicates an estimated coefficient. The effect of the j-th non-price explanatory variable on estimated WTP is calculated as

$$\frac{\partial \widehat{WTP}_{PM25}}{\partial X_j} = -\widehat{\beta}_j/\widehat{\beta}_p. \tag{5}$$

In addition to mean WTP estimates, this study uses the signs on the estimated coefficients from the logit model of WTP for the biochar potting mix to develop two profiles of home gardeners who are less (Profile 1) and more (Profile 2) likely to be willing to purchase the biochar potting mix. For example, if the estimated coefficient in the logit model is negative (positive), a lower (higher) example value of the variable is used. These example values for the explanatory variables included in the logit model are then used with the estimated coefficients from the logit model and Equation (4) to calculate the WTP for the biochar potting mix by the two example profile home gardeners. These profiles help illustrate how home gardener demographics and attitudes can influence WTP for the product.

We also conduct a sensitivity analysis to determine an optimal mark-up price for potting mix with biochar using Kohli and Mahajan's method [57]. The firm's expected profit of selling the biochar potting mix at P_{25} is:

$$\max_{P_{25}} \pi(P_{25}|\mathbf{X}) = m \cdot \Pr\left[PM25_i = 1|\mathbf{X},\ P_{25i}\right] \cdot (P_{25} - c_b) - f_b, \quad (6)$$

where $\pi(P_{25}|\mathbf{X})$ is the firm's profit, P_{25} is the 25% biochar potting mix product price, c_b is the marginal cost per unit of the 25%, f_b are fixed costs, Pr[ ] is the logistic probability of purchasing the 25% biochar potting mix, and m is the population of home gardeners.

The firm maximizes profit by choosing P_{25}. The optimal biochar mark-up price is that which maximizes a potting mix producer's profit, subject to marginal costs of production and a specific group of individuals compromising a market segment (in our example Profile 1, Profile 2, and the Respondent Average Profile are from the means in Table 1). In a perfectly competitive market, potting mix price equals its marginal cost of production. We use the five survey price points for biochar potting mix ($4.99, $6.49, $7.99, $9.49, or $10.99), as marginal costs of production, c_b. At each marginal cost point the optimal price, profit margin, and market share are projected. We also calculated optimal pricing, profit margin, and market share for the two example profiles and at the sample means. This sensitivity analysis illustrates how market shares, profit margins, and optimal price points can vary across marginal costs and home gardener demographic profiles. Using the sample means, we also provide estimates of the optimal price, profit margin, and market share at the breakeven biochar price of $9.20 projected in prior research [44].

2.2. Survey Instrument and Data Collection

Qualtrics, an online hosting service, conducted a pre-test survey with 108 respondents in June 2018. Pre-test results were used to modify the survey instrument. Qualtrics fielded the revised survey in July 2018 with 771 individuals responding. Qualtrics solicited respondents until a designated sample size was achieved. Both the pre-test and the full survey included Tennessee residents aged 18 years or older who self-identified as gardeners (indoor, outdoor, or both). Informed consent was obtained from all participants. The survey instrument was approved by the University of Tennessee Institutional Review Board (IRB) (UTK IRB-18-04526-XM).

The survey instrument included information screens as well as questions asking respondents about their preferences for the biochar product, expenditure patterns, demographics, and attitudes toward biofuels and the environment [58]. Prior to making a choice between the potting mix with and without biochar, respondents were asked to read the following information screen:

Biochar *is a charcoal-like material that can be added to soil to promote plant growth and reduce the amount of water and fertilizer needed. Biochar can also help with carbon sequestration, or the storage of carbon in soils, to help mitigate climate change. Biochar is made by burning biomass, such as crop residues, wood wastes or other organic matter, in an oxygen-starved environment through a process known as pyrolysis.*

Following the biochar information screen, a second screen provided respondents information on the hypothetical purchasing options. This screen also included language designed to diminish 'yea saying' by reminding respondents their purchase decision would affect their budget [59,60].

In the second section, we used a referendum style CV question to elicit consumer preferences for the biochar potting mix. Participants were asked to choose between two potting mix products. The first was a generic, 8.81 L (8-quart) bag of potting mix (compost, peat moss, vermiculite, and bone meal) priced at $4.99. The second product was an 8.81 L (8-quart) bag of potting mix (compost, peat moss, vermiculite, and bone meal) blended with 25% biochar priced at $4.99, $6.49, $7.99, $9.49, or $10.99. Prices were based on retail prices offered for 8.81 L (8-quart) bags of potting mix by major home improvement stores at the time of the survey. The sample was randomly divided into five groups, with each group receiving one of the 25% biochar potting mix prices. Respondents could choose the conventional potting mix bag (*PM*0), the 25% biochar bag (*PM*25), or neither.

3. Results and Discussion

3.1. Survey Respondents

There were 577 complete records available for the statistical analysis (Table 1). Only about 4.8% of respondents chose neither bag. These individuals were excluded from the WTP analysis because they were not willing to pay even the base price for a bag of potting mix. About 54% of the remaining respondents chose the biochar-supplemented potting mix product over the conventional potting mix. Average respondent age was just under 44 years, while 79% of the respondents were female. Just under 41% of the respondents had college degrees, and a third lived in rural areas. In 2014, the National Gardening Association reported that the typical U.S. gardener was female, over 45 years old, and held a college degree or had at least some college education [61]. The sample therefore appears to be similar to the population of U.S. gardeners represented by the National Gardening Association's statistics.

3.2. Logit WTP Estimates for Potting Mix with 25% Biochar

The results from the estimated logit model for the probability of choosing the 8.81 L (8-quart) bag of 25% biochar-blended potting mix are shown in Table 2, along with the WTP estimates and the marginal effects. The log likelihood is −318. The test against an intercept-only model produces a likelihood ratio statistic of 159. With 19 degrees of freedom, the null hypothesis that the covariates are unrelated to the purchasing choice is rejected at the 5% level of significance. The pseudo-R^2 is 0.20. The model correctly classified 73% of the responses.

The sign of the estimated coefficient on price is negative and significant. The probability a respondent selects the potting mix with biochar decreases as the price of the potting mix with biochar increases. For each dollar increase in price, the probability of selecting the potting mix with biochar decreases by 8.3%.

Older respondents (Age) are less likely to prefer the potting mix with biochar. A one-year increase in age decreases the probability of choosing the potting mix with biochar by 0.3%. Similarly, an increase in one year of age decreases respondent WTP for the potting mix with biochar by $0.03. Previous studies found that age is positively correlated with preferences for environmentally friendly gardening products [29,34–36], as in this study; however, another study reported a negative relationship [36]. Respondent preferences for the potting mix do not appear to be influenced by the other demographic variables included in the regression.

Respondent gardening and shopping behaviors are associated with respondent preferences for the potting mix with biochar. The marginal effect of a 1.1 L (one quart) increase in the amount of potting mix the respondent usually purchases in a year (PottingMixAmt) on the probability of choosing the potting mix with biochar is 0.001. For each additional 8.8 L (8 quart) bag of potting mix the respondent usually purchases in a year, the probability of the respondent choosing the potting mix with biochar increases by a modest 0.1%. The marginal effect of percent of household income spent on gardening supplies

(PctIncGard) on the probability of choosing the potting mix with biochar is 0.163. For each one percent increase in percent of household income spent on gardening supplies, the probability of choosing the potting mix with biochar increases by 16.3%. The percent of household income spent on gardening supplies has a non-linear effect, first increasing the probability of purchasing the biochar mix, then decreasing it. The turning point is at 7.4% of household income spent on gardening supplies. The WTP for the potting mix with biochar increases by $1.48 for each one percent increase in the percent of household income spent on gardening supplies.

Table 2. Estimated logit model of willingness to pay for 25% biochar potting mix [a].

Variable Name	Estimated Coefficient [a]		Marginal Effect on Pr[*PM*25 = 1] [b]		Effect on WTP Mean [c]	LCL	UCL
Intercept	1.931	**					
Price	−0.451	***	−0.083	***	—	—	—
Age	−0.015	**	−0.003	**	−$0.03	−$0.06	−$0.00
Female	0.085		0.016		$0.19	−$0.86	$1.23
CollGrad	−0.237		−0.044		−$0.53	−$1.41	$0.35
Rural	0.270		0.050		$0.60	−$0.34	$1.54
PottingMixAmt	0.006	*	0.001		$0.01	−$0.00	$0.03
PctIncGard	0.839	**	0.163	**	$1.48	$1.45	$1.50
PctIncGardSq	−0.179	*	—		—	—	—
Outdoor	−0.168		−0.031		−$0.37	−$1.33	$0.58
Organic	0.495	**	0.092	**	$1.10	$0.12	$2.08
GardenCntr	0.755	**	0.140	**	$1.67	$0.30	$3.05
BioFuel	0.337	**	0.063	***	$0.75	$0.16	$1.33
DecInput	0.152		0.028		$0.34	−$0.21	$0.88
RespFutGen	−0.020		−0.004		−$0.05	−$0.73	$0.64
NoUrgentNeed	−0.180	**	−0.033	**	−$0.40	−$0.75	−$0.05
Consequentiality	0.072		0.013		$0.16	−$0.34	$0.66
InfoExt	0.415	**	0.045		$0.54	−$0.50	$1.58
InfoMed	0.244		0.077	**	$0.92	$0.00	$1.84
InfoSocInter	−0.231		−0.040		−$0.51	−$1.38	$0.35
LL −318			Percent Correctly Classified = 73%				
LR(20 df) = 159 ***			Pseudo R^2 = 0.20			N = 577	

[a] *** = significant at $\alpha = 0.01$, ** = significant at $\alpha = 0.05$, and * = significant at $\alpha = 0.10$. [b] The marginal effect of the demographic or attitude variable, X_j is $\mathrm{ME}(X_j) = \frac{\exp(\alpha+\beta' X_i+\beta_p P_i)}{(1+\exp(\alpha+\beta' X_i+\beta_p P_i))^2}\beta_j$ and for the PctIncGard it is $\frac{\exp(\alpha+\beta' X_i+\beta_p P_i)}{(1+\exp(\alpha+\beta' X_i+\beta_p P_i))^2}(\beta_{PctIncGard} + \beta_{PctIncGardSq} * \mathrm{PctIncGard}*2)$. [c] Krinsky and Robb method used to calculate the 95% Confidence Interval (5000 reps) [62]. [d] The effect of PctIncGard on WTP is calculated by $\frac{-(\beta_{PctIncGard}+\beta_{PctIncGardSq}*\mathrm{PctIncGard}*2)}{\beta_{Price}}$.

The probability a respondent is willing to purchase the potting mix with biochar is 14.0% higher for respondents who typically purchase gardening material from a local garden center (GardenCntr). These individuals are, on average, willing to pay $1.67 more for the potting mix with biochar than those who typically purchase gardening material from other types of retail outlets. Respondents who use television and magazines to gather information about gardening (InfoMed) are 7.7% more likely to choose the potting mix with biochar and are willing to pay an additional $0.92 for the biochar mix than those not using these information sources.

Similar to findings by previous studies [29,33–35,39,40], this study found that environmental attitudes influenced WTP. Respondents using organic gardening practices (Organic) are 9.2% more likely to choose the biochar potting mix and willing to pay $1.10 more for potting mix with biochar than those who do not use organic gardening practices. A one-unit increase in the strength of respondent belief that there is no urgent need to take measures to prevent climate change (NoUrgentNeed) decreases the probability of a respondent choosing the biochar mix by 3.3% and WTP for the biochar mix by $0.40. The strength of respondent belief in the importance of biofuels for meeting the nation's future energy needs (BioFuel) is associated with preference for the potting mix with biochar. A one-unit increase in the strength of this belief increases the probability of choosing the biochar mix by 6.3% and WTP for the mix by $0.75. On the other hand, respondent preferences for the potting mix with biochar are unassociated with respondent belief in either obligations to future generations to protect the environment or the importance of purchasing gardening products that require less fertilizer and water. This result suggests marketing a biochar blended potting mix to consumers as supportive of biofuels industry development may be more influential on WTP or the product than its potential to reduce input use by the gardener.

The mean WTP for the potting mix with biochar is $8.52 per 8.8 L (8-quart) bag with lower and upper confidence bounds of $8.09 and $8.97, respectively (Table 3). Compared with the base product price of $4.99, this represents a premium of $3.53 per 8.8 L (8 quart) bag. Assuming the base price for the conventional potting mix implies a WTP of $0.57 L^{-1} for conventional potting mix ($4.99/8.8 L), respondents are willing to pay a premium of $3.53 for a bag of potting mix, where 2.2 L of the mix have been replaced with 2.2 L of biochar. This finding suggests an implicit WTP of $2.17 L^{-1} of pre-mixed biochar.

Table 3. Estimated WTP for 25% Biochar Potting Mix and Premium Compared with Conventional Biochar.

	WTP			Premium		
		95% Confidence Interval [a]			95% Confidence Interval [a]	
	Mean	**Lower**	**Upper**	**Mean**	**Lower**	**Upper**
Sample Mean	$8.52	$8.09	$8.97	$3.53	$3.09	$3.98
Profile 1	$2.64	$0.32	$4.68	−$2.35	−$4.67	−$0.31
Profile 2	$14.29	$11.41	$17.56	$9.30	$6.42	$12.57

[a] Krinsky and Robb method used to calculate 95% Confidence Interval (5000 repetitions) [62].

3.3. Market Demands, WTP, Breakeven Prices, and Volumes for a Pyrolysis Biofuels-Biochar Co-Products Facility

Using the WTP results, it is helpful to provide some perspective on the potential market demand for a biochar-blended potting mix and compare this with the amount of biochar a pyrolytic conversion biofuels facility might co-produce. In 2018, Tennessee had about 2,038,944 single-unit detached homes [63]. If 20% of these are assumed to participate in container gardening based on national gardening survey results [64], then there would be 407,789 single-unit homes with dwellers who practice container gardening. According to our results, the respondents used, yearly, on average 48.731 L of potting mix per household. If 50% of the households purchased the product at the WTP value of $8.52, this would constitute a value of 9.9 × 106 L of 25% biochar potting mix (407,789 households × 48.731 L potting mix purchased yearly × 0.50 probability of purchasing biochar potting mix). With 25% of this amount being biochar, an estimated 2.5 × 106 L of biochar could be purchased by Tennessee home gardeners.

By comparison, a 6.8 × 106 L biofuels-biochar co-product pyrolysis facility is been estimated to produce about 17,700 t of biochar [57]. Using an average biochar density of 1.65 g cm^{-3} [58], this results in a projected 10.7 × 106 L of biochar produced by a pyrolysis biofuels-biochar facility. The value of 10.7 × 106 L can be then compared with the 2.5 × 106 L that might be demanded by home gardeners across the state. Hence, the market application considered in this study would likely only use a part, about 23%, of the biochar produced by a conversion facility of this size when priced at consumers' WTP for biochar.

The breakeven price of biochar in the biofuel-biochar co-product pyrolysis facility investigated in [57] with a biofuel price of $.66 L^{-1} is $1504 t^{-1} or $2.48 L^{-1}. The implicit average WTP for biochar from this study, as stated above, is estimated to be $2.17 L^{-1}, which falls well below the breakeven biochar price of $2.48. On a per bag basis, this represents a WTP-breakeven price difference of $8.52–$9.20, or −$0.68. If the breakeven price from the biochar is considered as the marginal cost of biochar to the potting mix manufacturer, the market share drops considerably lower than 23%, as discussed in Section 3.5.

3.4. Two Example Home Gardener Profiles and Effects on Optimal Price, Profit Margin, and Market Captured under Various Marginal Costs

For the purposes of illustrating the effects of being a low probability purchaser (Profile 1) or a high probability purchaser (Profile 2), the signs on the estimated coefficients in Table 2 were used to develop two example profiles of consumers (Table 4). The first consumer profile is that of a 60 year-old female with a college degree living in an urban area. This person is an outdoor gardening enthusiast that seeks information about gardening using social media and uses 27.5 L (25 qts) of potting mix each year. This generic individual has a lower probability of purchasing the product. The second profile is that of a 30 year female organic gardener without a college degree. This individual lives in a rural area, uses 71.6 L (65 qts) of potting mix each year, and seeks information about gardening through extension or television or news magazine media. Holding the biochar price at its mean, the Profile 1 home gardener has less than 10% chance of choosing the biochar product, while the Profile 2 home gardener has over a 95% chance of choosing the biochar product. These profiles are then used in Equation (4) along with the estimated model coefficients to develop WTP estimates for the two profiles (Table 3). A Profile 1 home gardener would discount the 25% biochar potting mix $2.35 below the conventional product price. A Profile 2 home gardener would pay $14.29, a $9.30 premium over the conventional product.

Table 4. Example Home Gardener Profiles for a Low Probability (Profile 1) and High Probability (Profile 2) of Purchase.

Variable	Profile 1	Profile 2
Age	60	30
Female	No	Yes
CollGrad	Yes	No
Rural	No	Yes
PottingMixAmt	27.53 L (25 qts)	71.58 L (65 qts)
PctIncGard	0.35	0.65
PctIncGardSq	0.1225	0.4225
Outdoor	Yes	No
Organic	No	Yes
GardenCntr	No	Yes
BioFuel	Somewhat Disagree	Somewhat Agree
DecInput	Somewhat Disagree	Somewhat Agree
RespFutGen	Somewhat Agree	Somewhat Disagree
NoUrgentNeed	Somewhat Agree	Somewhat Disagree
Consequentiality	Somewhat Disagree	Somewhat Agree
InfoExt	No	Yes
InfoMed	No	Yes
InfoSocInter	Yes	No

3.5. Optimal Pricing, Market Shares, and Profits

Using the method described in Equation (6), the profiles in Table 4, and the respondent average profile from the means in Table 1, the optimal prices, market shares and profits at varying marginal costs to the potting mix manufacturers are calculated and shown in Table 5.

Optimal prices for potting mix with biochar were 11 to 40% higher for consumer Profile 2 compared with Profile 1, depending on an assumed marginal cost of production (Table 5). At the lowest marginal cost, the optimal price for the Profile 1 (Profile 2) consumer was $7.45 ($12.40). Only 10% of the Profile 1 market segment would purchase the potting mix with biochar at the lowest marginal cost. At the highest assumed marginal cost of $10.99, only 1% of this market segment is captured.

Table 5. Optimal prices, profit margins, and market captured given marginal costs across three market profiles.

	Marginal cost→	$4.99	$6.49	$7.99	$9.49	$10.99
Profile 1	Optimal price	$7.45	$8.84	$10.28	$11.74	$13.23
	Profit margin	$0.24	$0.13	$0.07	$0.03	$0.02
	Market captured	10%	5%	3%	2%	1%
Respondent Average Profile	Optimal price	$9.01	$9.95	$11.03	$12.37	$13.49
	Profit margin	$1.81	$1.21	$0.76	$0.49	$0.25
	Market captured	45%	35%	25%	17%	10%
Profile 2	Optimal price	$12.40	$12.88	$13.45	$14.11	$14.90
	Profit margin	$5.19	$4.17	$3.24	$2.40	$1.69
	Market captured	70%	65%	59%	52%	43%

The results are quite different for the second profile. At the lowest marginal cost, roughly 70% of this market is expected to purchase the biochar potting mix product. At the highest costs of production, the market share of Profile 2 consumers captured decreases to 43%. Unsurprisingly, the profit margin earned by a potting mix supplier is higher with the Profile 2 consumer.

Using the respondent averages, at the lowest marginal cost, about 45% of the market is captured and the optimal price is $9.01. As the marginal cost increases to $10.99, the market share captured declines to 10 percent, while the optimal price increases to $13.49 at a marginal cost of $10.99.

Notably if the estimated biochar co-product breakeven cost from prior research [47] of $2.48 L^{-1} is used as the marginal cost of biochar to the potting mix manufacturer and blended assuming a $0.57 L^{-1} marginal cost of the conventional potting mix component ($4.99/8.8 L), the marginal cost of the biochar blended potting mix is $9.20. Using $9.20 as the marginal cost, the optimal biochar potting mix blend price to the potting mix manufacturer is $11.92. This price results in profit of $0.49 to the potting mix manufacturer and a market share of 18%. At a market share of 18%, this would constitute 894,238 L or about 8.3% the biochar production of the example pyrolysis facility.

4. Conclusions

Biochar is a significant co-product of pyrolytic biofuel production, comprising 15 to 50 percent of production. Development of biochar co-product markets could enhance the overall profitability of lignocellulosic-to-energy biofuel conversion facilities. One potential use of biochar is as a soil amendment that could be used either commercially or residentially. While previous research has provided estimates of the costs of producing biochar and breakeven prices under varying assumptions, research is lacking that provides information regarding consumer perceptions about biochar in retail-oriented products, such as a biochar-blended potting mix. Finding relatively high-value biochar market applications with sufficient magnitudes of demand could help boost the overall profitability of a biofuel-biochar co-product facility.

This research sought to identify consumers' preferences and WTP for a biochar-blended potting mix. The results from this study suggest that consumers would pay a premium for a biochar-blended potting mix compared with conventional. Furthermore, those more concerned about biofuels industry development and climate change are willing to pay higher premiums, suggesting that consumers make the connection between biochar both as a biofuels co-product and a means to store carbon. Consumer-oriented products containing biochar, particularly as a co-product of biofuels, should likely provide product information alluding to the idea that consumers' purchases of a biochar-based product could aid in development of a biofuels industry. The use of two example profiles of consumers illustrates the considerable differences in probabilities of selecting the biochar-blended potting mix and their WTP.

The optimal prices across differing marginal costs of production illustrate how higher marginal costs can eat away at market share and profitability of selling a biochar potting mix blend. The effects of these higher marginal costs are magnified for the consumer profile that is older, less gardening involved (do not use organic practices, use less potting mix, and spend a lower share of their income on gardening supplies), and less concerned about biofuels industry development and climate change.

Findings from this research suggest that overall consumer WTP for biochar equivalent in a biochar-blended potting mix is lower than estimated breakeven biochar price at the pyrolysis facility estimated from prior research [47]. At the estimated breakeven prices used in prior research, the market demand for the biochar within the potting mix product application and study area would constitute about 8.3% of the biofuels-biochar pyrolysis facility's output of biochar. Given that the market for biochar in potting mix across the state is smaller than production, the profitability of selling biochar into other alternative markets, such as other consumer-oriented products or direct bulk sales to nurseries and greenhouses and other agricultural applications should also be considered. In addition, target marketing of the biochar product could bring higher prices among certain market segments.

This study has several limitations. First, the geographic area was limited to one state in the U.S. and consumer attitudes may vary across regions of the U.S. and across other countries. Second, the survey included a hypothetical choice. Measures were taken to reduce overstatement of WTP, but this can be problematic in hypothetical choice experiments. If a 25% biochar potting mix product is to be further tested for market introduction, in-store experiments and data collection could aid in further product decision making. Third, most respondents were very unfamiliar with biochar. Over 86% of the survey's respondents indicated they had never heard of biochar prior to the survey. Because the biochar information screen in the survey may have informed or made the majority of respondents more aware about biochar, the respondents may exhibit higher WTP than the average potting mix consumer who has little information about biochar. One might therefore view these WTP estimates as being representative of gardeners who had been exposed to marketing campaigns for biochar-supplemented soil amendments. A future area of research could be to provide estimates of the effects of biochar information provision, including if it is a co-product of biofuels conversion, on WTP for a biochar potting mix.

Additional research should also examine consumer preferences for and market feasibility of other consumer-oriented biochar products that will have higher value-added versus more bulk-oriented product markets. In addition, an integrated approach to assessing the overall economic feasibility of biochar products will be needed as biofuels-biochar co-product facilities emerge on a commercial scale. Such an analysis would include both consumer or buyer preferences within a targeted market area surrounding a conversion facility, conversion specifications and associated costs, including financial factors, as well as further processing and distribution costs.

Author Contributions: Conceptualization, K.L.J., D.M.L., B.C.E., C.D.C. and F.R.W.; Data curation, K.L.J.; Formal analysis, M.T., K.L.J., D.M.L.; Funding acquisition, K.L.J., D.M.L., B.C.E., C.D.C. and F.R.W.; Methodology, K.L.J., D.M.L., B.C.E., C.D.C., and F.R.W.; Project administration, K.L.J.; Writing—original draft, M.T., K.L.J., D.M.L., B.C.E., C.D.C. and F.R.W.; Writing—review & editing, M.T., K.L.J., D.M.L., B.C.E., C.D.C. and F.R.W. All authors have read and agreed to the published version of the manuscript.

Funding: This work was funded in part by the US Federal Aviation Administration (FAA) Office of Environment and Energy as a part of ASCENT Project 1 under FAA Award Number: 13-C-AJFEUTENN-Amd 5. Funding also was provided by USDA through Hatch Project TN000444 and through the Sparks Chair in Agricultural Sciences and Natural Resources. Any opinions, findings, conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the FAA or other ASCENT sponsor organizations.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of The University of Tennessee (protocol code UTK IRB-18-04526-XM and 6/13/2018).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data for this study were collected using appropriate human subjects protocols. As part of the protocol used in this study, confidentiality to the survey participants was promised. As such, the individual data are not available. Only summary results from the survey may be provided.

Conflicts of Interest: The authors declare no conflict of interest.

Notations

c_{25}	Marginal cost of producing 25% biochar potting mix
Exp	Exponential
f_{25}	Fixed cost of producing 25% biochar potting mix
L	Liter
LCL	Lower 95% confidence level
LL	Log likelihood
LLR	Log likelihood ratio test statistic
π	Profits from producing 25% biochar potting mix
P_{0i}	Price of conventional potting mix for the ith individual
P_{25i}	Price of 25% biochar-blended potting mix for the ith individual
$PM0$	Conventional potting mix
$PM25$	25% biochar-blended potting mix
Pr	Logistic probability function
t	Dry metric tons
U_{i0}	Utility from conventional potting mix for the ith individual
U_{i25}	Utility from 25% biochar-blended potting mix for the ith individual
UCL	Upper 95% confidence level
USDA	United States Department of Agriculture
WTP	Willingness to Pay
$\widehat{WTP}_{PM25i}$	Estimated WTP for 25% biochar-blended potting mix for the ith individual
X_i	Vector of demographic and attitude variables for the ith individual

References

1. Garcia-Perez, M.; Lewis, T.; Kruger, C. *Methods for Producing Biochar and Advanced Biofuels in Washington State. Part 1: Literature Review of Pyrolysis Reactors*; Washington State University Department of Biological Systems Engineering, Center for Sustaining Agricultural and Natural Resources: Pullman, WA, USA, 2010; Pub. No. 11-07-2017.
2. Winsley, P. Biochar and Bioenergy Production for Climate Change Mitigation. *N. Z. Sci. Rev.* **2007**, *64*, 5–10.
3. Jahirul, M.I.; Rasul, M.G.; Chowdhury, A.A.; Ashwath, N. Biofuels Production through Biomass Pyrolysis—A Technological Review. *Energies* **2012**, *5*, 4952–5001. [CrossRef]
4. Gupta, S.; Mondal, P.; Borugadda, V.; Dalai, A. Advances in upgradation of pyrolysis bio-oil and biochar towards improvement in bio-refinery economics: A comprehensive review. *Environ. Technol. Innov.* **2021**, *21*, 101276. [CrossRef]
5. Bozell, J.; Petersen, G. Technology Development for the Production of Biobased Products from Biorefinery Carbohydrates-The US Department Of Energy's "Top 10" Revisited. *Green Chem.* **2010**, *12*, 539–554. [CrossRef]
6. U.S. Department of Energy Alternative Fuels Data Center (USDA/AFDC). Renewable Fuel Standard. 2019. Available online: https://www.afdc.energy.gov/laws/RFS.html (accessed on 18 April 2021).
7. Schmidt, H. Uses of biochar. *Ithaka J.* **2012**, *1*, 286–289.
8. Reddy, G.; Nagender, T.; Yerasi, P. Biochar and its potential benefits—A review. *Environ. Ecol.* **2013**, *31*, 2000–2005.
9. Wang, J.; Xiong, Z.; Kuzyahov, U. Biochar stability in soil: Meta-analysis of decomposition and priming effects. *GCB Bioenergy* **2016**, *8*, 512–523. [CrossRef]
10. Schulz, H.; Dunst, G.; Glaser, B. Positive effects of composted biochar on plant growth and soil fertility. *Agron. Sustain. Dev.* **2013**, *33*, 817–827. [CrossRef]
11. Chalker-Scott, L. *Biochar: A Home Gardener's Primer*; Washington State Research and Extension Center: Puyallup, WA, USA, 2014; Available online: https://pubs.extension.wsu.edu/biochar-a-gardeners-primer-home-garden-series (accessed on 18 April 2021).
12. Kaufman, N.; Dumortier, J.; Hayes, D.; Brown, R.; Laird, D. Producing energy while sequestering carbon? The relationship between biochar and agricultural productivity. *Biomass Bioenergy* **2014**, *63*, 167–176. [CrossRef]
13. Grutzmacher, P.; Puga, A.; Bibar, M.; Coscione, A.; Parker, A.; de Andrade, C. Carbon stability and mitigation of fertilizer induced N2O emissions in soil amended with biochar. *Sci. Total Environ.* **2018**, *625*, 1459–1466. [CrossRef]
14. Van Zwieten, L.; Kimber, S.; Morris, S.; Downie, A. Influence of biochars on flux of N2O and CO2 from Ferrosol. *Aust. J. Soil Res.* **2010**, *48*, 555–568. [CrossRef]

15. Deenik, J.; McClellan, T.; Uehara, G.; Antal, M.; Campbell, S. Charcoal volatile matter content influences plant growth and soil nitrogen transformations. *Soil Sci. Soc. Am. J.* **2010**, *74*, 1259–1270. [CrossRef]
16. Hale, S.; Lehmann, J.; Rutherford, D.; Zimmerman, A.; Bachmann, R.; Shitumbanuma, V.; O'Toole, A.; Sundqvist, K.; Arp, H.; Cornelissen, G. Quantifying the total and bioavailable polycyclic aromatic hydrocarbons and dioxins in biochars. *Environ. Sci. Technol.* **2012**, *46*, 2830–2838. [CrossRef] [PubMed]
17. Hilber, I.; Blum, F.; Leifeld, J.; Schmidt, H.; Bucheli, T. Quantitative determination of PAHs in biochar: A prerequisite to ensure its quality and safe application. *J. A Food Chem.* **2012**, *60*, 3042–3050. [CrossRef]
18. Jeffrey, S.; Abalos, D.; Prodana, M.; Bastos, M.; van Groenigen, J.; Hungate, B.; Verheijen, B. Biochar boosts tropical but not temperate crop yields. *Environ. Res. Lett.* **2017**, *12*, 5. [CrossRef]
19. Oleszczuk, P.; Jośko, I.; Kuśmierz, M. Biochar properties regarding to contaminants content and ecotoxicological assessment. *J. Hazard. Mater.* **2013**, *260*, 375–382. [CrossRef] [PubMed]
20. Solaiman, Z. Use of biochar for sustainable agriculture. *J. Integr. Field Sci.* **2018**, *15*, 8–17.
21. Yoo, G.; Kang, H. Effects of biochar addition on greenhouse gas emissions and microbial responses in a short-term laboratory experiment. *J. Environ. Qual.* **2012**, *41*, 1193–1202. [CrossRef]
22. Zheng, E.; Guo, M.; Chow, T.; Bennett, D.; Rajagopalan, N. Sorption properties of greenwaste biochar for two triazine pesticides. *J. Hazard. Mater.* **2010**, *181*, 121–126. [CrossRef]
23. Margenot, A.; Griffin, D.; Alves, B.; Rippner, D.; Li, C.; Parikh, S. Substitution of peat moss with softwood biochar for soil-free marigold growth. *Ind. Crop. Prod.* **2018**, *112*, 160–169. [CrossRef]
24. Caron, J.; Heinse, R.; Charpentier, S. Organic materials used in agriculture, horticulture, reconstructed soils, and filtering applications. *Vadose Zone J.* **2015**, 14. [CrossRef]
25. Mason, S.; Starman, T.; Lineberger, R. Consumer preferences for price, color harmony, and care information of container gardens. *HortScience* **2008**, *42*, 380–384. [CrossRef]
26. Walker., F. (Department of Biosystems Engineering and Soil Sciences, The University of Tennessee). Personal communication with Dr. Forbes Walker, Professor. About Research Regarding Effects of varying Biochar Levels on Growth of Ornamental Plants, March 2017.
27. U.S. Department of Agriculture Biopreferred Program (USDA/Biopreferred). Biopreferred Products Catalog. 2019. Available online: https://www.biopreferred.gov/BioPreferred/faces/catalog/Catalog.xhtml (accessed on 19 April 2021).
28. Clayton, S. Domesticated nature: Motivations for gardening and perceptions of environmental impact. *J. Environ. Psychol.* **2007**, *27*, 215–224. [CrossRef]
29. Fan, Y.; McCann, L. Households' adoption of Drought Tolerant Plants: An Adaptation to Climate Change? In Proceedings of the 2015 AAEA & WAEA Joint Annual Meeting, San Francisco, CA, USA, 26–28 July 2015; Available online: https://ideas.repec.org/p/ags/aaea15/205544.html (accessed on 20 April 2021).
30. Choi, Y.; Lambert, D.M.; Jensen, K.L.; Clark, C.D.; English, B.C.; Thomas, M. Rank-ordered analysis of consumer preferences for the attributes of a value-added biofuel co-product. *Sustainability* **2020**, *12*, 2363. [CrossRef]
31. Dahlin, J.; Beuthner, C.; Halbherr, V.; Kurz, P.; Nelles, M.; Herbes, C. Sustainable compost and potting soil marketing: Private gardener preferences. *J. Clean. Prod.* **2019**, *208*, 1603–1612. [CrossRef]
32. Getter, K.; Behe, B.; Wollaeger, H. Comparative consumer perspectives on eco-friendly and insect management practices on floriculture crops. *HortTechnology* **2016**, *23*, 46–53. [CrossRef]
33. Behe, B.; Campbell, B.; Dennis, J.; Hall, C.; Lopez, R.; Yue, C. Gardening consumer segments vary in ecopractices. *HortScience* **2010**, *45*, 1475–1479. [CrossRef]
34. Yue, C.; Hall, C.; Behe, B.; Campbell, B.; Dennis, J.; Lopez, R. Are consumers willing to pay more for biodegradable containers than for plastic ones? Evidence from hypothetical conjoint analysis and nonhypothetical experimental auctions. *J. Agric. Appl. Econ.* **2010**, *42*, 757–772. [CrossRef]
35. Yue, C.; Campbell, B.; Hall, C.; Behe, B.; Dennis, J.; Khachatryan, H. Consumer preference for sustainable attributes in plants: Evidence from experimental auctions. *Agribusiness* **2016**, *32*, 222–235. [CrossRef]
36. Hawkins, G.; Burnett, S.; Stack, L. Survey of consumer interest in organic, sustainable, and local container-grown plants in Maine. *HortTechnology* **2012**, *22*, 817–825. [CrossRef]
37. Park, W.M.; Lamons, K.S.; Roberts, R.K. Factors associated with backyard composting behavior at the household level. *Agric. Resour. Econ. Rev.* **2002**, *31*, 147–156. [CrossRef]
38. Khachatryan, H.; Rihn, A.; Behe, B.; Hall, C.; Campbell, B.; Dennis, J.; Yue, C. Visual attention, buying impulsiveness, and consumer behavior. *Mark. Lett.* **2018**, *29*, 23–35. [CrossRef]
39. Hugie, K.; Yue, C.; Watkins, E. Consumer preferences for low-input turfgrasses: A conjoint analysis. *HortScience* **2012**, *47*, 1096–1101. [CrossRef]
40. Rihn, A.; Khachatryan, H.; Campbell, B.; Hall, C.; Behe, B. Consumer preferences for organic production methods and origin promotions on ornamental plants: Evidence from eye-tracking experiments. *Agric. Econ.* **2016**, *17*, 599–608. [CrossRef]
41. Jirka, S.; Tomlinson, T. *State of the Biochar Industry 2014 A Survey of Commercial Activity in the Biochar Sector*; International Biochar Initiative (IBI): Canandaigua, NY, USA, 2015.
42. Frank, J.; Brown, T.; Malsheimer, R.; Volk, T.; Ha, H. The financial trade-off between the production of biochar and biofuel via pyrolysis under uncertainty. *Biofuels Bioprod. Biorefining* **2020**, *14*, 594–604. [CrossRef]

43. Brown, T.R.; Wright, M.M.; Brown, R.C. Estimating profitability of two biochar production scenarios: Slow pyrolysis vs. fast pyrolysis. *Biofuels Bioprod. Biorefining* **2011**, *5*, 54–68. [CrossRef]
44. Campbell, R.; Anderson, N.; Daugaard, D.; Naughton, H. Financial viability of biofuel and biochar production from forest biomass in the face of market price volatility and uncertainty. *Appl. Energy* **2018**, *230*, 330–343. [CrossRef]
45. Brewer, C.; Chuang, V.; Masiello, C.; Gonnerman, H.; Gao, X.; Dugan, B.; Driver, L.; Panzacchi, P.; Zyrourakis, K.; Davis, C. New approaches to measuring biochar density and porosity. *Biomass Bioenergy* **2014**, *66*, 176–185. [CrossRef]
46. He, L.; English, B.; Menard, R.; Lambert, D. Regional woody biomass supply and economic impacts from harvesting in the southern U.S. *Energy Econ.* **2016**, *60*, 151–161. [CrossRef]
47. Hoyos, D.; Mariel, P. Contingent valuation: Past, present and future. *Prague Econ. Pap.* **2010**, *19*, 329–343. [CrossRef]
48. Mitchell, R.C.; Carson, R.T. *Using Surveys to Value Public Goods: The Contingent Valuation Method*; Johns Hopkins University Press: Baltimore, MD, USA, 1989.
49. Carson, R.; Hanemann, M.; Kopp, R.; Krosnick, J.; Mitchell, R.; Presser, S.; Ruud, P.; Smith, K.; Conaway, M.; Martin, K. *Referendum Design and Contingent Valuation: The NOAA Panel's No-Vote Recommendation*; Resources for the Future Working Group Discussion Paper 96-05; Resources for the Future: Washington, DC, USA, 1995. [CrossRef]
50. Bishop, R. Warm glow, good feelings, and contingent valuation. *J. Agric. Resour. Econ.* **2018**, *43*, 307–320.
51. Herriges, J.; Kling, C.; Liu, C.; Tobias, J. What are the consequences of consequentiality? *J. Environ. Econ. Manag.* **2010**, *59*, 67–81. [CrossRef]
52. Vossler, C.A.; Doyon, M.; Rondeau, D. Truth in consequentiality: Theory and field evidence on discrete choice experiments. *Am. Econ. J. Microecon.* **2012**, *4*, 145–171. [CrossRef]
53. McFadden, D. Conditional logit analysis of qualitative choice behavior. In *Frontiers in Econometrics*; Zarembka, P., Ed.; Academic Press: New York, NY, USA, 1974; pp. 105–142. Available online: https://eml.berkeley.edu/reprints/mcfadden/zarembka.pdf (accessed on 8 June 2021).
54. Greene, W.H. *Econometric Analysis*, 8th ed.; Pearson: Boston, MA, USA, 2018.
55. Cronbach, L. Coefficient alpha and the internal structure of tests. *Psychometrica* **1951**, *16*, 297–334. [CrossRef]
56. Hanemann, W. Welfare evaluations in contingent valuation experiments with discrete responses. *Am. J. Agric. Econ.* **1984**, *66*, 332–334. [CrossRef]
57. Kohli, R.; Mahajan, V. A reservation-price model for optimal pricing of multiattribute products in conjoint analysis. *J. Mark. Res.* **1991**, *28*, 347–354. [CrossRef]
58. Thomas, M. An Analysis of Consumer Preferences for Gardening Products with Environmentally Friendly Attributes. Master's Thesis, University of Tennessee, Knoxville, TN, USA, 2019.
59. Blamey, R.K.; Bennett, J.; Morrison, M.D. Yea-saying in contingent valuation surveys. *Land Econ.* **1999**, *75*, 126–141. [CrossRef]
60. Cummings, R.; Taylor, L. Unbiased value estimates for environmental goods: A cheap talk design for the contingent valuation method. *Am. Econ. Rev.* **1999**, *89*, 649–665. [CrossRef]
61. White, J. *Home Gardening Statistics. The Masters of Horticulture*. 2014. Available online: http://masterofhort.com/2014/03/home-gardening-statistics/ (accessed on 18 May 2019).
62. Krinsky, I.; Robb, A. On approximating the statistical properties of elasticities. *Rev. Econ. Stat.* **1986**, *68*, 715–719. [CrossRef]
63. U.S. Census Bureau. *Tennessee Single Unit Households. 2018 Households and Families*; American Community Survey: Washington, DC, USA, 2018.
64. National Gardening Association. *National Gardening Survey*; National Gardening Association: South Burlington, VA, USA, 2018.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
01-energies-14-03432		

4. Title and Subtitle

Consumer Preferences andWillingness to Pay for Potting Mix with Biocharan Energy Feedstock

5. Report Date

June 2021

6. Performing Organization Code

7. Author(s)

McKenzie Thomas, Kimberly L. Jensen, Dayton M. Lambert, Burton C. English, Christopher D. Clark and Forbes R. Walker

8. Performing Organization Report No.

9. Performing Organization Name and Address

Center of Excellence for: Alternative Jet Fuels and Environment

University of Tennessee, Agricultural & Resource Economics Department, Knoxville, TN 37996, USA

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

13-C-AJFE-UTENN-005

12. Sponsoring Agency Name and Address

Federal Aviation Administration
Office of Environment and Energy

13. Type of Report and Period Covered

Journal Article

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Biochar is a co-product of advanced biofuels production from feedstocks including food, agricultural, wood wastes, or dedicated energy crops. Markets for soil amendments using biochar are emerging, but little is known about consumer preferences and willingness to pay (WTP) for these products or the depth of the products' market potential for this product. This research provides WTP estimates for potting mix amended with 25% biochar, conditioned on consumer demographics and attitudes about product information labeling. Data were collected with an online survey of 577 Tennessee home gardeners. WTP was elicited through a referendum contingent valuation. Consumer WTP for an 8.81 L bag of 25% biochar potting mix is $8.52; a premium of $3.53 over conventional potting mix. Demographics and attitudes toward biofuels and the environment influence WTP. Biochar amounts demanded are projected for the study area's potential market. Optimal prices, profits, and market shares are estimated across different marginal costs of producing biochar potting mix.

17. Key Words

biochar; consumer preferences; potting mix; biofuels; feedstock; ASCENT

18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized