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Consumer Preference for Microgreens in the Presence of LED Lights and Information Treatments

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Abstract. **Since microgreens entered the market in the 1980s and 1990s, their use has expanded far beyond high-end restaurants. Most microgreens are grown in greenhouses with supplemental lighting (i.e., artificial lighting in addition to sunlight). Supplemental lighting usually includes high-pressure sodium (HPS) or light-emitting diodes (LEDs). HPS is the most common type of supplemental lighting, while LEDs are becoming more common. This article examines consumer preference and willingness to pay (WTP) for microgreens grown with LED lighting compared with HPS lighting and sunlight in the presence of different amounts and types of information. We find that negative information harms WTP, and positive information has little to no impact on WTP. We also examine how other attributes (i.e., price, location produced, production type, location purchased) impact WTP.**

Microgreens are a specialty crop that entered the market in the 1980s and 1990s as a garnish in high-end restaurants. They can now be found in casual dining establishments and private homes. They are used to add texture and color, as well as for their taste, aroma, and visual appeal (Verlinden 2020). Microgreens are leafy greens that are harvested at the first true leaf stage, with the stem attached. Typically grouped with sprouts and baby greens, they are middle-sized and usually harvested at two inches tall (Treadwell et al. 2020). Sales of microgreens was estimated to be ~$1.8 billion globally in 2021 and is expected to top $2 billion by 2028 (Allied Analytics LLP 2021).

Large-scale producers grow microgreens in greenhouses because of the time frame in which they are grown and harvested. To increase efficiency within production, many greenhouses use supplemental lighting (i.e., lighting in addition to sunlight) to speed up growth times and increase quality. Greenhouses can choose from multiple types of supplemental lighting, including high-pressure sodium (HPS) and light-emitting diodes (LEDs). HPS lighting is the most common type of supplemental lighting, while LEDs are becoming more commonly used in conjunction with, or as an alternative to, HPS lighting (Katzin et al. 2021).

Supplemental lighting in greenhouses is normally the second largest operating expense after labor. For vertical farms, it is estimated that 40% to 50% of their total operating costs are for supplemental lighting (van Iersel 2017). LEDs are better at converting electrical power into photosynthetic light. This could mean energy savings for greenhouses. LEDs put off less heat than HPS lighting. The heat emitted by HPS lights takes the load off the heating systems in greenhouses. If LEDs are implemented, more of a load could be put on the heating systems, allowing for increased total energy savings (Katzin et al. 2021).

LED lights emit three colors: red, blue, and white. The most efficient colors have been found to be red and blue (Bugbee 2017). The blue light that can be emitted by LEDs has been found to be important for the development of microgreens. Blue light increases the shoot tissue pigments, glucosinolates, and essential mineral elements (Viršilė et al. 2017). Glucosinolates have been reported to be able to stop the formation (mitosis) and increase the natural death (apoptosis) of human tumor cells (Barba et al. 2016). Supplemental blue light has been shown to increase the nutritional value of microgreens (Viršilė et al. 2017).

Although there are benefits to LED lighting, there are also some drawbacks. As noted by Rea (2010), the costs associated with incorporating LED lighting in a greenhouse can be expensive. Runkle (2014) noted that LEDs can be 4 to 6 times more expensive than HPS per photon. Furthermore, return on investment is highly dependent on greenhouse location given different parts of the United States receive varying amounts of natural sunlight, which impacts the amount of LED light needed and thereby variable costs.

Given the noted benefits and costs associated with LED lighting, this study investigates United States consumers' preferences and willingness to pay (WTP) for microgreens grown using varying lighting systems, specifically LEDs. The main objective of this work is to evaluate how consumers react when presented with both positive and negative information about LED lighting. Furthermore, we evaluate how LED lighting might benefit producers in the marketing (i.e., labeling and messaging) of their microgreens, which could be an avenue to generating additional revenues to offset the high cost of LED lighting. Respondents were split into random informational treatments to evaluate the impact of information.

Materials and Methods

An online survey was administered in Jan 2021 to assess consumer preference for, understanding of, and potential barriers for the use of supplemental lighting by greenhouses within their production. A total of 5308 US consumers answered questions about their purchasing habits of various fruits and vegetables, including participating in a choice experiment associated with a single fruit or vegetable. Potential respondents were randomly recruited from the online panel database of Toluna, Inc. (Dallas, TX, USA), which sent an e-mail requesting their participation in the survey. Respondents over 18 years of age and agreeing to participate were directed to the survey where they were shown the Human Subjects Institutional Review Board consent form. After agreeing to participate, respondents were randomly assigned to a fruit or vegetable choice experiment as well as a lighting informational treatment group. This article focuses on the 574 respondents that were randomly selected into and completed the microgreen choice experiment.

Before beginning the choice experiment, each respondent was randomly sorted into one of six treatment groups (Table 2). Treatment 1 (92 respondents) gave the advantages of LED lighting compared with HPS and natural sunlight as well as negative information associated with LED lighting. Treatment 2 (105 respondents) only provided the advantages of LED lighting compared with HPS and natural sunlight. Treatment 3 (93 respondents) gave the advantages of LED lighting compared with only HPS lighting. Treatment 4 (91 respondents) provided the advantages of LED lighting vs. natural sunlight only. Treatment 5 (104 respondents) provided only negative information regarding LED lighting. Treatment 6 (89 respondents) was a control group to which no information was provided.

After being randomly divided into treatment groups, respondents were instructed to act as though they were in an actual purchasing situation and reminded to keep their budget constraints in mind. Each product within a choice set was specified as a 2-ounce package of microgreens with varying attributes presented in the form of text describing the product's attributes.

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Table 1. Descriptive statistics of respondents from an online survey about light-emitting diode lighting and plant purchasing conducted in Jan 2021.

	Sample		US Census estimates[i]
Variable	Mean	*SD*	Mean
Mean income ($)	88,153	122,877	—
Median income ($)	62,500		65,712
Mean age	42.9	16.5	—
Median age	40		38.5
Children per household	0.82	1.16	—
Adults per household	2.13	0.92	—
Male	0.43	0.50	0.49
Caucasian	0.82	0.38	0.75
Location			
Metro	0.25	0.43	0.79
Suburban	0.53	0.50	—
Rural	0.22	0.41	0.21
Education			
High school or less	0.09	0.29	0.38
Some college	0.32	0.47	0.29
Bachelor's degree	0.34	0.47	0.20
Higher than bachelor's	0.25	0.43	0.13
Purchase of microgreens			
Yes (1 = yes)	0.55	0.50	—
No, not interested (1 = no, not interested)	0.14	0.35	—
No, but interested (1 = no, but interested)	0.31	0.46	—
No. of respondents	574		
No. of obs. (574 respondents × 12 sets × 4 products)	27,552		

[i] US Census Bureau (2010, 2019, 2021).

The attributes included in the choice experiment included price, lighting type, origin, production type, and purchase location (Table 3). The choice design included four prices ($6.49, $9.99, $13.49, and $16.99) per 2-ounce package to incorporate the dispersion of prices found in various retailers across the United States. A 2-ounce package was chosen after examining microgreens packaging at local (Georgia) grocery stores as well as website searches for microgreens on major grocery retailers throughout the United States. All attributes had been found to be important drivers of purchase decisions for other specialty crops. The price attribute levels were chosen based on market conditions at the time of the survey as found in the local and website grocery store searches. Microgreen origin specified the location of production, including "in your state," Mexico, and California. The "in your state" represented a local option. The use of the "California" label represented domestic products, and "Mexico" represented imported products. California was included because more than a third of US vegetable production is located within this state (California Department of Food and Agriculture 2022). Purchase location is where the microgreens could be purchased, either at a farmers' market or supermarket. The choice design also included organic as an attribute with the attribute levels being organic and nonorganic. There has been an increase in people purchasing organic goods, mainly believed to be caused by consumers being more aware of potential health issues and environmental concerns (Dumortier et al. 2017).

Of particular interest to this article, the choice design included three lighting types: sunlight, LED lights, and HPS. When growing plants with sunlight, they face daily and seasonal fluctuations of light composition. Other things that can affect light composition are location and weather (Fiorucci and Fankhauser 2017). HPS lighting has a distinct yellow color that limits its applications and has a power requirement of 35 to 1000 W. LED lighting can be seen in four colors: red, blue, green, and white. LED lights have a power requirement of 0.1 to 5 W (Gupta and Agarwal 2017).

The D-efficiency criterion was used to identify the number of choices set to be included in the choice experiment. As noted by Kuhfeld (2010), the D-efficiency criterion allows for the comparison of an orthogonal balanced design with the design efficiency. Each respondent was presented with 12 choice sets consisting of three choices and an option to choose "none of the above" (Fig. 1). Respondents chose the option they preferred within each choice set.

Sample characteristics. Overall, the sample was representative of the US population with respect to age, race, household income, and percent of urban/suburban respondents (Table 1). The sample's median age was 40 years compared with the estimated US median age of 38.5 (US Census Bureau 2019). Caucasians made up 82% of the sample compared with 76% of the US population (US Census Bureau 2021). The median household income for the sample was $62,500 compared with the estimated US median household income of $62,843 (US Census Bureau 2021). The sample matched the dispersion of residents throughout the United States, with 78% of our sample being urban/suburban compared with US census estimates of 79% (US Census Bureau 2010). The sample oversampled females, 43% of our sample being male compared with US census estimates of 49% (US Census Bureau 2021) because females have been shown to more likely be the primary shoppers within a household (Flagg et al. 2013; Wolfe 2013; Zepeda 2009). A caveat to the analysis is that although our sample appears to be representative of the United States, there is no method to ensure it is entirely representative. As a result, any generalizations outside of the sample are subject to this caveat.

Econometric model. To account for potential heterogeneity in consumer taste and preferences, a random parameters logit (RPL) model was used to estimate the model. This allows for some of the model parameters to be randomly distributed. The utility function is (Hensher et al. 2005)

$$U_{jsi} = \sum_{k=1}^{K} \beta_{ik} x_{jsik} + \varepsilon_{jsi} \quad [1]$$

where x_{jsik} are explanatory variables such as attributes in choice task i and β_{ik} and ε_{jsi} are unobserved and stochastic with ε_{jsi} representing independent and identically distributed errors (i.i.d.). Errors may not be i.i.d. for several reasons, but, most important for our model, is because of clustered data. However, the RPL model clusters on each consumer, limiting the potential for a violation of i.i.d. From each choice set, respondents choose the product that maximizes utility. To assess the impact of the informational treatments and state effects, interaction terms were added to the model such that utility could be defined as

$$\begin{aligned} U_{jsi} = {} & \beta_1 + \beta_2 \text{NoneAbove} + \beta_3 \text{FarmersMarket} \\ & + \beta_4 \text{Mexico} + \beta_5 \text{California} + \beta_6 \text{HPSLight} \\ & + \beta_7 \text{LEDLight} + \beta_8 \text{Organic} + \beta_9 \text{MGPrice} \\ & + \beta_{10} \text{LED*T1} + \beta_{11} \text{LED*T2} + \beta_{12} \text{LED*T3} \\ & + \beta_{13} \text{LED*T4} + \beta_{14} \text{LED*T5} + \varepsilon_{jsi} \quad [2] \end{aligned}$$

where NoneAbove is a one when a respondent chose "none of the above" option and zero if another product option was chosen. FarmersMarket, Mexico, California, HPSLight, LEDlight, and Organic represent the attribute levels in the choice experiment and take a value of one when the level was shown to a respondent and a zero when it was not shown to the respondent. MGPrice is the continuous price level. LED*T1, LED*T2, LED*T3, LED*T4, and LED*T5 represent the interaction of the LED attribute with the information treatments (Table 2). β_1–β_{14} represent the increase/decrease in utility associated with each attribute level.

The interactions between LED lighting and the informational treatment groups are a main focus of the results discussion. WTP was calculated for each attribute without an interaction as

$$WTP_{ik} = -\left(\frac{\beta_{ik}}{\beta_p}\right) \quad [3]$$

where β_{ik} is the coefficient for the attribute level of interest and β_p is the coefficient for price (Louviere et al. 2000). For attribute levels with interactions, total WTP effect was calculated as

$$WTP_{ik} = -\left(\frac{\beta_{ik} + \beta_{(n)}(D)}{\beta_p}\right) \quad [4]$$

where β_{ik} is the coefficient for the k^{th} attribute level, plus $\beta_{(n)}$ is the coefficient value of the

Table 2. Information treatments randomly provided to respondents from an online survey about LED lighting and plant purchasing conducted in Jan 2021.

Treatment 1: all information	Treatment 2: all LED positive information	Treatment 3: alternative information	Treatment 4: sunlight information	Treatment 5: LED negative information	Treatment 6: control (no information)
Typical lighting sources in greenhouses	Typical lighting sources in greenhouses	Typical lighting sources in greenhouses	Typical lighting sources in greenhouses	Typical lighting sources in greenhouses	Typical lighting sources in greenhouses
Natural sunlight	Natural sunlight	Natural sunlight	Natural sunlight	Natural sunlight	Natural sunlight
LED	LED	LED	LED	LED	LED
HPS	HPS	HPS	HPS	HPS	HPS
LED lighting vs. HPS					
LED lights have better energy efficiency (HPS require a lot more electricity)	LED lights have better energy efficiency (HPS require a lot more electricity)	LED lights have better energy efficiency (HPS require a lot more electricity)			
LED lights produce fewer greenhouse gases	LED lights produce fewer greenhouse gases	LED lights produce fewer greenhouse gases			
LED lights bulbs do not have to be changed as often	LED lights bulbs do not have to be changed as often	LED lights bulbs do not have to be changed as often			
LED lights do not contain mercury (potential health risk in production)	LED lights do not contain mercury (potential health risk in production)	LED lights do not contain mercury (potential health risk in production)			
LED lighting vs. sunlight					
LED lighting allows for year-round production and for production in areas where it would not be possible	LED lighting allows for year-round production and for production in areas where it would not be possible		LED lighting allows for year-round production and for production in areas where it would not be possible		
LED lighting may contain large amounts of copper (potential environmental threat), nickel (potential health risk during production), and lead (potential health risk during production)				LED lighting may contain large amounts of copper (potential environmental threat), nickel (potential health risk during production), and lead (potential health risk during production)	

HPS = high-pressure sodium; LED = light-emitting diode.

n^{th} interaction that corresponds to the k^{th} attribute level times the interacted dummy. Standard errors for the WTP estimates were calculated via Delta Method. WTP values for each treatment were compared by examining overlap with confidence intervals.

Results and Discussion

Results from the RPL model are presented in Table 4. The price attribute has a significant negative sign (–0.054), which is consistent with economic theory (Varian 2002, p. 147–151). This indicates that the consumers in the sample prefer lower prices to high prices. The none of the above choice has a significant negative coefficient (–4.265), which shows that the consumer would receive disutility by making this selection.

Lighting type

The results for lighting type show HPS lighting has a significantly negative coefficient (–0.144) compared with sunlight. However, there is no statistical difference between LED lighting and sunlight. Only treatment 5 significantly affects consumer preferences (–0.253) as all other treatments have an insignificant effect. Treatment 5 only offers negative information about LED lighting, which implies that if producers want to use LED lighting, controlling the perception of LED lighting could be important. Importantly, negative information has a larger effect than positive information in absolute value terms. Additionally, it has a larger effect than positive and negative information combined in absolute value terms.

From a production perspective, there is a preference for microgreens grown under LED lighting compared with HPS though negative information (e.g., negative media) would offset any consumer preference for microgreens produced under LED lighting. Although there is a preference gain for LED lighting compared with HPS, the gain is most likely not worth firms switching solely due to the preference gain. However, for firms considering LED lighting the preference gain is a benefit that needs to be considered in the lighting decision.

Table 3. Attributes and levels included in the choice experiment given in an online survey about LED lighting and plant purchasing conducted in Jan 2021.

Price ($)	Lighting type	Location produced	Production type	Purchase location
6.49	Natural sunlight	In your state	Organic	Farmer's market
9.99	LED lights	Mexico	Not organic	Supermarket
13.49	HPS	California		
16.99				

HPS = high pressure sodium; LED = light-emitting diode.

Purchase location, location produced, and production type

Consumers would rather purchase their microgreens at a farmers' market (0.403) than at the supermarket. Consumers also have apreference for microgreens grown in their state compared with California grown (–0.150) microgreens. This could be due to

Assume you are purchasing a 2-ounce package of fresh microgreens, which option would you purchase?

- Supermarket for $16.99 grown in your state using LED lighting (1)
- Farmers market for $13.49 organically grown in your state using LED lighting (2)
- Supermarket for $16.99 grown in Mexico using HPS lighting (3)
- None of the above (4)

Fig. 1. Example of a choice set used in an online survey about light-emitting diode (LED) lighting and plant purchasing conducted in Jan 2021.

the negative connotation that California has for many people. The negative preference for California specialty crops is not new; negative preference have been found for turfgrass (Campbell et al. 2021), tomatoes (Berning and Campbell 2021), and mushrooms (Chakrabarti et al. 2019). Microgreens that are grown organically have a negative coefficient (–0.203). This is interesting because more people are purchasing organic goods (Dumortier et al. 2017). Growth in the consumption of organic goods likely comes from concerns about ecological sustainability and ethical choice considerations (Tandon et al. 2020). The negative effect could be the result of the short production time associated with microgreens: a shorter growth window may result in the perception of more sustainability without the need for organic production practices.

Table 4. Random parameter logit (RPL) model results from an online survey about LED lighting and plant purchasing conducted in Jan 2021.

Variable	RPL coefficients	*P* value
Means of the random parameters in utility functions		
None of the above	**–4.265**[i]	0.000
Purchase location		
Farmers' market	**0.403**	0.000
Supermarket	—[ii]	—
Location produced		
Mexico	0.019	0.651
California	−0.150	0.003
In your state	—	—
Lighting type		
HPS	**–0.144**	0.001
LED	0.147	0.111
Sunlight	—	—
Production type		
Organic	**–0.203**	0.000
Not organic	—	—
Nonrandom parameters in the utility function		
Price	**–0.054**	0.000
LED lighting × treatment interaction		
LED × treatment 1	−0.176	0.156
LED × treatment 2	−0.157	0.183
LED × treatment 3	−0.088	0.477
LED × treatment 4	−0.147	0.238
LED × treatment 5	**–0.253**	0.035
Derived standard deviations of parameter distributions		
None of the above	**2.301**	0.000
Farmers market	**0.128**	0.030
Mexico	**0.337**	0.000
California	**0.484**	0.000
Organic	**0.310**	0.000
HPS lighting	**0.434**	0.000
LED lighting	**0.683**	0.000
Log likelihood function: −8,074.574		
χ^2: 2,948.442		
Significance level: 0.000		
McFadden pseudo R^2: 0.154		
Akaike information criterion = 16,231.500		
Observations (no. respondents): 574		

[i] Bold text indicates significance at the 10% level.

[ii] Dash (—) indicates that the variable was the base category.

HPS = high-pressure sodium; LED = light-emitting diode.

Treatment interaction

Marginal WTP: attributes. Several attributes have statistically significant willingness to pay values. If the microgreens are sold in a farmers' market, they experience a $7.52 increase in WTP per 2-ounce package (Table 5). The discount associated with microgreens being produced in California is $2.79. There was no premium/discount associated with microgreens produced in one's home state vs. Mexico. Microgreens that are produced organically experience a $3.80 discount in WTP. Microgreens grown with HPS lighting experience a $2.69 discount in WTP compared with those grown with sunlight, whereas there is no statistical difference in WTP for LEDs compared with microgreens grown in the sunlight. This seemingly implies that consumers view LED lighting and sunlight similarly in some fashion, whether it is a similar environmental impact, production efficiency, or some other reason.

Marginal WTP: treatments. Only one information treatment has a significant effect on WTP (Table 6). Treatment 5, which is the negative information-only treatment, results in a $4.72 decrease in WTP compared with the control (no information). However, this negative effect is mitigated in the total WTP calculation by the positive coefficient associated with LED lighting. This finding should cause some concern for greenhouses that produce microgreens with LED lighting or may be considering it. These results indicate that negative information could push consumers toward microgreens produced with natural sunlight. Negative information could come from non-LED using producers providing negative information to consumers or from media picking up on potential negative impacts associated with LED lighting. Although not examined in this study, negative information (associated with light pollution from LED using greenhouses) has already been a topic in many studies (Martindale 2019; Meadows 2019). The other informational treatments, whether only positive or positive/negative, do not have a significant effect on WTP.

Conclusion

As the use of LED lights becomes more common, it is important for producers and retailers to identify and understand how information impacts consumer preference and WTP. We find that negative information, like that given in treatment 5, can decrease preferences for microgreens grown with LED lighting. For marketers of microgreens, it is important to know how to counter this negative information. Other negative information about LED lights that is important to address is how LED lights have increased light pollution. Some popular press articles suggest that the new excess in light is endangering ecosystems and altering humans' biochemical rhythms (Drake 2021). If LED lighting gets a negative image due to light pollution in neighborhoods, this could adversely influence preference for microgreens

Table 5. Willingness to pay estimates calculated from the random parameter logit model (RPL) from an online survey about LED lighting and plant purchasing conducted in Jan 2021.

Variable	Willingness to pay ($)	P value	Confidence interval Lower limit	Confidence interval Upper limit
Purchase location				
Farmers' market	**7.515**[i]	0.000	5.641	9.390
Supermarket	—[ii]	—	—	—
Location produced				
Mexico	0.354	0.654	−1.192	1.901
California	−2.794	0.002	−4.556	−1.032
Your state	—	—	—	—
Production type				
Organic	**−3.800**	0.000	−5.151	−2.240
Nonorganic	—	—	—	—
Lighting type				
HPS lighting	**−2.690**	0.001	−4.262	−1.118
LED lighting	2.738	0.117	−0.682	6.158
Sunlight	—	—	—	—

[i] Bold text indicates significance at the 10% level.

[ii] Dash (—) indicates that the variable was the base category.

LED = light-emitting diode.

(and potentially other vegetables/fruits) produced under LED lights. Our results give validity to consumers' turning on LED lighting given the significant impact of negative information of preference within the results.

Another aspect that is important to understand is that microgreens sold in a farmers' market have a much high WTP than microgreens sold in a supermarket. This can have an effect on pricing seen in these different locations. It is also seen that organic microgreens are not preferred to conventional microgreens. This information can be beneficial to farmers deciding what production practices to use. Finally, we see that microgreens grown in California are not preferred to microgreens grown in Mexico or locally. This may help a producer decide whether microgreens are worth producing in their area.

The information gained from this study can help producers better understand if they should produce microgreens, and if they do, where they should focus their market and what type of labels should be considered. This study also provides a better understanding of what the use of LED lights could mean for their production and marketing.

Table 6. Decomposing the WTP interaction effects calculated from the random parameter logit model from an online survey about LED lighting and plant purchasing conducted in Jan 2021.

Variable	LED effect $-(\beta_{LED}/\beta_{price})$	Information effect $-(\beta_{Treatment*LED}/\beta_{price})$	Total effect $-[(\beta_{LED}+\beta_{Treatment*LED})/\beta_{price}]$
LED, treatment 1: WTP	2.738	−3.291	−0.553
P value	0.117	0.160	0.746
Lower CI	−0.682	−7.878	−3.895
Upper CI	6.158	1.295	2.788
LED, treatment 2: WTP	2.738	−2.931	−0.193
P value	0.117	0.186	0.902
Lower CI	−0.682	−7.274	−3.254
Upper CI	6.158	1.412	2.868
LED, treatment 3: WTP	2.738	−1.641	1.097
P value	0.117	0.478	0.514
Lower CI	−0.682	−6.172	−2.201
Upper CI	6.158	2.891	4.400
LED, treatment 4: WTP	2.738	−2.741	−0.003
P value	0.117	0.241	0.999
Lower CI	−0.682	−7.321	−3.347
Upper CI	6.158	1.838	3.340
LED, treatment 5: WTP	2.738	**−4.718**	**−1.980**
P value	0.117	0.038	0.216
Lower CI	−0.682	−7.321	−5.114
Upper CI	6.158	−0.263	1.155

LED = light-emitting diode; WTP = willingness to pay; CI = confidence interval.

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