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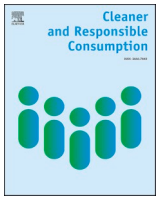

Changes in appearance during the spoilage process of fruits and vegetables: Implications for consumer use and disposal

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ABSTRACT

People waste a lot of food, especially at the consumption stage in consumer households. Despite the urgency of this topic, little is known about how consumers use visual inspection to decide to throw away fruits and vegetables at different stages of ripening and spoilage. We presented 366 US consumers with images of a banana, mango, cucumber, and avocado in 5 stages of decay in an online study and we determined how signs of decay affected participants' consumption, preparation and disposal behaviors. As expected, product attractiveness, freshness, healthiness, and nutritiousness decreased, while the degree of decay, overripeness, and disgust increased over time. The number of people willing to consume the product was linearly related to the perceived proportion of the product affected by decay, while the number of people wanting to cut off bad parts was highest when about 40% of the product was judged to be affected. As time went on, the banana was cooked and mashed more often, while the cucumber was peeled more often. As growing, ripening and decay differ considerably between agricultural products, it is important to take sensory and preparation differences into account when investigating consumption and disposal behaviors.

1. Introduction

Avoiding food waste in consumer households is important on the path to a more sustainable society. Before a food product enters a consumer's household, a lot of resources, energy and time have been invested in the product. Nonetheless, people tend to waste a lot of food, particularly in the household context (Stenmarck et al., 2016) as the unintended result of a set of entangled daily routines, including meal planning, grocery shopping and food storing (Dobernig and Schanes, 2019). Since many people buy food products in advance and store them for a while before consuming them (Evans, 2012), being able to assess the quality of stored food products is an important capability that helps avoid safety hazards and can reduce the amount of food that is unnecessarily thrown away.

In the present paper, we investigate consumers' decisions to prepare and eat a product or throw it away based on its visual appearance. We focus mainly on whole fresh fruits and vegetables because these products are sold without expiration dates and consumers mainly rely on their senses to evaluate product quality. Whereas other studies of the food spoilage process typically focus on instrumental measures and microbiological cell counts (e.g., Steele, 2004), we focus on consumer perception and how this affects people's decisions regarding preparation and consumption.

1.1. Focus on fresh fruits and vegetables

Many consumers rely partly on the expiration dates that manufacturers indicate on food packages when deciding whether to eat a food product (Parizeau et al., 2015). However, expiration dates are often conservative estimates and can result in discarding perfectly edible food (Davenport et al., 2019; Karanth et al., 2023; Newsome et al., 2014). On the other hand, expiration dates are not infallible indicators of food safety, because they cannot guarantee temperature control throughout the supply chain and in the home. Some people use the dates as the basis for determining product storage time, although the dates no longer apply after opening a package (Terpstra et al., 2005). Therefore, the sensory inspection of food products remains a valuable procedure to determine whether a person can still consume a food item or not.

This certainly applies to fresh produce, for which no advisory dates are provided. The storage of fresh produce is complex as different products may have different requirements for optimal storage, which not only involves temperature but can also depend on humidity, amount of light, or the presence of other foods (Watkins and Nock, 2012). As a consequence, fruits and vegetables are often stored incorrectly at

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consumers' households (Terpstra et al., 2005). In addition, many people forget how long a food remains in the refrigerator and may not be sufficiently aware of the appropriate storage period (Terpstra et al., 2005).

Consumers are likely to associate spots of microorganisms on food with contamination and may try to protect themselves from potential health risks (Schaller and Park, 2011; Waitt and Phillips, 2016). When people observe such spots, they may immediately assume that the entire food item is spoiled and unsafe for consumption. According to the U.S. Department of Agriculture USDA, soft fruits and vegetables with high moisture content can be contaminated below the surface and should be discarded in their entirety if moldy. On the other hand, molds in firm, low-moisture fruits and vegetables have a harder time penetrating the food. In that case, small mold spots can be cut out with a one-inch diameter from the spot (USDA/FSIS, 2013). However, we are unsure to what extent consumers are aware of these guidelines. In addition, these guidelines generalize over products and may be too conservative for some products.

1.2. Product quality at purchase versus consumption

External food quality is the main determinant of consumers' choices at the point of purchase. External quality plays a central role in the definition of agricultural quality standards, which are mainly based on morphometric attributes, product integrity, and lack of external appearance defects (De Hooge et al., 2018; Kyriacou and Rouphael, 2018). Among consumers and experts alike, blemishes and odd shapes are generally regarded as minor defects, while signs of rot or mold, or where the skin has been cut, are considered major quality defects (Jaeger et al., 2018a). At the point-of-purchase, consumers are critical of quality defects (Aschemann-Witzel et al., 2017); they desire optimal products and avoid products with defects (De Hooge et al., 2017; Jaeger et al., 2018b) because buying suboptimal products may be risky (Castagna et al., 2021). Consumer-based sensory methods have been found to be very informative for determining product shelf-life (Giménez et al., 2012). At the point-of-consumption acceptance of suboptimal products is higher than at the point-of-purchase (Ares et al., 2008; Jaeger et al., 2018b). Apparently, the process of selecting food in a supermarket and storing it at home will lead to consumers taking ownership of some of the decline in quality (Campbell et al., 2009).

1.3. From sensory perception to visual appearance

Although consumers may involve the product's smell, texture and taste when evaluating the quality of fresh fruits and vegetables (Moskowitz, 1995), most studies indicate that judgments on whether to discard food products are mostly based on visual impressions (Campbell et al., 2009; Dusoruth and Peterson, 2020; Parizeau et al., 2015). Factors include looking rotten, withered, wrinkly, bruises, and spots (Campbell et al., 2009). This reliance on vision is not surprising, given that vision plays a dominant role in many interactions with products. While the role of taste and smell may be more important when eating food (Schifferstein, 2006), visual impressions may be dominant in deciding whether a food is edible because tasting food of questionable quality can pose a health hazard. Hence, in this study we focus on the visual appearance of foods, and we determine its effects on expected sensory properties in other modalities (Schifferstein and Cleiren, 2005).

In the case of fruits and vegetables, the color of the product may give clues about the state of ripening, and deterioration and skin irregularities (e.g., spots, bumps) may indicate areas that are damaged. For instance, many unripe fruits have a green color, hard texture, and will taste sour or bitter. While they ripen their color changes to yellow, orange, red or blue, and the fruit will become softer and sweeter over time (Campbell et al., 2009; Kapoor et al., 2022; Lee et al., 2013; Prasanna et al., 2007; Tucker and Grierson, 2013). When the food deteriorates, the product may lose its firmness or shrink (Brahem et al., 2017; Brummell et al., 2004) and may develop off-flavors (Whitaker, 2008).

1.4. Relating visual appearance to consumer behavior

Visual signs of food spoilage, such as mold or shriveling, reduce consumers' willingness to touch and try food products (Coulthard et al., 2022). Discoloration plays a significant role in product shelf life and people's tendency to discard produce (Ares et al., 2008; Zhou et al., 2004). Browning may affect sensory properties and decrease nutritional value (Moon et al., 2020). Products with brown spots are judged as less attractive, healthy, and fresh (Schifferstein et al., 2019) and evoke associations such as bad taste, unsafe to eat, to use in cooking or to be discarded (De Hooge et al., 2017). Although consumers may not eat these partially spoiled products raw, they may find alternative uses: they can cut off any bad parts and use them for cooking, baking, stewing, mashing, making soup or juicing (Campbell et al., 2009; Schifferstein et al., 2019; Waitt and Phillips, 2016).

To gain more insight into the spoilage process and its consequences for consumer behavior, we are interested in the shape of the curve that shows how perceptual attributes change over time. In microbiological studies, the logarithm of cell number is commonly plotted as a function of time, yielding a sigmoidal curve (e.g., Dalgaard, 1995; Huis in't Veld, 1996). Jaeger et al. (2018b) presented the number of consumers who would throw away (part of) apples as a function of the size of the affected area where browning was visible when a bite was taken. This analysis also produced sigmoidal curves and showed that about half of the consumers would throw away at least part of the apple with a small, affected area (8%), while they would throw away the entire apple when 35% was affected. We are curious to see what similar functions look like for other types of spoilage and behavior.

Besides the rational aspects of assessing whether a product is safe, edible, and pleasant to eat, consumers may also respond emotionally to a product that shows signs of decay. The quality of food is essential to survival and signs of decay are likely to provoke an alarm response (Becker et al., 2016). Disgust is a basic human emotion (Ekman, 1999) that prevents close contact with poisons and pathogens as it decreases the appetite for food and is commonly referred to as a guardian of the mouth (Motoki and Sugiura, 2018). Disgust acts as a protective, disease-avoidance mechanism (Oaten et al., 2009), helping individuals avoid potentially harmful or spoiled foods. It is closely associated with feeding behavior and can evoke instantaneous bodily responses as well as more cognitive, ethical/moral deliberations (Kelly, 2011; Rozin and Fallon, 1987). The use of visual images is an engaging way to activate a mental representation of interacting with a decaying product as a source of disgust (Ammann et al., 2018).

1.5. The present study

In the present study, we examine how changes in the appearance of products at different stages of ripening and spoilage influence consumers' perceptions and behavioral intentions regarding consumption, preparation and disposal. Although such processes seem obvious because people know them from everyday life, the academic literature on the subject is limited, which hinders our understanding. We describe processes for different products, to gain insight in the variety of considerations when deciding whether to eat or discard a product.

Because we are studying spoilage, we expect the products to deteriorate over time. As time progresses, we expect that people will notice that their freshness, attractiveness, healthiness, and nutritiousness decline. Moreover, over time, more people are likely to conclude that the products are overripe, decaying, and find them disgusting. How the expected sensory properties change over time likely depends on the properties of the fresh product. Nonetheless, because many fresh products are appreciated for their sweetness and their firm texture, the undesirable tastes that develop over time are likely to include sourness or bitterness, and the products become more flexible as they lose their tone. In some cases, juiciness may increase over time, while other products may dry out and become tough. We would like to determine how these

product quality attributes and sensory properties change over time and to what extent patterns differ between products.

We expect the proportion of the product estimated to be affected by decay to increase over time. Furthermore, the percentage of participants who (do not) want to consume the product is likely to decrease (increase) over time. However, the exact shape of these relationships is unknown and may be product specific. We are also interested in the alternative strategies people employ to still make use of the products they purchased, even though they are withering and showing signs of decay. This relationship may follow an inverted U-shape: while the percentage of people cutting off parts is likely to increase at first – as the degree of spoilage increases –, it is likely to diminish when too much of the product is affected and the consumer throws it away.

Together, these new insights will improve our understanding of consumers' subjective experience of product spoilage, its implications for their behavior, and its consequences for the amount of food waste generated.

2. Method

Participants were shown images of two fruits (banana, mango) and two vegetables (cucumber, avocado) in different stages of decay. They evaluated the quality of the products in each image, their expected sensory properties, and indicated how they would prepare it and whether they would eat it or not.

2.1. Participants

The questionnaire was filled out by 366 participants recruited from the Prolific database, who were born and living in the USA. 57% were female, 42% male and 1% other or unknown. Ages ranged from 18 to 89, with mean 38 years. 66% were Caucasian, 10% African American, 8% Asian, 9% mixed and 7% other or unknown. Each participant rated one of the five variants for each of four different products (71–74 responses per stimulus). Participants received financial remuneration according to standard Prolific rates. The research proposal was approved by the Human Research Ethics Committee of TU Delft under ID number 1332.

2.2. Stimuli

We studied spoilage for products that can be bought fresh and unpacked: two types of fruit (banana and mango) and two vegetables (cucumber and avocado). Two of these have a high moisture content (mango and cucumber) and the other two have a low moisture content (banana and avocado). Images were derived from time lapse videos of decaying fruits and vegetables found on the Internet (stock.adobe.com and time-laps-footage.com). We removed irrelevant details from the images, but kept the shadows to ensure a natural product presentation and avoid the impression of floating (e.g., see Becker et al., 2016). For each food product five images were selected. The first image was always of a fresh product and the last of a product that we found unfit for consumption. The three intermediate images have been selected to show different types and stages of decay, such as discoloration, the appearance of brown spots, or the appearance of mold. The distribution of images over the time lapse videos varied substantially, as the visual signs of decay and the speed at which they appear vary widely over products. For banana the images were taken at 0, 3, 4, 5, and 8 s; for mango they occurred at 0, 7, 16, 20 and 24 s; for cucumber at 0, 2, 4, 7, and 25 s; and for avocado at 0, 6, 12, 24, and 27 s in the videos (see Table 1). Because the time lapse videos have elevated speeds that vary by product, only the relative values of these time indications have any meaning and we rescaled them to values between 0 and 100 for presentation purposes.

2.3. Procedure

After reading instructions and providing informed consent, the participants rated the extent to which they found various foods disgusting, including the 4 target products (banana, mango, cucumber, avocado) and 4 control products (mussels, beef steak, blue cheese, brussels sprouts). As we did not expect participants to have strong disgust responses to the target products on average, we included control products that were more likely to evoke an aversive response to help frame the response scale (Parducci, 1974). The 5 response categories were "not disgusting at all – slightly disgusting – moderately disgusting – very disgusting – extremely disgusting". Participants could also indicate if they did not know the product.

Then they were presented with one of the images and they rated their degree of disgust for consuming the food in the image on the same 5-point scale as above. Subsequently, they indicated to what extent they agreed or disagreed with statements on the quality and attractiveness of the product on a 7-point scale: "I think this product is … (attractive/fresh/healthy/nutritious/overripe)". The 7-point scale contained verbal anchors for "strongly disagree-disagree-somewhat disagree-neither agree nor disagree-somewhat agree-agree-strongly agree". Then they rated the expected sensory qualities of the products "If I try this product, I think it will be …" on six 5-point bipolar scales with end anchors "not sweet/bitter/sour at all – very sweet/bitter/sour", "dry-juicy", "firm-flexible", and "soft-hard". These cover the items that Campbell et al. (2009) used, where we used hardness and flexibility as measures of firmness and added bitterness to reflect any signs of unripeness or off-flavors. An overview of the items is given in Table 2.

After the image was presented again, participants rated the perceived

Table 1
Images of the 4 products at five different points in time. Images were obtained from time lapse videos from stock.adobe.com (banana) and time-lapse-footage.com (mango, cucumber, avocado).

	1	2	3	4	5
Banana					
Mango					
Cucumber					
Avocado					

Table 2
Overview of questionnaire items.

Concept	# scale points	Left anchor	Right anchor
Emotional responses			
Disgust	5	Not disgusting at all	Extremely disgusting
Product attributes and benefits			
Attractive	7	Strongly disagree	Strongly agree
Fresh	7	Strongly disagree	Strongly agree
Healthy	7	Strongly disagree	Strongly agree
Nutritious	7	Strongly disagree	Strongly agree
Overripe	7	Strongly disagree	Strongly agree
Expected sensory qualities			
Sweet	5	Not sweet at all	Very sweet
Bitter	5	Not bitter at all	Very bitter
Sour	5	Not sour at all	Very sour
Juicy	5	Dry	Juicy
Flexible	5	Firm	Flexible
Hard	5	Soft	Hard
Decay			
Degree of decay	100	Nothing, it is fresh	The whole product has decayed
Usual consumption			
Consumption	5	Never	Daily

degree of decay and the consequences for their consumption behavior. They used a slider scale (0–100) to indicate "How much of this product is affected by decay in your opinion (0 = nothing, it is all fresh; 100 = the whole product has decayed)". "Would you consider eating this product?" was answered with options "yes, definitely; yes, but only after cutting off part of it; I might, but I first need to peel it to decide; definitely not". All participants who would or might consume the product then indicated what they would do before consuming the product by selecting one or more of the following options: "peel it, wash it, cut it into pieces, cook it, mash it, cut off any bad parts" or "nothing needs to be done". Then they indicated how often they usually ate the product on a scale with five categories: "never, about 1–2 times a month, about 1–2 times a week, about 4–5 times a week, daily". This procedure was repeated for each of the 4 products. Which of the 5 images they saw for each product and the order of the four products was determined by chance. Throughout the questionnaire, items belonging to a single block of questions were presented in random order that differed between participants. Finally, participants reported gender, age, and the countries where they were born and where they currently lived.

2.4. Data analyses

The first analyses focused on how the perception of product characteristics changed over time for the different products. To identify trends over time, we calculated Spearman rank correlations coefficients between responses and the five moments in time. These analyses were performed on individual data (n = 71–74 per stimulus). To investigate how the perceived degree of decay affected subsequent behavior, we performed regression analyses to fit polynomial functions predicting the type of response (e.g., to consume or not, or to cut off bad parts) based on the perceived proportion of decay. Because each participant evaluated only one variant per product, these analyses were performed on group means (N = 20). In addition, for those willing to consume the product, we calculated the percentage of participants who used alternative strategies to use the product (e.g., mashing, cooking, peeling) at the different time points. In this case, the sample size varied per stimulus (n ≤ 74).

3. Results

3.1. Consumption frequencies and pre-experimental disgust

Fig. 1 shows the consumption frequencies for the different products. They show that the banana is eaten most often, followed by the cucumber and the avocado, while the mango is eaten least often. The Chi^2 test of independence comparing the four products was significant [$Chi^2(12) = 227.1$, $p < 0.001$]. In paired comparisons of food products with Bonferroni correction, only the difference between cucumber and avocado did not reach significance in the Chi^2 test [$p > 0.20$].

We carried out several checks to determine whether the groups of participants were comparable at different time points. For banana, cucumber, and avocado, the numbers of participants who indicated that they "never" consumed the product were equivalent at the five time points, but for mango the number of people who did not eat mango was smaller at t = 0 than in the other four groups (19% versus 31–35%).

Although the number of participants that indicated that they "never" consumed a particular product was substantial, especially for mango, this does not imply that they have no experience with the product. There can be multiple reasons why they do not consume it regularly: They may not like it, it may not be available in their local store, they can find them too expensive, and so on. Consequently, they can have a reliable opinion on the product, even though they are not regular consumers. To check the effect of excluding consumers who did not regularly consume the product, we analyzed the data for mango without the people who said they "never" consumed the product and compared them to the whole group. For the means on the quality and sensory attributes this resulted in an average absolute deviation of 0.09 in mean (range 0.00–0.30). Because such deviations would hardly be noticeable in the Figures below, we decided to retain all participants in the subsequent analyses.

Before seeing the pictures, participants rated the disgust they generally perceived for the four target foods. These mean disgust ratings were similar for banana (1.29), mango (1.27) and cucumber (1.21), but a bit higher for avocado (1.45). Repeated measures ANOVA found a significant difference between the food products [$F(3,360) = 8.8$, $p < 0.001$], as the ratings for avocado were higher than for the three other products in paired comparisons with Bonferroni correction [$p < 0.01$].

3.2. Perception of product quality attributes and sensory properties over time

Fig. 2 shows how the five images for each of the four foods were experienced as the products changed over time. We determined for each variable whether they increased or decreased over time by calculating

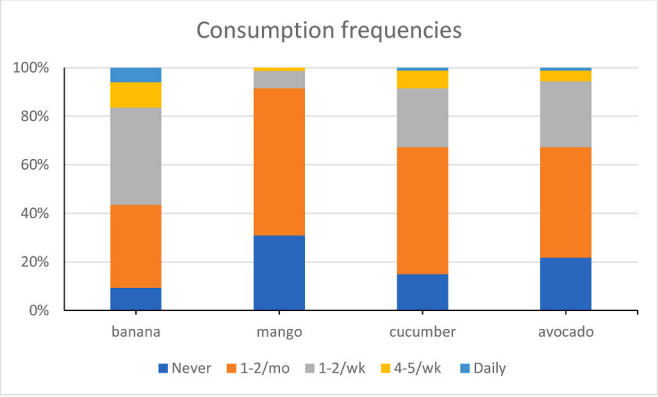

Fig. 1. Reported consumption frequencies for the 4 target products (mo = month, wk = week).

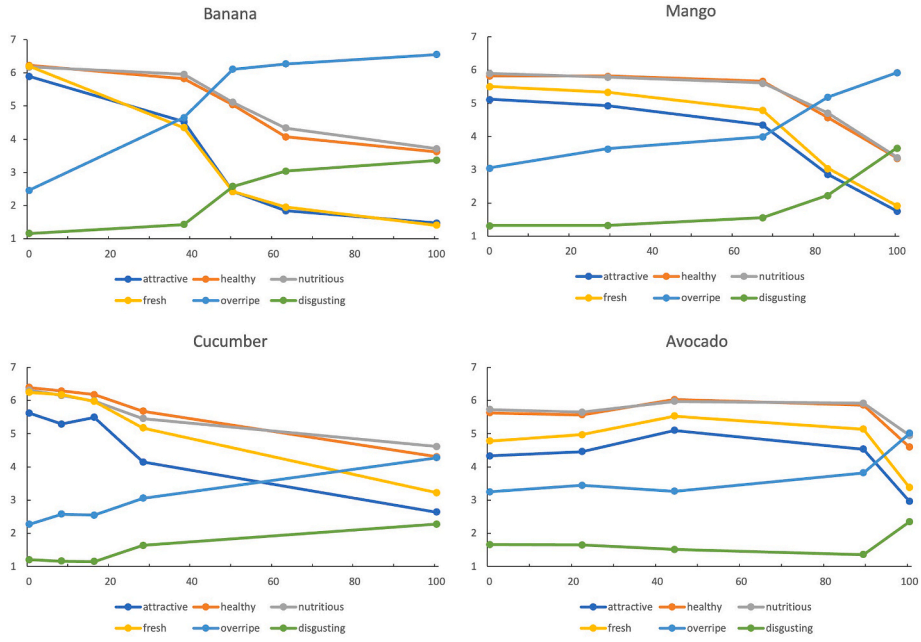

Fig. 2. Mean responses on experiential dimensions for the 4 products at different points in time. Please note that disgust was measured on a 5-point scale, the other attributes on a 7-point scale.

the Spearman rank correlation with the moment in time (see Appendix A). As expected, for all products attractiveness, freshness, healthiness and nutritiousness decreased, while the degree of overripeness and disgust increased. However, the degrees of change differed between products: the absolute sizes of the coefficients for avocado and -to a lesser extent- cucumber seemed to be lower than those for banana and mango. For avocado, attractiveness and healthiness seemed to increase a bit over the first three time points before it started to decrease. This might suggest that the avocado on the first pictures was perceived as unripe.

Fig. 3 shows the expected changes in sensory properties over time. As each product has a different sensory profile, the ratings for expected sensory properties started at different levels for the different products. However, some trends were evident for each product: hardness ratings decreased, and flexibility ratings increased over time for all products. In addition, for three products (banana, mango, cucumber) bitterness and sourness ratings increased over time. The trends for juiciness and sweetness differed between products: while expected juiciness decreased for mango and cucumber, it increased for banana. Expected sweetness decreased for mango but was quite constant for the other products (see Appendix A).

3.3. *Percentage of product affected and the decision to eat*

We analyzed the percentage of participants who indicated if and under what conditions they would like to consume the product (yes –

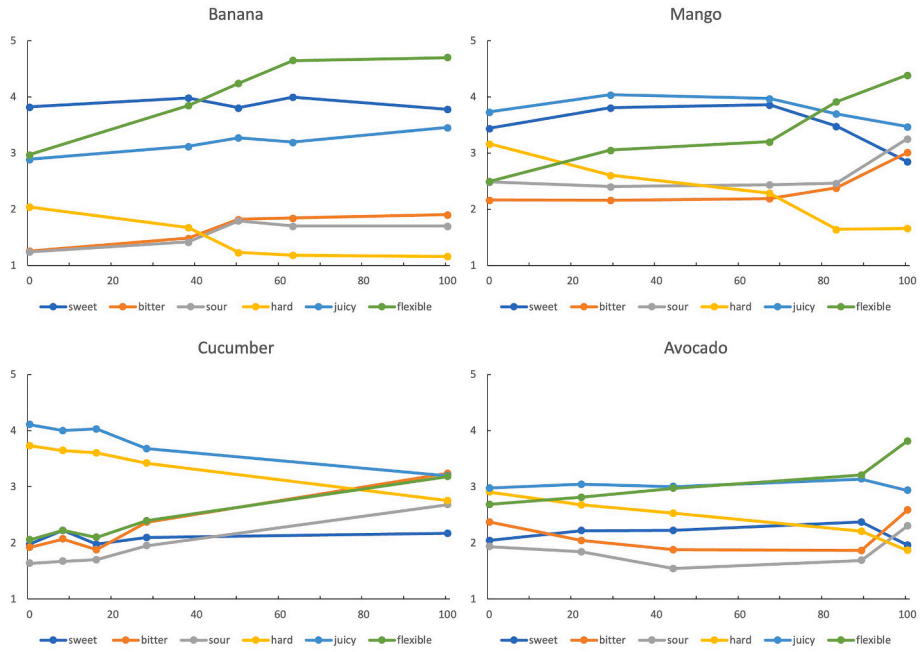

Fig. 3. Mean responses for expected sensory properties for the 4 products at different points in time.

after cutting off bad parts – would first need to peel it - no). As the dependent variable (the choice for one of the response categories) is nominal, we tested whether the distribution of responses was similar for the five moments in time. This was not the case for banana [$Chi^2(12) = 203.5$, $p < 0.001$], mango [$Chi^2(12) = 136.4$, $p < 0.001$], cucumber [$Chi^2(12) = 115.7$, $p < 0.001$], nor avocado [$Chi^2(12) = 59.5$, $p < 0.001$]. As the decision to peel the product first would be logical for banana, mango, and avocado before consumption, we decided to add these responses to the "yes" category for all four products. Only for the cucumber, the decision to peel the product could be a strategy to deal with reduced product quality. The group of participants who wanted to peel the cucumber varied from 5 to 11 % for the first three observations and increased to 20% at $t = 28$ and 35% at $t = 100$. In all cases, peeling the product implies that the participants will consume the product and, therefore, they can be added to the "yes" category. These percentages are shown in Fig. 4, together with the estimated degree of decay, as a function of the different time points.

As expected, the degree of decay increased over time. For banana, mango and cucumber, the number of people who would definitely consider eating this product decreased approximately monotonically over time. For the avocado this number first increased, before it decreased at a later point in time. We see approximately opposite patterns for the percentage of participants who would definitely not eat the product. These trends are in line with the attractiveness ratings in Fig. 2 and suggest that the avocado on $t = 0$ and $t = 22$ might still be unripe.

The number of people who would eat the product after cutting off bad parts was fairly low in all cases. For the banana it reached its peak near $t = 50$, when 55% of the banana was judged to be affected by decay. As the number of blemishes increased further, more and more people probably decided to throw away the product. For the mango, the lowest percentage of people cutting off bad parts was found at $t = 100$, when 76% was allegedly affected by decay. For the avocado, we also observed the highest value at $t = 100$, when 45% was affected by decay and people might still be reluctant to throw the product away.

We investigated how the perceived degree of decay may have affected participants' decisions to eat the product, cut off bad parts, or discard it. We performed a set of polynomial regression analyses ($N = 4$ products x 5 time points = 20) with the mean perceived degree of decay as explanatory variable and the different proportions of participants as dependent variables. This showed that for the proportion of people that does (not) consume the product, the relationship is approximately linear, as the quadratic terms are not statistically significant (Table 3). For the proportion who cut off bad parts, we found an equation with a significant quadratic term, indicating an inverted U-shape (Table 3 and Fig. 5). The estimated curve reached its peak when about 40% of the product seemed to be affected by decay. Cubic terms were not significant in any equation.

Additionally, we tested for differences between products by adding dummy variables to the equations. This indicated that the results for banana deviated significantly from the other products when the percentage of people saying "yes" or "no" were concerned [dummy variable effect: $p < 0.001$ for "yes" and $p < 0.05$ for "no" responses]. We can observe this difference also in Fig. 4, where the curves for degree of decay and proportion of "no" are clearly separated for banana, while they are close together in the other three panels.

3.4. What to do before eating?

All participants who would or could consume the product (who indicated yes, after peeling or after cutting off bad parts in Fig. 4) were asked to indicate which actions they would take before consuming the product, with multiple response possibilities. We focused the analysis on aspects that could reveal strategies for alternative uses of the product, including cutting off the bad parts, mashing and cooking. For the cucumber, we also included peeling the product. Fig. 6 shows the percentage of potential consumers using the different strategies. Other responses, such as cutting the product into pieces, washing the product, do nothing, or peeling the banana, mango or avocado are not shown. For every product, we see an increase in the proportion of consumers wanting to cut off bad parts over time. The other options seem product specific. With the banana, the share of people who cook or mash the product increased, while with the cucumber the share of people who peel the product increased.

4. Discussion

This study set out to examine how consumers perceive decay in fruits and vegetables at different stages of spoilage and how they act upon this information. For four different products, we observed a decrease in attractiveness, freshness, healthiness and nutritiousness over time. Interestingly, the curves for the healthy and nutritious ratings largely overlapped. The fresh and attractive ratings followed the same pattern over time, but while they overlapped for banana, the freshness ratings were consistently higher for cucumber and avocado than the attractiveness ratings (Fig. 2). This suggests that participants saw that the product was fresh, but possibly not all participants found the product

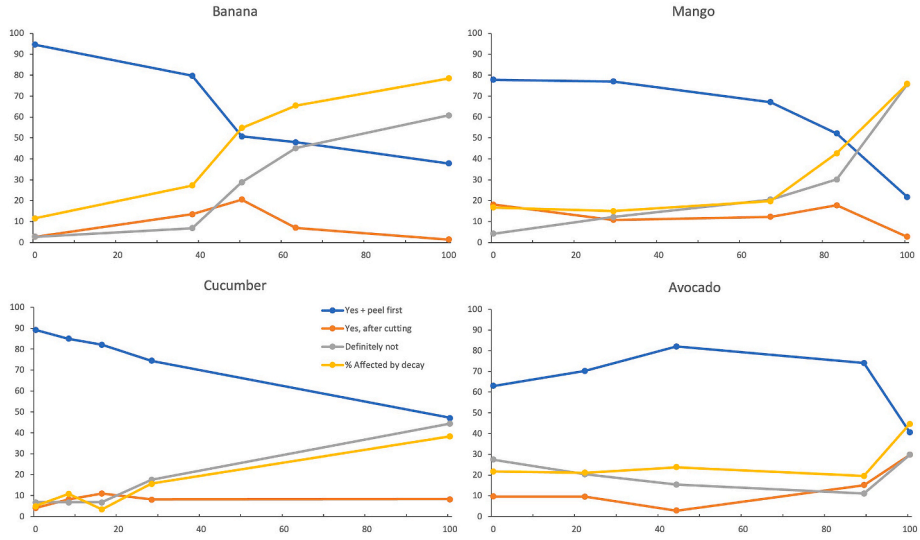

Fig. 4. The percentage of participants who indicate they would like to consume the product (yes – after cutting off bad parts – no) and the perceived degree of decay as a function of time. Responses in the categories "yes, definitely" and "first need to peel it" were combined.

Table 3
Results of polynomial regressions relating the proportion of participants with different responses (yes – after cutting off bad parts – no) to the perceived degree of decay in the product. Analyses were performed on group means (N = 20).

			% Affected			(% Affected)^2		
Dependent	Model	R^2	Beta	Standardized beta	p-value	Beta	Standardized beta	p-value
Yes	Linear	0.82	−0.785	−0.907	<0.001			
	Quadratic	0.83	−1.157	−1.337	<0.01	0.005	0.443	0.297
Cut off bad parts	Linear	0.00	−0.007	−0.022	0.925			
	Quadratic	0.37	0.755	2.430	0.008	−0.009	−2.526	0.006
No	Linear	0.82	0.792	0.908	<0.001			
	Quadratic	0.84	0.401	0.460	0.277	0.005	0.462	0.274

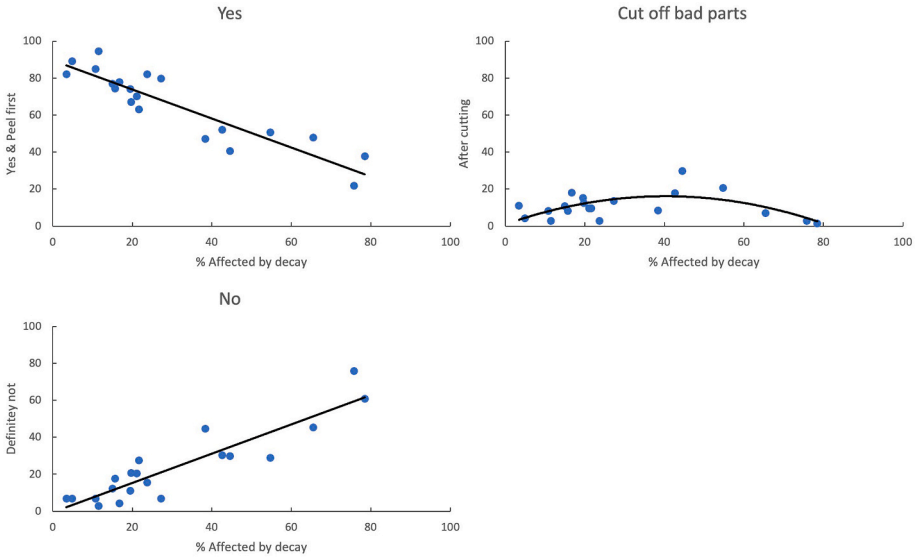

Fig. 5. Scatter plots with best fitting regression curves relating the proportion of participants who want to consume the product, cut off bad parts or do not want to consume the product as a function of the perceived degree of decay. Data are included from all four products (banana, mango, cucumber, and avocado). Analyses were performed on group means (N = 20).

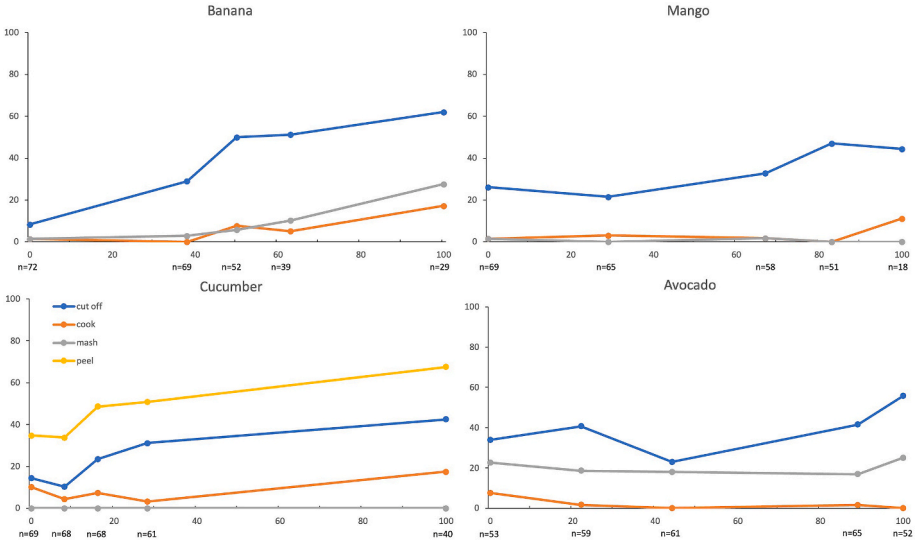

Fig. 6. Proportion of potential consumers who cut off bad parts, mash, cook, or peel the decaying product before consumption as a function of time. The proportion is calculated based on the number of people willing to consume the product (n values are included below the time axis).

attractive to eat. Comparing the four patterns in Fig. 2 indicates that the banana showed more signs of visual decay as it turned black, while for the other products participants were less likely to conclude that the product deteriorated. The patterns for overripe were opposite to the changes in freshness, while disgust ratings largely followed the overripe ratings (Fig. 2). Interestingly, the curves for the perceived degree of decay in Fig. 4 did not seem to have the same shape as the curves for overripeness in all cases, suggesting that these constructs are only indirectly related.

As expected, the sensory properties showed different patterns over

products, but some changes occurred similarly when products deteriorated: hardness decreased and flexibility increased for all products, while for banana, mango, and cucumber bitterness and sourness ratings increased over time. For juiciness and sweetness, we found more variation in patterns over products. Hence, the changes in sensory characteristics with ripening and decay may coincide with a variety of changes, although a decrease in hardness and an increase in sourness and bitterness seems common for multiple products.

4.1. Theoretical implications

Previously, Jaeger et al. (2018b) have estimated sigmoid curves relating the area of damage on an apple to the amount of people willing to consume the product. In the present study, we found a linear relationship between the degree of decay and the number of people who were (not) willing to consume the product. These outcomes are not necessarily conflicting, as the middle parts of a sigmoid curve can be well approximated by a linear relationship. Analogously, Tsiros and Heilman (2005) found a linear relationship between the number of days until expiration date and consumers' willingness to pay for two vegetables (lettuce and carrot). For meat (beef and chicken), they found an exponential relationship, suggesting that a larger discount earlier in the meat's shelf life was necessary to encourage purchase. The authors partly explained this difference by suggesting that meat poses a higher product quality risk than vegetables. The expensiveness of meat may also play a role in this case: Consumers claim to be more careful with storage and stricter in adhering to the expiration date for meat, dairy and eggs than for vegetable products (Ghinea and Ghiuta, 2019; Terpstra et al., 2005). However, Tsiros and Heilman (2005) only found an exponential curve for meat and not for milk or yogurt.

4.2. Managerial implications

In today's fast-paced world, where convenience often takes precedence over traditional practices and the distance between consumers' food experience and agricultural production is large, there has been a concerning decline in people's ability to assess food quality using their common sense and their sensory systems (Wijayaratne et al., 2018). Many people in developed countries buy their food products in supermarkets where many products are standardized in color and size and are provided in standard packages that seem to come from a large-scale industrial facility. In addition, they can buy ready-to-eat meals that only need to be reheated or they can order food to be delivered, hence requiring little from their cooking skills. Therefore, it is essential to prioritize food education, raise awareness about the limitations of expiration dates, and encourage individuals to trust their sensory systems when assessing the edibility and palatability of fruits and vegetables. However, for many people living in cities their degree of food literacy has decreased (Caraher and Lang, 1999; Slater, 2013), and they may decide to discard food items that they do not trust anymore, especially if the food is relatively cheap. For instance, superficial packaging damage automatically activates thoughts of contamination and health and safety concerns (White et al., 2016). This low threshold to discard is disturbing, because a lot of time, energy, and scarce resources have been invested in the consumer product. Understanding proper storage practices, such as refrigeration, freezing or using airtight containers, can help minimize the occurrence of bacterial or mold growth and extend the shelf life of food. Knowledge of the correct ways to store vegetables, fruits and leftovers and the best locations in the refrigerator could help preserve products better and reduce food waste (Terpstra et al., 2005).

In addition, since expiration dates may be absent, unclear, unreliable (Wilson et al., 2018) or have passed already and storage conditions may have been suboptimal, it is important that consumers can base their judgment whether a food product is still edible or enjoyable on sensory impressions to avoid risks while preventing unnecessary food waste. For the same reason the "Too Good to Go" company recently launched their "Look, Smell, Taste, Don't Waste" Campaign in the UK, reminding consumers to use their senses to determine whether a food item is still edible and enjoyable, rather than discarding it just to be safe (https://www.toogoodtogo.com/en-gb/initiative/look-smell-taste).

It is often suggested that the price of fruit is a barrier to consumption (Uetrecht et al., 1999). Especially for people with limited resources (Kempson et al., 2002), it would be valuable to possess the capabilities to reliably asses food quality, so that scarce food is not unnecessarily wasted and food hazards are avoided. Limited financial means may urge people to use as much of the product as possible, and they may be more willing to take chances when products are less than optimal (Waitt and Phillips, 2016). The finding that some participants were willing to consume also the most spoiled products in our selection (Fig. 6) indicates that some people are willing to accept quite serious quality defects. This is consistent with an observation by Campbell et al. (2009) that consumers are willing to accept a range of qualities, realizing that product quality is likely to be highly variable, both within and between seasons, and due to home storage. In addition, people may differ in the extent to which they experience disgust when encountering withering or moldy foods (Ammann et al., 2019; Siegrist et al., 2020) and assessing people's attitudes towards suboptimal products may help predict purchase likelihood (Bolos et al., 2019). Therefore, these personal variables should be included in future studies to assess their impact on food product purchase and disposal decisions.

Although we expected the products to deteriorate over time, for one of the products (avocado) we saw attractiveness ratings first increase, suggesting that the product in the first pictures was not yet completely ripe. This indicates another interesting topic for food literacy, namely how people use their senses to decide that a product is ripe. For instance, while in the apple industry the background skin color, the amount of blush, the size of the fruit and the amount of greasiness of the skin are all used as external ripeness indicators (Kingston, 1992; Lau, 1988), for consumers the visual cues are greater drivers of perceived apple ripeness than tactile cues of skin greasiness and apple firmness (Richardson--Harman et al., 1998). Another interesting topic may be which parts of foods are considered edible, as people may differ considerably in what parts they usually eat or not (Nicholes et al., 2019).

4.3. Limitations

Designing the present study proved more challenging than expected, as people use multiple, product-dependent strategies to determine whether a food product is fresh or not. For instance, people may want to take the skin off before deciding how much of the product they can use (Campbell et al., 2009) and this could be an interesting extension of the current study. Similarly, the patterns of decay depend on the specific product, its desirable properties, its main drivers of decay (bacteria, molds, yeasts, enzymes), storage and packaging conditions, and so on. To get a good insight in the mechanism and speed of decay, assessment criteria need to be decided upfront, and that is more difficult when these differ per product. In fact, this is why developing food literacy is important: To be able to assess and treat each product in an optimal way, to make meals an enjoyable experience that contributes to personal health and minimizes environmental impact. Possibly, a qualitative study can provide a more complete picture on people's thoughts during everyday practices while interacting with fresh and deteriorating food products.

The time-lapse videos in the current study provided no information about the storage conditions and the actual time frame in which the deterioration in the video occurred. Consumers who know where and how long a product has been stored in a specific location can use this information to decide whether to consume the product. Although consumers may not always keep track of such information or use it correctly (Terpstra et al., 2005), such clues can help them determine whether they have confidence in the quality of a product.

We measured people's expectations based on the visual impressions from pictures. Restricting participants to visual appearance as the sole indicator of food quality resembles common practices in today's supermarkets when buying products that are fully wrapped in transparent packages or foil. This practice disregards that people may need other sensory inputs to fully assess product freshness and nutritional value (Koller et al., 2023; Peck and Childers, 2003). In addition, consumer expectations depend on the experiences that people have with decaying products and may not reflect actual changes. For instance, the participants expected the cucumber to become less juicy over time, while our personal experience with an overripe, yellow cucumber is that it becomes watery rather than dry. Therefore, we cannot be sure that the participants have tasted a product that looks like the one in the picture.

In the present study we did not include any foods that were damaged (e.g., show bumps) or that were precut. This would be interesting material for follow up studies, as these foods tend to decay faster and show different patterns of decay (e.g., showing more browning or molds). In addition, in future studies we would like to have people explore decaying products through all their senses, so they will not be limited to visual information. However, designing such an experimental study may be challenging, as patterns of decay are hard to control, multiple products will be needed when people use taste and smell to explore the stimuli, and participants should be protected from food hazards.

5. Conclusion

Although many people purchase food products in supermarkets where products are standardized and often come in packaging with an expiration date, sensory impressions remain important as a final check to assess palatability and prevent health risks, while also preventing unnecessary food waste. Because the characteristics of agricultural products vary significantly, it is important to educate people about how the different products grow, are harvested, stored and how they spoil. Nonetheless, studying decay for four fruits and vegetables revealed some similarities across products, with firmness decreasing and expected bitterness and sourness increasing over time. In addition, we found a linear relationship between the degree of decay and the number of people who (did not) want to consume the product. Because decay processes are specific to each product, future studies should predefine assessment criteria for each product separately, allowing comparison on multiple output measures simultaneously.

CRediT authorship contribution statement

Hendrik N.J. Schifferstein: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made publicly available through the TU Delft repository at https://doi.org/10.4121/21740060

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Appendix A

Spearman rank correlation coefficients of each attribute with the moment in time. All values are significantly different from 0 [N = 366, $p < 0.001$], except for those with superscript.

Concept	Banana	Mango	Cucumber	Avocado
Emotional responses				
Disgust	0.66	0.63	0.44	0.14
Product attributes and benefits				
Attractive	−0.79	−0.63	−0.55	−0.20
Fresh	−0.81	−0.65	−0.57	−0.19
Healthy	−0.56	−0.50	−0.52	−0.16
Nutritious	−0.53	−0.51	−0.47	−0.13
Overripe	0.73	0.56	0.37	0.30
Expected sensory qualities				
Sweet	-0.06^{NS}	−0.17	0.04^{NS}	0.01^{NS}
Bitter	0.21	0.23	0.35	0.02^{NS}
Sour	0.15	0.19	0.28	0.07^{NS}
Juicy	0.17	−0.13*	−0.31	-0.01^{NS}
Flexible	0.59	0.54	0.26	0.31
Hard	−0.49	−0.50	−0.24	−0.30
Decay				
Degree of decay	0.69	0.60	0.42	0.24

*$p < 0.05$; ^{NS} not significant [$p > 0.15$].

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