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Potential Applications of Food-Scanners in Fruit and Vegetable Supply Chains and Possible Consequences for the German Market

Simon Goisser[1], Heike Mempel[1], Vera Bitsch[2]

[1]University of Applied Sciences Weihenstephan-Triesdorf, Greenhouse Technology and Quality Management
[2]Technical University of Munich, School of Management & School of Life Sciences Weihenstephan, Chair of Economics of Horticulture and Landscaping

simon.goisser@hswt.de, heike.mempel@hswt.de, bitsch@tum.de

Abstract

Originally advertised as tools for end-consumers, food-scanners have recently gained publicity and show potential as instruments for quality assessment along the fruit and vegetable supply chain. The current study explores preferences and concerns of chain actors regarding the implementation of this technology through semi-structured interviews. Results indicate that food-scanners could facilitate quality control at different levels of the fresh produce supply chain by providing fast, non-destructive and objective measurements. Concerns about the application of food-scanners could be identified with respect to potential additional requirements of trading companies resulting in more pressure on producers. The use of food-scanners by end-consumers is discussed critically. To further a goal-oriented and user-directed development of this new technology, future research should be directed at its impacts on perception of fruit quality along the chain as well as end-consumers' readiness to use these devices in everyday life.

Keywords

food-scanner; fruit and vegetable supply chain; quality measurement; qualitative research

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Introduction

Quality and shelf life of produce depend on various product-specific parameters. Sugar content, acid-brix ratio, firmness and dry matter content are among the key parameters to determine maturity and ripeness of produce. Depending on the product, marketing standards for some parameters must be met to allow distribution via retail chains (UNECE, 2017). The verification of internal quality standards such as dry matter, sugar content and fruit acidity is often time-consuming and, in some cases, requires destructive measurement methods in combination with sample preparation and handling of chemicals (OECD, 2009). To optimize quality throughout the fresh food supply chain, degradation models and algorithms were developed and applied in several case studies for specific fruits (Rong, Akkerman, & Grunow, 2011; Yu & Nagurney, 2013).

In recent years, so-called food-scanners have gained publicity. Food-scanners are mobile and miniaturized devices operating on the principle of near infrared spectroscopy (NIRS). NIRS is a type of vibrational spectroscopy which depends on the stimulation of molecular vibration using infrared light in the wavelength range 750-2500 nm. It can be used to acquire quantitative and qualitative information from a sample through the interaction of NIR electromagnetic waves with molecular bonds of the samples constituents (Pasquini, 2003). Therefore NIR spectrometers allow the determination of the physical and chemical composition of produce (e.g., sugar content, dry matter, firmness) in a rapid and noninvasive way. Whereas traditional NIR spectrometers are expensive laboratory benchtop devices, portable devices apply the same operating principle for a fraction of the cost. Dos Santos et al. (2013) summarized commonly reported portable NIR instruments and applications for fruit and vegetable analysis in the literature and illustrate the main advantage of these devices as well as the possibility of using them under production conditions.

The latest innovations in this field of technology include smartphone-based food-scanners like TellSpec Enterprise Scanner (TellSpec Inc.), SCiO (Consumer Physics) and FoodScanner (Spectral Engines Oy) (Rateni, Dario, & Cavallo, 2017). These wireless sensors can be operated via smartphone or tablet and use advanced algorithms in combination with big sample libraries and cloud-based prediction models to identify contents like fat, sugar, starch, moisture, protein and total energy in real-time (Consumer Physics, 2017a; Spectral Engines Oy, 2018). Some companies are already promoting mobile applications for end-consumers for the determination of sugar content in fruits (Consumer Physics, 2017b) or testing of fresh fruits for quality, ripeness and flavor (TellSpec Inc., 2018).

Because the use by end-consumers is an emerging field of application for food-scanners, experts have started discussing opportunities and threats through consumers using these food-testing devices for produce. According to these experts, main challenges arise in the scope of application and the interpretation of results. Lack of understanding and wrong handling by consumers as well as potential invalid models can lead to false results. This presents a risk to consumers and can cause severe brand damage for producers and retail markets due to negative social media exposure and unnecessary food waste and recalls (Popping & Bourdichon, 2018). To mitigate these risks and help consumers better understand and interpret results, guidelines for consumer device manufacturers were developed (Popping et al., 2018). Furthermore the question arises whether these devices are suitable as quality analysis tools on prior steps along the supply chain of fresh produce. An examination of various studies addressing the topic of portable NIR-spectrometers (dos Santos et al., 2013) shows that there are some advantages compared to traditional destructive and time-consuming quality control methods. Initial studies of the performance of the device SCiO showed acceptable results in predicting dry matter of apples and kiwifruit (Kaur, Künnemeyer, & McGlone, 2017) as well as predicting sugar content in kiwifruit and classifying feijoa according to maturity and 'Hass' avocado according to ripening stage (Li et a., 2018).

The implementation of food-scanners as tools for quality assessment along the fresh produce supply chain (FSC) constitutes a discrete innovation. According to Tidd (2006), opportunities for innovation can present themselves due to different triggers of discontinuity (e.g., new markets, new technologies) within a set of rules. These opportunities can be overlooked by established players because they are beyond the usual focus of attention. Also, the convergence and maturing of established technological streams, which in combination could offer a benefit, can be underestimated. The set of rules in the context of quality management are traditional methods of quality measurement, such as the determination of sugar content with refractometers and measuring firmness with penetrometers. Furthermore, the miniaturization of NIR-spectroscopy and application as a new form of technology can be considered as a trigger, providing various opportunities in quality control processes. Therefore actors along the FSC could potentially benefit from this innovation of measuring fruit quality in the process of quality control.

The potential for practical applications of food-scanners perceived by actors along the FSC has not yet been studied. Since chain actors' opinions play a key role in the success of the implementation of food-scanners in FSCs, it is important to investigate these perspectives. The objective of the current study is to examine the advantages and drawbacks as well as limitations of food-scanners as tools to complement traditional quality measurement methods. Therefore, preferences as well as concerns of supply chain actors regarding the implementation and use of these devices in day-to-day work are explored. Besides applications desired by supply chain actors the present study also investigates requirements that have to be fulfilled for food-scanners to be of practical use along the FSC in Germany.

Materials and Methods

In order to explore the research question in-depth the present study employed a qualitative research approach. A qualitative approach is suitable when new or not well-known research issues are investigated or the research is aimed at future issues (Bitsch, 2005). Previous studies related to food-scanners focused on prediction-accuracy of selected quality parameters like dry matter and sugar content (Kaur et al., 2017; Li et al., 2018). The perception and evaluation of FSC actors regarding the implementation of this technology as a new way of measuring quality are yet unknown, therefore a qualitative approach is appropriate. Furthermore, quality management differs from company to company due to internal organizational structures, consequently semi-structured interviews were deemed suitable for data collection.

In 2018, eleven semi-structured interviews were conducted with actors on different steps of the FSC from companies in different parts of Germany (Table 1). Interviewees were recruited through the researchers' personal contacts and all interviews were conducted by the first author. Four interviews were conducted face-to-face at the interviewees' companies, in quiet and neutral rooms, e.g., conference or break rooms. The remaining seven interviews were held via phone. Each interview lasted 30-60 minutes. Each interview started with the current quality measurement at the interviewees' respective companies. Since all interviewees were familiar with these topics from their daily work, these questions also served as icebreakers, and allowed a smooth start into the discussion. The following questions addressed potential applications as well as concerns and preferences of supply chain actors regarding the implementation of the technology. Furthermore, requirements for the practical use in their operations, opinions about possible areas of application outside the interviewees' companies and opinions about the potential consequences of end-consumer use of these devices were explored. A prepared interview guide was used and all topics were addressed over the course of the interview following the flow of conversation.

Table 1. Interviewees and their background

Interviewee	Duty	Company position along the FSC
Employee	Cultivation and direct selling of fruit	Fruit production
Owner	Cultivation and direct selling of fruit	Fruit production
Sales manager	Managerial and administrative duties	Producer cooperative
Quality manager	Managerial and administrative duties	Producer cooperative
Trade manager	Managerial and administrative duties	Wholesale fruit and vegetables
Regional manager	Managerial and administrative duties	Wholesale fruit and vegetables
Quality manager	Managerial and administrative duties	Wholesale fruit and vegetables
Project manager	Managerial and administrative duties	Logistics
Team manager fruit and vegetables	Managerial and administrative duties	Food distribution center
Branch manager	Orders produce and monitors quality	Food retail market
Department manager fruit and	Orders, sorts and shelves produce	Food retail market

vegetables

All interviews were audio-recorded and transcribed verbatim. Content off-topic was omitted during transcription (Halcomb & Davidson, 2006). Since the present study focused on the content of the interviews, simple transcript method (Dresing, Pehl, and Schmieder, 2015) was used. Therefore, colloquial language and dialect were adjusted to standard German language. Qualitative content analysis using the Atlas.ti software (version 8.2.32.0) was applied to structure the results, utilizing coding and the establishment of categories. In the process of open coding, sections of the text were labeled and assigned with the main thought behind each section. Afterwards categories were established, where codes were grouped together according to their meaning and the relationships between them.

Results

Results are structured into four parts. The first part describes the status quo of quality assessment along the supply chain, including practical experiences of actors along the FSC in their day-to-day work. The second part discusses preferences and concerns of supply chain actors regarding the implementation of food-scanners for quality control. The third part presents the requirements food-scanners have to fulfill to be of practical use in quality management. The fourth part highlights potential applications of food-scanners along the FSC.

Current practice of quality assessment along the FSC

When asked about their daily routine in the context of quality control of fresh produce, actors described practices at their respective companies to ensure high quality standards. Since differences in these practices with regard to different supply chain steps (production, trade, retail market) could be identified, the description is divided into these parts. According to actors from fruit production companies, quality, maturity as well as harvest date of fruits is often monitored via cultivation consultants. These consultants provide suggestions whether harvest time is reached. Therefore quality assessment at that stage is mostly limited to optical inspection of fruits in the orchard. Internal quality parameters such as firmness and sweetness are solely examined through subjective testing, e.g., hand-squeezing and degustation in the field. Furthermore, experience established over time, working in the business, is paramount for producers, rendering additional testing obsolete.

“We don’t have a device or anything. Of course, we are going in [the orchard], I would say, we take a look, we taste, and over time we developed a feeling, kind of an experience when something is ready for harvest”(Employee in fruit production, male, 20-30 years old).

To sell fruits to central markets and reach a high price statutory provisions have to be fulfilled, e.g., a specific degree of fruit coloring and specific fruit size. Internal quality parameters like sugar content are often not specified by central markets. Actors handling fruits along the FSC (producer cooperatives, wholesale, and fruit distribution centers) described a combination of external and internal quality parameters regarding incoming produce. In a first step, fruits are visually inspected and conformity of sizes, colors, weights and storage temperatures are verified, sometimes in combination with hand-squeezing to test fruit firmness. For this assessment of quality, the know-how and experience of the staff is important and dominated by visual impressions. In a second step, quality parameters related to internal quality are tested, e.g., sugar content using refractometers or fruit firmness using penetrometers. One interviewee stated that in addition to these objective measurements a degustation of fruits was implemented to verify fruit quality and taste.

“There is always a degustation, though. So, we slice [the fruit] and take a bite. But then as subjective evaluation, is it well, is it not well” (Quality manager at wholesale fruit and vegetables, male, 40-50 years old).

On the one hand these tests are performed to make sure statutory standards (UNECE, 2017) are met, on the other hand to fulfill customer-specific standards which can be stricter than the marketing standards. Some of these tests are described as elaborate and costly, e.g., the determination of sugar content or the acid-brix ratio, and criticized for a lack of reproducibility. Other tests like the determination of dry matter are characterized as difficult, since employees require special knowledge, which results in outsourcing of analyses to laboratories.

According to actors at retail markets, quality evaluation of fruit and vegetables is divided into two sections, first, control of statutory provisions (e.g., origin, grade) and, second, assessment of fruit quality during sorting and shelving of produce. This procedure of quality control is solely based on visual inspection and haptic testing of fruit firmness and described as tedious and not particularly hygienic work which sometimes leads to defects being overlooked due to monotonous and repetitive work. Experience of retail market staff responsible for sorting and shelving is paramount, since criteria for rejecting produce are sometimes vaguely phrased.

“Well the company by itself specifies that they say fruit, which oneself would no longer buy. So it is relatively vague, fruit and vegetables which oneself would no longer buy” (Branch manager at food retail market, male, 30-40 years old).

Preferences and concerns regarding the implementation of food-scanners

When interviewees were asked where they see the main advantages of food-scanners several aspects were identified. Compared to traditional methods of quality evaluation, the non-destructive nature of food-scanners posed an important advantage, making destructive tests like refractometer analysis obsolete. Produce must no longer be touched, allowing a more hygienic workflow. Also, the speed of measurement of internal quality parameters was deemed advantageous. The time saved in comparison to destructive measurements could be used more efficiently, e.g., by increasing the number of inspections at each arrival of produce. Additionally, laboratory analyses could be reduced to a minimum. A rapid, nondestructive and laboratory-independent measurement would save money for companies.

According to several interviewees, food-scanners could provide an opportunity for objectifying current measurement methods, which are mainly visual and based on staff’s experience. Consequently, food-scanners could replace subjective grading. As a result, incoming employees could assist earlier in produce control with food-scanners as support. As mentioned by various interviewees, food-scanners could further be used as additional decision-support tools to accept or refuse produce at incoming goods control. For instance, fruit and vegetables could be tested via conventional methods (e.g., visual inspection) and food-scanners added to give information about internal quality attributes, indicating if produce passes all requirements or a complaint has to be filed. Consequently, feedback can be directed to suppliers, allowing communication of internal quality along the FSC.

Some actors perceive a downside of the fact that internal quality measurements could be easily available. According to these critical voices, additional pressure for producers could arise due to additional quality requirements from trading companies, where specified scan results have to be met to be accepted as good quality. Critical attention is also paid to the accuracy of the new devices. To avoid discrepancies between scan results at different levels of the supply chain, the transferability of predictions from different devices has to be guaranteed. Informative and accurate predictions are demanded to allow long-term utilization of these devices and prevent frustration.

The application of food-scanners by end-consumers is viewed critically. Some actors see potential in these devices as an additional incentive and decision-support for consumers during purchasing decisions, especially for a young and health-conscious target group. Others hold the opinion that most consumers will not purchase an extra device like a food-scanner for testing food, but will more likely give it a try when implemented in smartphones. Even then, most supply chain actors do not perceive food-scanners as devices for the general public, but rather for small consumer-groups with special interests in health and diets.

Another aspect critically discussed is the impact on food waste due to the application of food-scanners. As a result of the above mentioned advantages like fast quality evaluation at incoming goods control, more and precise quality measurements could be demanded leading to a higher rejection rate and thus to more food waste. Furthermore, additional food waste could emerge at retail markets due to end-consumers being more selective in their choice. However, the increase is not expected to be large compared to current amounts.

Requirements of food-scanners to be of practical use in day-to-day processes of quality control

An important requirement of food-scanners to allow the application in day-to-day quality control processes according to various interviewees are investment costs. As stated by multiple actors along the supply chain, devices which cost several thousand euros are unlikely to be purchased. The more realistic it is to generate additional value such as more or better test results or saving time through the implementation of these devices, the more realistic it will be that they will be applied.

Another important aspect, as mentioned by many interviewees, is the fact that the reference models and the database used as well as the predictions of quality have to be accurate and reliable. Additionally it is important, whether there will be different prediction models for each variety of produce or one global model which allows the measurement of all varieties of this produce. Since the technique and the way of operating with these devices would be a technical innovation compared to traditional quality measurement methods for all interviewees, almost all stated the importance of building confidence as an important step in adopting these devices in day-to-day routine measurements. According to interviewees, results would be cross checked with traditional measurement methods like refractometer or penetrometer tests during the introduction phase to generate experience. After gaining evidence for the reliability of food-scanner predictions, these cross checks would be terminated and the devices used independently. Regarding the operability of food-scanners two factors are important to allow application in day-to-day quality control processes. On the one hand, handling of these devices by employees has to be as easy as possible to allow a fast and simple workflow, as stated by one interviewee.

“Those must be easy to use devices, which allow the result by a simple push of a button” (Team manager fruit and vegetables at food distribution center, male, 40-50 years old).

On the other hand, display of measured values has to be arranged in a way to allow easy interpretation. As suggested by several interviewees, a traffic light food labelling system with colors such as green, yellow and red could serve as an indicator to support decisions for employees at incoming goods control. With regard to the utilization by end-consumers, results should be displayed in a comprehensible way without technical terms to avoid confusion and unintended waste.

Another requirement besides operability is a certain convenience in handling and robustness of the devices. Robustness was mentioned by both interviewees from fruit production with regard to the nature of work in orchards, so that devices withstand falling to the ground during utilization in the field. Due to rough environmental conditions in trading companies, a similar robustness is required at this step of the supply chain, as mentioned by one interviewee.

“The device now has to withstand the environment in our warehouse, at our produce arrival, so it must survive falling down. It will be touched by wet, sticky hands. It has to withstand the cold, the high humidity, so these environmental conditions at our cold storage” (Quality manager at wholesale fruit and vegetables, male, 40-50 years old).

Potential applications of food-scanners along the FSC

When interviewees were asked to describe possible applications of food-scanners along the FSC, different fields of application can be distinguished. For instance, sorting produce as well as the determination of maturity and ripeness, especially in the context of produce new to the assortment, are viewed as promising applications. Furthermore, product-specific applications such as the detection of internal fruit damage will make food-scanners attractive to use, allowing a leap forward in quality assessment, as illustrated by one interviewee.

“Principally one topic, where I currently don’t know if such a device is capable of, would be testing of internal browning for avocados, discovering internal deterioration for pineapple or detecting internal browning for mango. […] So, if something like this would be possible that would imply a big leap forward for us in [quality] control” (Quality manager at wholesale fruit and vegetables, male, 40-50 years old).

Additionally, the potential of implementing food-scanners is considered promising along the whole FSC. At production, food-scanners could be used to determine optimum harvest time, whereas trading companies operating in wholesale and retail could profit from food-scanners by using them as tools for fast quality assessment of incoming and outgoing produce.

Discussion and conclusions

The study showed that currently there are different practices of quality control for fresh produce along the supply chain, varying between production, trade and retail companies. Quality determination at production and retail companies is often highly dependent on trained and experienced staff performing subjective and mostly visual examination of produce. In contrast, trade companies often follow established protocols to ensure quality and conformity with guidelines. Various interviewees described food-scanners as tools for objective quality measurement. Therefore, these devices could help to overcome existing discrepancies in quality assessments along the FSC by establishing a uniform measurement method. These findings are in accordance with Abbott (1999) who stated that instrumental measurements are often preferred over sensory evaluation since they allow reduction of variation between individuals, offer a higher precision and provide a standardized language among researchers, industry and consumers.

Results indicate that there are several perceived advantages of food-scanners compared to traditional methods of quality evaluation that make these devices attractive to use. Aspects such as lower costs due to fewer laboratory costs, non-destructive and rapid measurements are of high importance and underline the advantages of NIR spectroscopy mentioned in the literature (e.g., dos Santos et al., 2013). Since the study focused on day-to-day application along the FSC, new aspects such as the application by untrained employees and utilization as decision-support tools for incoming goods were identified as additional advantages. However, concerns of some supply chain actors due to the possibility of additional quality requirements from trading companies, resulting in further pressure for producers, were identified. These results confirm findings that small producers can face considerable challenges meeting the requirements of supermarkets as described by Boselie, Henson, and Weatherspoon (2003).

The current literature on implications of consumer testing devices for the industry is limited to the need of developing guidelines to help consumers interpret and understand test results in order to allow a save consumption of products as well as reduce the risk of recalls due to false measurement results (Popping et al., 2018; Popping & Bourdichon, 2018). Results of the present study confirm the need for an easy interpretation of results. Furthermore, results indicate that there are additional aspects that have to be considered with regard to the implementation of food-scanners, such as the impact on food waste.

Investment costs, high prediction accuracy, convenience in handling and robustness of food-scanners were identified in the present study as important requirements to allow the application in daily quality control processes. These critical requirements were also identified by dos Santos et al. (2013). The preference of supply chain actors of integrating food-scanners in existing systems of information technology posed an additional requirement, which should be considered in future developments to simplify the application along the supply chain.

The determination of maturity and sorting of produce according to ripeness are desired by actors as potential applications of food-scanners along the FSC. Current studies by Li et al. (2018) indicate the possibility of using food-scanners for this type of application and could be feasible in the near future. The detection of internal fruit damage by applying NIR-spectroscopy seems generally possible (Fu et al., 2007). However, due to several advantages on the basis of the operating principle (e.g., applying transmittance compared to reflectance spectroscopy), internal defects are more likely to be detected using hyperspectral imaging (Ariana & Lu, 2010).

The present study highlighted preferences and concerns of actors along the FSC with respect to the application of food-scanners as additional tools for quality assessment. Since food-scanners are already commercially available and expected to be used more broadly along the supply chain of fresh produce soon, future work should focus on evaluating critical points like the impact on quality perception along the supply chain, guaranteeing a goal-oriented further development of the new technology. To evaluate possible consequences due to use by end-consumers, future work should critically evaluate the general readiness of end-consumers in applying these devices in everyday life. Furthermore, it has to be possible to interpret predictions by food-scanners by non-experts.

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