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Food-Scanners as a Radical Innovation in German Fresh Produce Supply Chains

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ABSTRACT

Originally advertised as tools for end-consumers, portable food-scanners have recently reached a high level of awareness and show potential as instruments for quality assessment along fruit and vegetable supply chains. 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 fruit wholesaler resulting in more pressure on producers. 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*

1 Introduction

Quality and shelf life of produce depend on various product-specific parameters. Sugar content, brix/acid ratio, firmness and dry matter content are among the key parameters to determine maturity and ripeness of produce. Depending on the product, standards concerning the marketing and commercial quality control for some parameters must be met to allow distribution via retail chains (UNECE, 2017). In Germany, compliance with these standards are required from leading fruit retail companies. 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, 2018). To optimize quality throughout the fresh food supply chain, degradation models and algorithms were developed and applied in several case studies for different fruit like bell peppers (Rong, Akkerman, & Grunow, 2011) and cantaloupes (Yu & Nagurney, 2013).

In recent years, so-called food-scanners became more and more popular for potential end-consumer applications, but also were tested in scientific studies. Food-scanners are mobile and miniaturized devices operating on the principle of near infrared (NIR) spectroscopy. Whereas traditional NIR spectrometers are expensive laboratory benchtop devices, portable devices apply the same operating principle for a fraction of the cost. Dos Santos, Lopo, Páscoa, and Lopes (2013) summarized commonly reported portable NIR instruments and applications for fruit and vegetable analysis in the literature and illustrate the main advantages of these devices as well as the possibility of using them under production conditions.

The potential for practical applications of portable food-scanners perceived by actors along the fresh produce supply chain (FSC) has not yet been studied. Since food-scanners constitute an innovation to the FSC, this study focuses on the new technology within the framework of innovation as well as drivers and barriers of innovation adoption. The cooperation between key stakeholders, in this case actors along the supply chain including researchers and companies developing food-scanners, is of high importance when it comes to adoption and impact of new technologies (Douthwaite, Keatinge, & Park, 2001). The present study therefore investigates the perspective of supply chain actors in Germany by highlighting the status quo in quality control and exploring potential NIR applications along the FSC. The objectives of the current study are to identify advantages and drawbacks as well as limitations of food-scanners as tools to complement traditional quality measurement methods. Since the adoption rate of new technologies depends on the motivation of key stakeholders to get to know the technology and to tailor it to their needs (Douthwaite et al., 2001) an additional objective is to identify the motivation of supply chain actors in applying and adjusting the food-scanner technology to their companies' requirements.

The structure of the paper is as follows: The next section presents a brief background on the portable food-scanner technology, followed by a literature review on innovation terminology as well as drivers and barriers for innovation adoption in chapter three. Chapter four offers a detailed description of the qualitative data collection and analysis. Results are presented in chapter five, which are subsequently compared to previous research in the discussion section. The final chapter concludes with implications and propositions for future research.

2 Food-scanner technology

Food-scanners are miniaturized and portable NIR spectrometers. NIR spectroscopy is a type of vibrational spectroscopy which depends on the stimulation of molecular vibration using infrared light in the wavelength range 750-2500 nm. The interaction of NIR electromagnetic waves with C-H, N-H, O-H or S-H molecular bonds of the samples constituents leads to spectra which is captured by an optical sensor (Pasquini, 2003). By applying multivariate statistical analysis, these spectra can be correlated with the trait of interest, for example sugar content, dry matter or firmness of fruit. Therefore NIR spectroscopy can be used to acquire quantitative and qualitative information from a sample by determining the physical and chemical composition of produce in a rapid and non-destructive way.

The latest innovations in this field of technology include smartphone-based and portable 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 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). The operating principle of food-scanners is as follows (Figure 1): After illuminating the produce with NIR radiation from the light source (1) the food-scanner receives the spectrum through its detector (2). This spectrum is forwarded to a mobile device (e.g., smartphone, tablet) via Bluetooth (3), where a mobile application sends the spectrum via WLAN to a cloud database (4). Here, previously created sample libraries are used to analyze the spectrum using advanced algorithms (5). Finally, the result from the cloud database is sent to the mobile device and illustrated for the user (6). Some companies are already promoting mobile applications for end-consumers for the determination of sugar content in fruit (Consumer Physics, 2017b) or testing of fresh fruit for quality, ripeness and flavor (TellSpec Inc., 2018).

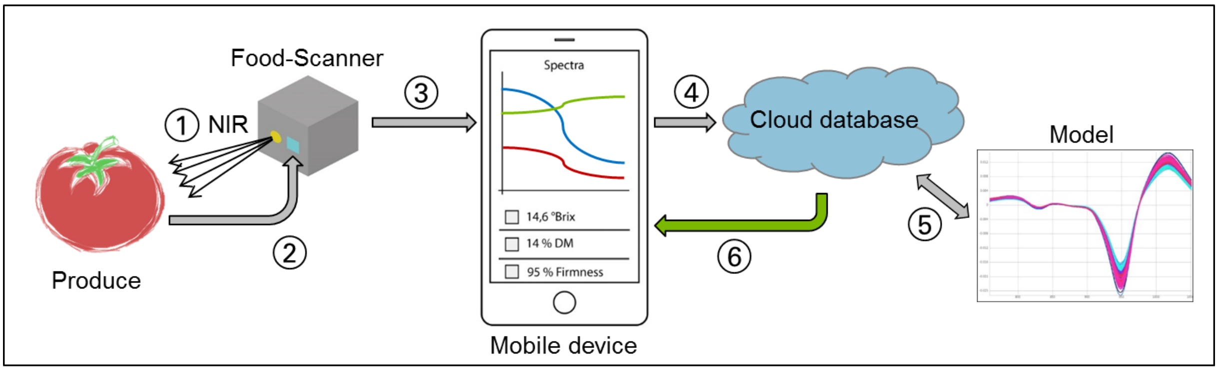

Figure 1. Operating principle of miniaturized food-scanners

An examination of various studies addressing the topic of portable NIR spectrometers shows that there are some advantages compared to traditional destructive and time-consuming quality control methods (dos Santos et al., 2013). Initial studies 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, Qian, Shi, Medlicott, & East, 2018). A recent study illustrated that these portable NIR sensors can be used for the prediction of shelf-life of stored tomatoes by predicting firmness and modeling the decline of firmness over storage time (Goisser, Krause, Fernandes, & Mempel, 2019).

3 Literature review

Originally some companies promoted portable food-scanners as tools for end-consumers, allowing real-time, portable analysis, assuring food safety and food security (TellSpec Inc., 2018) and aiming to be the consumer's "sixth sense" (Consumer Physics, 2017b). Since 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 mistakes in handling by consumers as well as potential imprecise models can lead to false results. Additionally, sampling performed by non-expert users can result in adulterated measurements due to contaminations of samples (Rateni et al., 2017). Therefore, handling by consumers is a challenge, since incorrectly performed measurements 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). A first examination of smartphone-based diagnostic platforms by Rateni et al. (2017) described a user-friendly design of commercial systems. Furthermore, the authors report instructions attached to these new devices to assist users during calibration and sampling procedure, indicating that measures against incorrect operation as described by Popping et al. (2018) are already taken adequately into account by device manufacturers.

Food-scanner as innovation to the FSC

A broad definition provided by Andersson, Lindgren, and Henfridsson (2008) describes innovation as "new application of knowledge, methods, and technologies that leverage an organization's competitiveness" (p. 21). Based on the fact that portable food-scanners were originally designed for end-consumers, the implementation of food-scanners along prior steps of the FSC constitutes a "new application of technology". First scientific studies show promising results regarding the prediction of internal quality as well as maturity of fruit, allowing a fast and non-destructive quality measurement. Therefore, the application of portable food-scanners as tools for quality measurement could leverage the competitiveness of an organization, since time-consuming and destructive measurements could be avoided.

Following Tidd's (2006) approach, the implementation of portable food-scanners as tools for quality assessment along the FSC can be classified as a process innovation within the FSC. 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 in product or process technology, 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. Actors along the FSC, which can be considered key stakeholders of this new technology, could potentially benefit from this innovation in measurement in the process of quality control.

Kim, Kumar, and Kumar (2012) divide innovation into five different types: incremental product, incremental process, radical product, radical process, and administrative. First, innovation is categorized as either administrative or technological innovation. Depending on the level of change, the target customer or market and the level of risk, technological innovation can be further categorized as incremental or radical innovation. Furthermore, the innovation subject refers to either a product or a process. Since the application of portable food-scanners introduces a new element for task specifications and workflow mechanisms, food-scanners can be considered as a radical process innovation in the FCS, even though for their producers they constitute a radical product innovation.

Sunding and Zilberman (2001), who examined the agricultural innovation process, give additional examples how innovations can be categorized and distinguished. Furthermore, they describe different ways of the generation of innovations and illustrate the process of adoption of new technologies. Referring to the "Cochrane treadmill" (Cochrane, 1979) and additional studies performed by Kislev and Shchori-Bachrach (1973), Sunding and Zilberman (2001) highlight the subgroup of the farming population called early adopters or early innovators. These farmers, who are the first to adopt a new technology, are able to benefit from technological change and the resulting profit. As further elaborated by Epperson and Estes (1999), early adopters within a technology-driven industry such as the fruit and vegetable industry are able to realize gains in productivity, higher than average season prices and enhanced market access.

With respect to reports on recent innovations in the field of horticulture there is high interest in new methods and technologies for postharvest produce treatment, e.g., ultrasound treatment of fruit to extend shelf life (Aday, Temizkan, Büyükcan, & Caner, 2013), UV-radiation of fresh-cut tropical fruit to enhance health promoting compounds such as phenols and flavonoids (Alothman, Bhat, & Karim, 2009), new developments in controlled atmosphere technology for storing organic produce (Prange, DeLong, Daniels-Lake, & Harrison, 2005), as well as new forms of packaging which allow the extension of shelf life and quality control of produce (Wyrwa & Barska, 2017).

Drivers and barriers for adoption of innovation

Most technological innovations follow the same pattern of organizational diffusion process (Hazen, Overstreet, & Cegielski, 2012). Rogers (2003) distinguished among five stages in this process, where the decision to adopt an innovation divides activities of initiation (gathering of information, conceptualization) and implementation (events, actions and decisions to utilize the innovation). Adoption therefore is the crucial step in realizing hitherto notional intentions. Within the literature, a number of drivers and barriers for innovation adoption have been identified. The following literature review focuses on drivers and barriers of adoption within the field of agriculture and horticulture and takes different steps along the supply chain into account.

By studying Irish farmers and clustering them into the two groups, innovators and adoption-averse farmers, Läpple, Renwick, and Thorne (2015) found a small but positive relation between farm size and innovation behavior, where innovators managed larger farms compared to adoption-averse farmers. The evaluation of farmer characteristics showed that younger farmers are less risk averse than older farmers. Additionally, the fact that farmers had completed agricultural education was positively correlated with innovation, concluding that agricultural education increases farmer's awareness of available innovations. Furthermore, the authors conclude that farmers with higher educational attainment might be more effective in processing new information. Pierpaoli, Carli, Pignatti, and Canavari (2013) studied adoption drivers for precision agriculture technologies and found that non-adopters do not have sufficient skills and competence in managing these technologies, which is in line with conclusions of Läpple et al. (2015). Furthermore, both studies conclude a positive relation between access to credit as well as financial resources and innovation. Dewar and Dutton (1986) investigated the adoption of radical and incremental innovations. According to the authors, the adoption of radical innovations is highly affected by knowledge resources and size of the company, corresponding with findings of the aforementioned studies.

Additionally, Pierpaoli et al. (2013) emphasized the importance of in-field demonstrations, support services and free trials as measures related to the use of new technologies, since these practices help farmers to perceive the use of a technology as easy. Aspects such as ease of use and usefulness are central aspects for the adoption of a new technology. The authors also highlight the need for an intrinsic simplicity of a new technology to avoid incompatibilities among different tools as well as difficulties in using different technological devices simultaneously. Kafetzopoulos and Skalkos (2019) examined the innovation capability of Greek agri-food firms and identified quality orientation and process management as the two most important innovation drivers. According to the authors' findings, quality orientation within a company creates a productive environment for innovation development, whereas effectively managed processes lead to concentration on important issues as well as avoidance of irrelevant activities.

Soderlund, Williams, and Mulligan (2008) investigated the adoption of assurance systems as an innovation in different agri-food value chains. According to their study, numerous strong drivers were successful in embedding the innovation in everyday practices. In contrast, just one driver led to minimalist behavior. As an example, producers in the cherry chain only adopted the new assurance system with the sole purpose of gaining access to supermarkets. Furthermore, the authors found that high complexity and cost of this innovation represented a major barrier to the adoption by small cherry producers. Additionally, manufacturers, processors and packers within each agri-food value chain performed as hubs and set the standards for adoption of various forms of assurance within the chain. These findings are in line with a study from Fortuin and Omta (2009) who observed a very high pressure on food-processing companies from their buyers within the retail sector. This unequal distribution of power within the value chain was identified as a powerful driver for the engagement in innovation.

With respect to the acceptance of innovations within a company, Talukder (2019) examined drivers and barriers of technological innovations by individual employees. In this study organizational support was found to be an important factor for an uncomplicated adoption process. Therefore, management needs to provide the necessary administrative and technical support such as spreading of information to and training for employees. Additionally, motivation of employees such as proper incentives by means of recognition, job security, and increased autonomy were found to influence employees' willingness to try and finally practice a technological innovation. As for innovation barriers, too many innovative features as well as too frequent changes in these features were identified. Pantano (2014) studied the retail industry and identified three main factors which influence innovation. On the one hand, consumers are demanding innovation at the point of sale with respect to entertaining elements, which increase the quality of the shopping experience, as well as supporting tools, which enhance their empowerment. As further elaborated by Pantano and Viassone (2014), especially young consumers are interested in new technologies that allow a support of their purchasing decision. As examples, interactive tools for searching, comparing and tasting products are highlighted. Attention should be paid to privacy of consumer data, since concerns could reduce users' intentions to use these tools. On the other hand, Pantano (2014) identified the availability of new software tools which allow the understanding of market trends and prediction of consumer behavior as important innovation drivers. Using these tools, customized future advertising and selling strategies can be deployed to maintain competitive advantage. As for a third factor, the acceptance of frontline employees' of these new technologies seems to be of high importance, but current literature is still scarce in that regard.

According to Douthwaite et al. (2001), the adoption rate of a new technology is subject to the key stakeholders, the direct beneficiaries from an innovation, as well as the researchers who provide scientific background and were involved in the development of the prototypes. A working partnership between these two groups allows researchers to impart scientific knowledge to stakeholders as well as learn about the performance of the innovation in work environments. Using promising innovations in the context of agricultural technologies as examples, Douthwaite et al. (2001) furthermore illustrate that modifications made by the key stakeholders can lead to either beneficial or detrimental changes in the fitness of the new technology. Therefore, stakeholders and researchers need to work together to prevent that knowledge gaps result in mistakes, which impede the fitness of the innovation. Especially at an early release of a new technology combining key stakeholders' and researchers' involvement is crucial for generating rapid improvements.

4 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 portable 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 September 2018 the German Fruit & Vegetable Congress in Dusseldorf as one of the most important congresses within the German fruit and vegetable supply chain was used to make contact with actors along the supply chain as potential research participants. Since attendants of this congress hold key positions along the German FSC and deal with quality management on a daily basis they were asked to participate in interviews and to suggest potential candidates for additional interviews. As a result, interviewees from two producer cooperatives, three wholesale companies, one logistics enterprise and one food distribution center could be recruited. With the objective of describing the whole FSC from producer to food retail market, interviewees from production companies and food retail markets were recruited through the researchers' personal contacts. In total thirteen semi-structured interviews were conducted with actors on different steps of the FSC from companies in different parts of Germany from fall 2018 to spring 2019 (Table 1).

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 nine interviews were conducted via phone. The interviews lasted between 25 to 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 an easy 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. An interview guide was used and all topics were addressed over the course of the interview following the flow of conversation. Before conducting the first interview for the study, the interview guide was tested and adjusted for comprehensibility. Adjustments were made by rearranging questions to improve interview flow and rewording questions to facilitate interviewees' comprehension of topics. Questions addressing the motivation of supply chain actors were added to the interview guide halfway through the process of data collection, since this topic was brought up and deemed important. The procedure of adding questions and therefore extending the focus of a research project is in line with qualitative research procedures and indicates a maturing research process (Bitsch, 2005).

Table 1.
Interviewees and their background

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

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, the 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 by grouping codes together according to their meaning and the relationships between them. A category with three codes, respective definitions and examples of interview excerpts is provided as illustration of the analysis process (Table 2).

Table 2.
Codes for the category "motivation for the application of portable food-scanners" with excerpts from interviews

Code	Interview excerpt
Intrinsic motivation Interviewees' motivation is driven by intrinsic forces, e.g. to motivate employees, be innovative and distinguish oneself from competitors due to better quality	"Exactly, that is absolutely the case, to know the newest technology in our immediate environment, and then I have to decide for myself, yes that could be of interest for us, because we get better results, because we save time, because whatever. This motivation is absolutely there." (Quality manager of a wholesale company of fruit and vegetables)
Extrinsic motivation Motivation to apply food-scanners comes from outside the interviewees' own company	"At the very moment we have a requirement, from trading companies, from our customers, we have to deploy that, we have to produce results. And in order to produce reliable results I have to be ready in this moment to say okay, we will do it." (Quality manager of a producer cooperative)
Non-existent motivation At the moment there is no need and motivation for the application of food-scanners	"And at the moment, I don't see the need. I say now perhaps, as mentioned earlier, I am in the lucky position to have employees who can then also say: that is all right, this is not all right. (Owner-manager of a fruit production company)

5 Results

Results are structured into five parts. The first part describes the status quo of quality assessment along the supply chain, including the experiences of interviewees along the FSC in their day-to-day work. The second part analyzes their preferences and concerns regarding the implementation of portable 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. The fifth part characterizes different patterns of motivations of supply chain actors for implementing portable food-scanners as tools for quality control.

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. Since differences in these practices with regard to different supply chain steps (production, trade, retail) could be identified, the description is divided into these parts. According to interviewees from fruit production companies, quality, maturity as well as harvest date of fruit 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 fruit 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, as experience is 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 fruit to central markets and reach a high price marketing and commercial quality control standards 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 fruit 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, fruit is 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 (Figure 3). One interviewee stated that in addition to these objective measurements a degustation of fruit 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 standards regarding marketing and commercial quality control (UNECE, 2017) are met, on the other hand to fulfill customer-specific standards which can be stricter than the aforementioned standards. Some of these tests are described as elaborate and costly, e.g., the determination of sugar content or the brix/acid 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 marketing and commercial quality control standards (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 the retail 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 portable 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, portable 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 portable 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 by subsequent purchasers in the FSC. According to these critical voices, additional pressure for producers could arise due to additional quality requirements from fruit wholesalers, 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 required to allow long-term utilization of these devices and prevent frustration.

The application of portable food-scanners by end-consumers is viewed critically. Some interviewees 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 portable food-scanners as devices for the general public, but rather for small consumer-groups with special interests in health and diets.

On the other side, 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.

Another aspect critically discussed is the impact of the application of food-scanners on food waste. As a result of the above mentioned advantages like fast quality evaluation at incoming goods control, more and precise quality measurements could be required, 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 portable 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. Besides investment costs, the potential revenue of food-scanner applications also is of high importance. According to interviewees the application of food-scanners would be more realistic if additional benefits such as a higher number and more accurate test results as well as time-saving due to faster measurements could be achieved.

Another important aspect, 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 radical process innovation compared to traditional quality measurement procedures 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 accumulating evidence for the reliability of food-scanner predictions, these cross-checks would be terminated and the devices used independently. Several interviewees highlighted the importance of media reports, which describe and verify a high accuracy of measurement of portable food-scanners in order to be acknowledged as adequate tools for quality assessment. 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 (Figure 2). 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 fruit wholesale, 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).

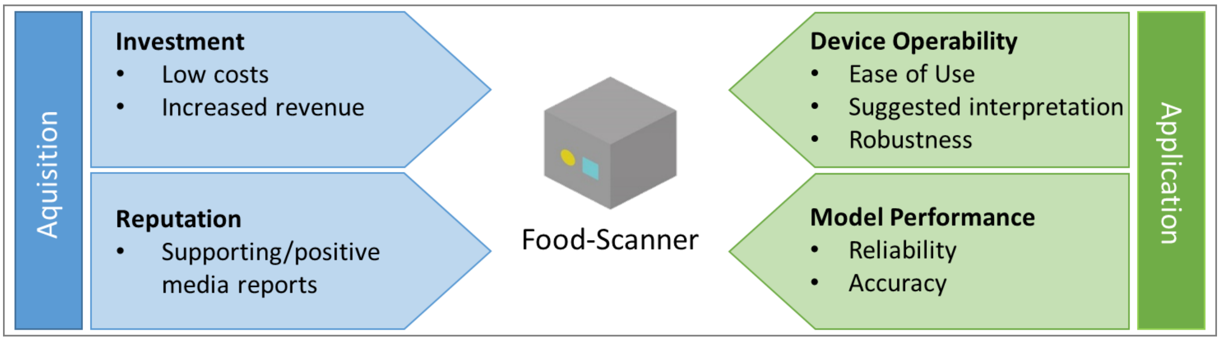

Figure 2. Requirements of food-scanner to be of practical use as stated by interviewees

Potential applications of food-scanners along the FSC

Interviewees perceived different fields of possible applications of portable food-scanners along the FSC. 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 or prediction of taste patterns such as sweetness of fruit 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, portable food-scanners could be used to determine optimum harvest time, ripeness and maturity of fruit, whereas wholesalers and retailers could profit from food-scanners by using them as tools for fast and objective quality assessment of incoming and outgoing produce. Additionally, these devices could be useful as decision support tools in retail markets to promote the internal quality of produce to a health-conscious target group.

Motivation of actors along the supply chain for implementing food-scanners as a tool for quality control

Although not specifically addressed by interview questions in the beginning, different patterns of motivation for the implementation of food-scanners as tools for quality assessment could be distinguished. In order to further evaluate this topic, questions addressing the motivation of supply chain actors were added in subsequent interviews. Some interviewees' motivation seems to be driven intrinsically. According to one interviewee, food-scanners could be helpful for profiling the quality of fresh produce up to the next step of the supply chain as well as distinguishing good from mediocre quality:

"As I have previously mentioned our aspiration is that we produce the highest quality, and there I don't have to hide and I would not be afraid of [the application of food-scanners], because when I say that, I want to have it and do it that way. […] But nevertheless there are black sheep [among producers] and I believe that especially those could be taken out of trading" (Employee at fruit production, male, 20-30 years old).

Furthermore, this sort of profiling of quality also seems of interest for retailers, where food-scanners could be implemented in advertising quality and new varieties of produce to customers. Compared to traditional quality control, this could provide additional value, as described by one interviewee:

"And so one would have this device as a tool. Then I could scan my tangerines in the morning and it tells me they are sweet and then I can attach an extra note and say 'today extra great'" (Department manager fruit and vegetables at retail market, female, 40-50 years old).

Besides profiling quality, aspiration for new technologies as innovation was identified as a form of intrinsic motivation of utilizing food-scanners. According to various interviewees it is important to stay up-to-date with technology. Given the above mentioned condition that prediction accuracy were guaranteed and devices passed cross-checks, application of these devices in daily work routine would not pose a problem. Furthermore, implementation of portable food-scanners would also be exciting and comfortable for employees compared to traditional destructive measurements.

In contrast to these intrinsic patterns of motivation, the second pattern can be viewed as extrinsic motivation. According to some interviewees, the implementation of food-scanners would have to be a requirement demanded by trade companies in order to continue business relationships. Since at the moment there oftentimes is no requirement in providing information about internal quality, companies have no benefit in performing and providing these measurement results. Additionally, interviewees described an already high and stressful workload, which does not allow the experimental implementation of a new and uncertain technology. Until buyers demand consequent internal quality measurements, an application in companies of these interviewees seems rather unlikely.

As for a third pattern, one interviewee seemed to have no motivation at the moment to implement food-scanners in his respective business in vegetable production. According to the interviewee's statements, he has no need to apply this technology since his employees are very well trained and know to distinguish good from bad quality from years of experience. Although being conservative in introducing this technology in his own company there is understanding for applying these devices in companies further down the supply chain where there is a higher percentage of untrained personnel and a larger variety of produce. There, portable food-scanners could constitute a technical support besides training courses to distinguish different qualities.

6 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, wholesale and retail companies. Quality determination is often highly dependent on trained and experienced staff performing subjective and mostly visual examination of produce. In addition, wholesalers often follow established protocols to ensure quality and conformity with standards. Various interviewees described portable 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 correspond 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. Additionally, potential applications which could arise through the implementation of food-scanners were described by actors along the FSC (Figure 3).

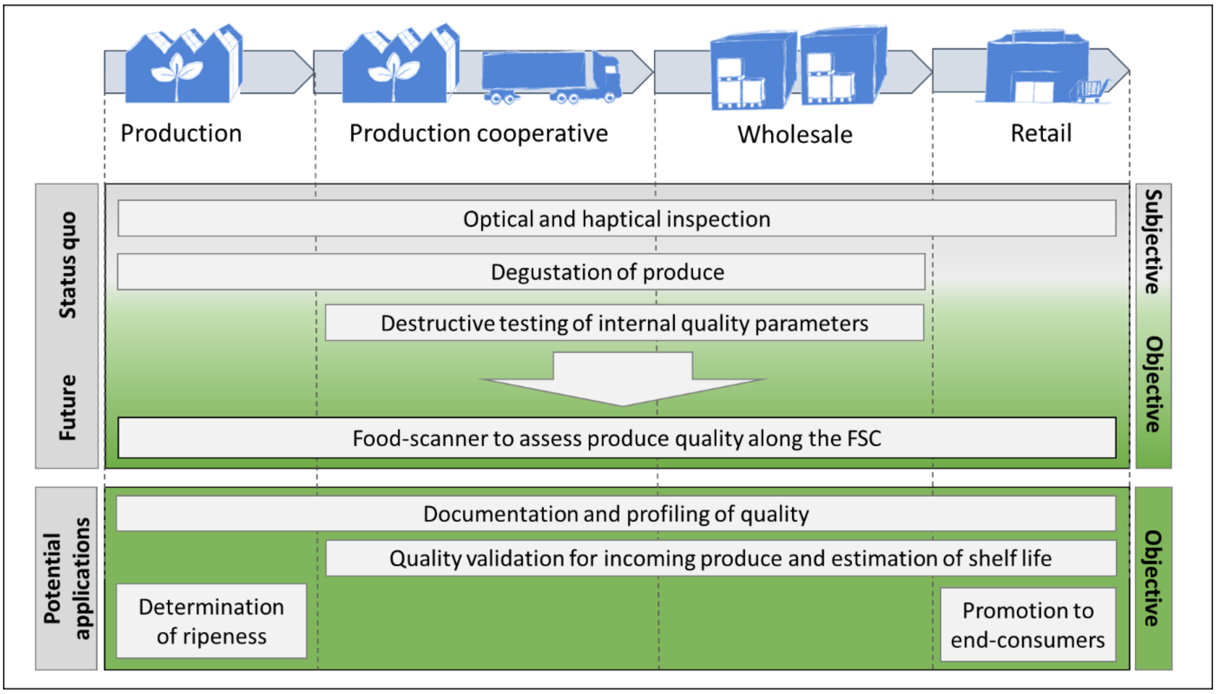

Figure 3. Status quo of quality assessment along the FSC and potential applications of food-scanners through their implementation along the FSC

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 as identified in this study and underline the advantages of NIR spectroscopy mentioned in the literature (dos Santos et al., 2013). Since the current 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 fruit wholesalers, resulting in further pressure for producers, were identified. These results confirm findings that small producers can face considerable challenges meeting the requirements of retail chains as described by Boselie, Henson, and Weatherspoon (2003).

The prior 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). With respect to consumer's complex decision-making process (Kaine, 2004), portable food-scanners could assist users during the step of information processing by searching, screening and gathering of information, therefore simplifying product evaluation and purchase decision. Onwezen and Bartels (2011) identified a health-oriented consumer group, which places value on healthiness, taste and safety aspects of food. According to interviewees' statements, especially these health-conscious consumers could benefit from food-scanner supported decisions. Results of the present study confirm the need for an easy interpretation of results (Popping & Bourdichon, 2018). Furthermore, results indicate that there are additional aspects that have to be considered with regard to the implementation of portable food-scanners, such as the impact on food waste. Drivers and barriers of the adoption of new and smart technologies by consumers have been identified in several studies (Antioco & Kleijnen, 2010; Arts, Frambach, & Bijmolt, 2011; Joachim, Spieth, & Heidenreich, 2017; Mani & Chouk, 2016) and should be considered by food-scanner manufacturers, especially when a widespread incorporation of miniaturized NIR spectrometers into the hardware of future smartphones is considered.

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 identified in the current study. To date, food-scanner systems require the connection to a mobile application and database provided by food-scanner manufacturers (Figure 1). In order to enable the integration of these devices in existing systems of information technologies, supply chain actors and food-scanner manufacturers need to work together to avoid a decrease in fitness of the innovation (Douthwaite et al., 2001). Otherwise, a too high complexity of this new technology could constitute a barrier for the adoption of food-scanners, as similarly described by Soderlund et al. (2008) for the implementation of assurance systems by cherry farmers.

Trienekens, van Uffelen, Debaire, and Omta (2008) assessed innovation and performance in the fruit supply chain by analyzing Dutch apple growers and a fruit cooperative. Their findings indicate that on the cooperative level, the most important innovations are process innovations. Furthermore, the most important critical success factor for innovation in a cooperative is process superiority, which refers to a fully automatic first-in-first-out (FIFO) system. There is a constant drive for innovation with respect to logistics, storage and processing techniques. When the application of food-scanners becomes feasible in the near future and the prediction of shelf-life is possible, this could lead to a shift from current standards like first-in-first-out to new standard systems such as a "least shelf-life, first-out". Therefore, produce with longer shelf-life could be stored for a longer period of time at cooperatives and allow produce which shorter shelf-life a faster turnover, preventing food-waste. At this moment, this potential development is a hypothesis which should be investigated in future research.

Additionally, the interviews performed by Trienekens et al. (2008) revealed that an information system, e.g., specialized newspapers, magazines, fruit advisor recommendations and visits to research facilities, is crucial for Dutch apple growers to keep up-to-date with new and emerging technologies. Results from the present study confirm these findings, since several interviewees highlighted the importance of media reports about these new devices with respect to reliability and accuracy of quality predictions. Measures such as in-field demonstrations and free-trials (Pierpaoli et al., 2013) as well as professional development courses (Läpple et al., 2015) have been highlighted as opportunities to promote innovation by broadening farmers' horizons. Therefore, information events and advanced training sessions could be first actions in promoting the application of portable food-scanners along the whole FSC.

Farm size, farmer's age, the level of education and the availability of financial resources have been described in the literature (Dewar & Dutton, 1986; Läpple et al., 2015; Pierpaoli et al., 2013) as factors influencing innovation adoption, but due to the qualitative nature of this study, these aspects were not deemed representative. Statements from interviewees on the production level regarding the intrinsic motivation to produce high quality are in line with findings from Kafetzopoulos and Skalkos (2019) and can be considered a driver for the adoption of food-scanners as an innovation. According to statements by one interviewee from a producer cooperative, food-scanners would only be implemented if they were stipulated requirements from their buyers. This result is in line with findings from Fortuin and Omta (2009) who identified high pressure from buyers and unequal power distribution along the value chain as powerful driver for the adoption of innovations. It is important to note that for future applications of food-scanners there should be additional incentives for providing these measurements, e.g., financial compensation for high quality produce. Otherwise the sole driver of applying food-scanners in gaining market access could lead to minimalist behavior, as described for agri-food assurance systems by Soderlund et al. (2008). Interviewees in retail markets deemed portable food-scanners useful as decision support tools for end-consumers, since these devices could help promote fruit quality to a health-conscious target group. This aspect confirms results from Pantano (2014) identifying consumer demand for innovations as the main driver in the retail industry. Therefore, new technologies could serve as entertaining elements and supporting tools enhancing the shopping experience and increasing consumers' empowerment.

Magwaza et al. (2012) described the commercial utilization of NIR technology in pack-houses and fruit sorting lines since the mid-1990s. The determination of maturity and sorting of produce according to ripeness are desired by actors as potential applications of food-scanners along the FSC as highlighted in this study. A recent study by Li et al. (2018) indicated the possibility of using portable 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, Ying, Lu, & Xu, 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).

According to Banks, Maguire, and Tanner (2000), "fruit industries of the world are beginning to recognize the revolutionary potential of technologies for characterizing invisible aspects of product quality" (p. 294). As they further specified, these technologies could help to separate fruit based on invisible traits such as storage behavior, susceptibility to shrivel, and flavor. Recent studies by Goisser et al. (2019) on shelf life prediction of tomatoes and Jamshidi, Minaei, Mohajerani, and Ghassemian (2012) on taste characterization of oranges indicate that NIR could be a technology with the potential of detecting such invisible traits. As the present study has shown, actors along the FSC also see possible applications of food-scanners in the prediction of taste patterns such as sweetness of fruit as well as the detection of internal fruit damage. Therefore, food-scanners could lead to a radical process innovation within the field of quality assessment of fruit, since conventional and time-consuming measurement procedures could be replaced and reduced to a minimum. As further elaborated by Banks et al. (2000), these new technologies could enhance consumers' eating experience in eliminating the current "unpredictable lottery of satisfaction" (p. 294), which at the moment is mainly based on outward appearance of produce.

The present study highlighted preferences and concerns of actors along the FSC with respect to the application of portable 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 development of the new technology according to the goals of food-scanner manufacturers as well as stakeholders along the FSC. To evaluate possible consequences due to food-scanners being used by end-consumers, future work should critically evaluate the general readiness of end-consumers in applying these devices in everyday life. Furthermore, to facilitate the widespread application of food-scanners it has to be possible to interpret predictions by food-scanners by non-experts.

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