A crowdsensing-based smartphone app for optimal food storage and real-time best-before dates

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Abstract: Private households are responsible for 59% of Germany's 11 million tons of food waste. Consumers' behavior significantly contributes to food waste, prompting our concept to develop a smartphone application aimed at diminishing uncertainties about food expiration and safety. Utilizing a Design Science approach, we developed a prototype for a smartphone app, integrating novel functionalities to minimize food waste at the consumer household level. We analyzed existing market applications and, as a result, introduced the Freshlimeter, a unique feature that estimates the real-time best-before date within our app using feedback from consumers. We also highlight the potential for innovative app features, such as integrating a chatbot with image recognition capabilities to enable freshness assessments, especially for unpackaged or opened food.

Keywords: agri-food chain, agri-food systems, design science approach, food waste, machine learning, smartphone application

1 Introduction

Every year in Germany, around 11 million tons of food are wasted. Private households produce the highest amount (59%) of this wastage [St23]. The origin of this excessive food waste can be attributed to several factors, most notably: 36.6% was due to the perception that the product was spoiled, 15.2% because it seemed unsavory, and 5.8% because of an expired best-before date (BBD) of which almost half is disposed in unopened packaging [SSC19]. Besides saving resources, a 50% reduction of food waste in private households, which the German government aims for until 2030, can save six million tons of CO_2-equivalent greenhouse gas emissions [BM23].

Some consumers are uncertain about the food's freshness. This uncertainty worsens when individuals lack knowledge or guidance on the product's shelf life and optimal storage

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conditions [Zi20]. Without clear information, such uncertainties can lead to premature disposal of edible food, contributing to the food waste problem.

To help tackle this, we propose a smartphone application to reduce food waste by enhancing the confidence of consumers' decision-making regarding the expired BBD for packaged products and the edibility of opened or unpacked products. The app distinguishes itself from existing applications by focusing on food items that consumers already possess. Users can scan products and receive feedback regarding the BBD based on reviews from other users. Further, the app offers information about the optimal storage conditions.

In the following, we present a comprehensive overview of the role of the app within the food supply chain. Additionally, we will showcase the app's user interface and functionalities and discuss future features that could enhance the app's value.

2 Design and Implementation of the Smartphone Application

This work follows a Design Science Approach [HMP04]. Hence, we developed a prototype of the app as a tool to reduce food waste. In this section, we present the smartphone app concept and its integration into the food supply chain. Further, we describe the app's user interface and implementation. The app was developed in Android Studio, using Kotlin. Kotlin, being concise and interoperable with Java, offers robustness and flexibility for Android development.

2.1 Concept and integration into the food supply chain

Fig. 1 shows the food supply chain as part of a digitalized agri-food system [KS24], with our app distinctly positioned at the final consumer stage. Arrows indicate the flow of information, illustrating how feedback from consumers, captured through the app, loops back into the system, benefitting both consumers and manufacturers. A central data repository is fed by the app data, stores data provided by manufacturers (product information) or retailers (discount promotion), and collects and aggregates consumer feedback on the BBDs. As a result, companies can retrieve and utilize this valuable consumer feedback. They also have the option, respecting data sovereignty, to share it with other institutions, such as consultancy firms or research facilities. This data is also used to calculate the *Freshlimeter* score, which indicates the consumability of a food product after exceeding the BBD. Additionally, the data supports a verification of the consumers' reviews. For both types of analysis, we plan to apply machine learning procedures; however, those metrics are not in the scope of this paper and, hence, omitted.

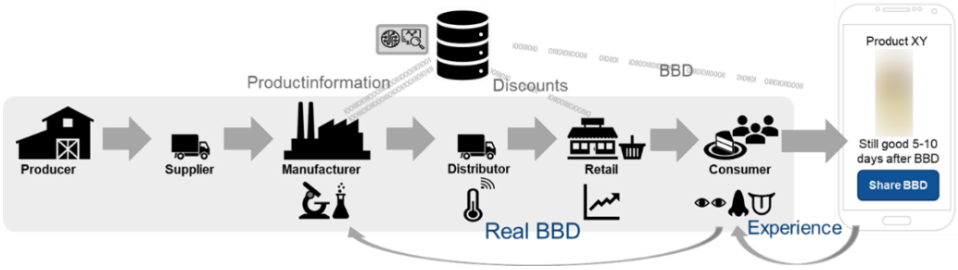

Fig. 1: Integration of the app into the food supply chain

2.2 User interface design

An intuitive and user-friendly interface is essential for app engagement. This study focuses on the functionality for determining food freshness and optimal storage conditions. Fig. 2 shows the design of this functionality, which we explain in the following.

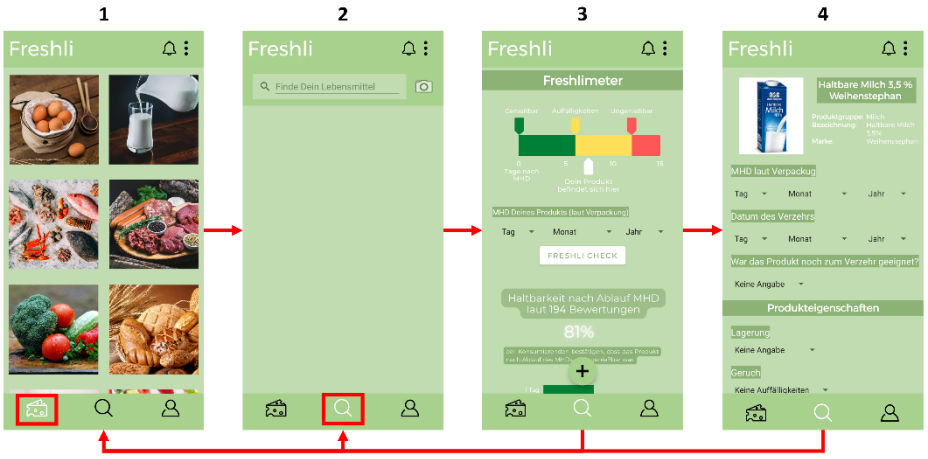

Fig. 2: Interface and interaction of the smartphone application; home screen (1); product search (2); product information (3); product feedback (4)

The home screen (1), indicated by the cheese icon (e.g., (1) bottom left) on the navigation bar, visualizes the product groups of a typical supermarket. Users can tap on any of these categories to access product information and their ideal storage conditions. Navigating to the products search functionality by clicking the magnifier glass icon (e.g., (2) bottom middle), users can effortlessly search for a product in multiple ways: (i) directly entering a product name into the text bar, (ii) using the built-in scanner to capture the barcode, or (iii) snapping a picture of the product package for a visual search.

The search function leads to the product information page (3). Along with general product details, the page presents the unique *Freshlimeter*, a traffic light system that provides an intuitive indication of the product's freshness status after surpassing its BBD. If available, the user can input the BBD of the product to get a personalized freshness assessment based on collective user experiences. The app offers to share product experiences using a standardized form when accessing the consumer feedback page via the plus sign (4). The forms entail details about the product's BBD, consumption date, acceptability, and specific characteristics like taste, smell, and texture. Users also provide information about storage type and a consumption experience rating on a scale from 0 (unable to consume) to 5 (perfectly fine). Additionally, they can leave further comments. This data is assimilated upon submission to refine the app's prediction model for the freshness assessment.

The freshness assessment described above is mainly suitable for packaged food due to the availability of a BBD on the package. A different approach is required for opened or unpacked food since the BBD no longer applies or is missing. For these cases, we plan to integrate a digital assistant designed to simulate human-like dialogue, embark on queries, and provide feedback tailored to the user's responses. This chatbot can offer an educated assessment of the food item's freshness by matching user descriptions with pre-programmed knowledge, such as a sour taste indicating fermentation. However, this approach might need adjustment to cover the different needs of users by integrating an advanced image recognition system into the application to bridge this potential gap. This function enables users to capture a photograph of their food item and compare it against a database of reference images. Each image in this database is tagged with various freshness stages, serving as a visual benchmark. Users will also be able to compare their food to existing pictures provided by the chatbot due to their description to tackle the limitations of picture quality differences. However, this technology exceeds the scope of this paper and will be part of future research.

3 Discussion

In this section, we discuss the capability and limitations of the app prototype based on the previously described features. Furthermore, we conducted a preliminary study with ten students (21-29 years) to evaluate the app prototype; the following section will discuss the insights and results.

3.1 App capability and limitations in minimizing food waste

Factors that can increase or decrease the likelihood of app utilization, regarding consumer satisfaction and loyalty, can be summarized to four thematic areas: learning benefits, personal benefits, social benefits, and hedonic benefits [Sh23]. The app supports users in learning the best food storage practices and clarifies real BBDs of products, going beyond just their stated expiry dates. Significant advantages include reduced expenses from

extended food life and minimized wastage, combined with peace of mind by removing uncertainties regarding freshness. The ability to share reviews facilitates community engagement, empowering users to benefit from shared experiences and insights.

In this preliminary study, the participants expressed difficulties interpreting the *Freshlimeter* on the product information screen. The freshness assessment further compounded this confusion since its presence was not immediately apparent to them. Enhancing its visibility or positioning it more prominently on the page could ensure that users recognize and utilize this essential functionality more intuitively. Furthermore, presenting users with both the *Freshlimeter* and a bar chart on the same page made the information feel dense and overwhelming. Given the consistent feedback, prioritizing one of these visualization tools and centering it on the page can improve the user experience. The feedback mechanism was straightforward and intuitive, suggesting that universal symbols can effectively guide user actions without explicit instructions. The participants also emphasized a distinct need for assessing the freshness of unpacked foods, given their lack of "best before" indications compared to packaged items. Since the chatbot approach was not part of the prototype development, evaluating this feature was impossible.

Furthermore, the data aggregated from these interactions holds immense value. It can offer important feedback to food producers and manufacturers, allowing them to refine their processes based on real-time consumer and industry insights. This proactive approach ensures the maintenance of high-quality standards across the food supply chain.

4 Conclusion and Outlook

This work investigated the design of a smartphone application concept to reduce food waste. Therefore, a prototype of the proposed app was developed. Despite challenges in design and functionality, the app concept presents a promising tool for addressing food waste effectively, not just for consumers but throughout the food supply chain. Though the app educates about optimal food storage and real BBDs, our preliminary study highlighted areas for improvement, such as enhancing the visibility and user-friendliness of the *Freshlimeter*.

Given that unpacked food plays a significant role in the uncertainty and gaps in storage knowledge, the app's emphasis on chatbot-like support for supporting consumers in the decision of the edibility of food is an interesting planned future work. For this, we propose the implementation of a chatbot integrated with image recognition capabilities. We are establishing a testbed to assess food freshness by measuring emitted aroma components throughout storage time with metal-oxide sensors. This research also incorporates destructive measurement methods and image-based analysis to create a freshness assessment model. The resulting digital food twin [KNB22] will be integrated into the chatbot to evaluate food freshness according to user responses, considering varied storage conditions and common consumer errors. While the primary aim is to reduce household

food wastage, the application's potential utility extends far beyond individuals. This tool can be deployed across the whole agri-food chain. Employees can swiftly assess product quality without special training at transportation stages or points of sale. Similarly, consumers can use the tool's capabilities during shopping trips for on-the-spot evaluations. There is an opportunity even at the first stage of food production, i.e., harvesting. Farmers and agricultural workers could use the tool to detect and separate spoiled goods instantly, ensuring that only the freshest produce makes its way to the market.

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