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Review

Integrated science-based approach to study quality changes of shelf-stable food products during storage: A proof of concept on orange and mango juices☆

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ABSTRACT

Background: Defining the exact shelf-life of a shelf-stable food product is still a real challenge for food manufacturers as there are many variables to be considered. Currently, many shelf-life determinations of commercial shelf-stable products are based on trial-and-error methods which could pose risks resulting in brand damage (overestimation) or food waste (underestimation). Because degradation reactions determining shelf-life are really complex, predicting quality changes remains a challenge; consequently, a scientific approach which considers multiple variables is greatly needed. Recent advances in analytical methods (e.g. GC-MS fingerprinting) and data analysis techniques (e.g. multivariate data analysis and kinetic modelling) can play a key role in this context if they are used in (accelerated) shelf-life studies. Moreover, the role of sensory evaluations should not be forgotten as changes in sensorial properties or decreases in consumer acceptance levels as a function of storage time are in most cases the primary reasons for defining the end of shelf-life.

Scope and approach: This review paper focuses on research progresses in this field and addresses future challenges for quality investigation during storage and prediction of shelf-life dates. As proof of concept, the paper focuses on investigating quality changes of pasteurised shelf-stable orange and mango juices during storage.

Key findings and conclusions: In the study of shelf-stable orange and mango juices, the (combined) analytical targeted and untargeted fingerprinting approach proved to be a useful approach for identifying major-quality related chemical changes and was able to select shelf-life markers (i.e. quality parameters with a clearly observable time- (and temperature-) dependent change). In studying the kinetics of change of the monitored quality attributes, it is tempting to think that the fastest reactions will determine the shelf-life of a shelf-stable product. However, consumer acceptance through sensory evaluation plays also an important role in determining the acceptability limit and therefore the best before date. The integrated science-based approach put forward can be used to investigate quality changes of a wide range of shelf-stable products during storage.

1. Introduction

The growing need for increased food sustainability should boost the need for more accurate shelf-life predictions. In addition, the rapidly changing food product portfolio (due to new product formulations, new packaging materials or new technologies applied, etc.), results in a daily need for new/updated shelf-life dates (Man, 2015; Stone & Sidel, 2004). Shelf-life is generally known as the period of time during which a food product maintains its acceptable characteristics under specified storage conditions. On a food label, shelf-life can be indicated by either a 'best before' date which refers to the quality of the food or a 'use by' date which is linked to the food safety (EUFIC, 2013). In case of a shelf-stable product, shelf-life is determined by a decrease in quality (mostly food sensory characteristics, such as colour, aroma or taste) rather than safety. Having an accurate shelf-life prediction is important not only for food industries but also for consumers (Giménez, Ares, & Ares, 2012).

From food manufacturers point of view, defining an exact shelf-life of a food product can be a real challenge as there are many variables to be considered. Factors determining shelf-life range from intrinsic factors inherent to the food (e.g. product composition) to extrinsic factors

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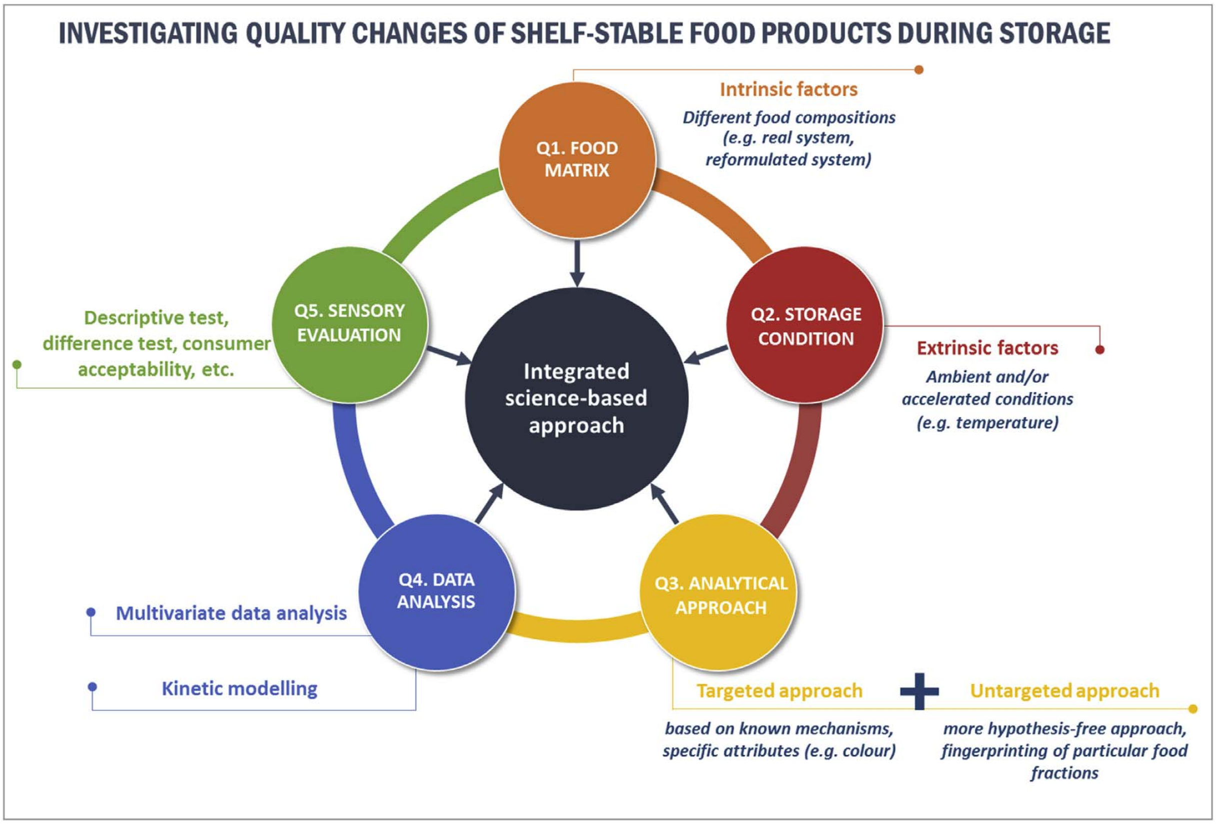

Fig. 1. Schematic representation of the integrated science-based approach for investigating quality changes of shelf-stable food products during storage. Q1. How to understand the influence of the intrinsic food matrix characteristics (e.g. food composition ranging from a simple model to complex real food systems)?; Q2. How to evaluate the impact of extrinsic storage conditions (e.g. normal and/or accelerated conditions)?; Q3. How to combine a range of analytical approaches (e.g. targeted, untargeted and a combination of targeted and untargeted approaches)?; Q4. How to apply various data analysis techniques (e.g. multivariate and kinetic modelling)?; and Q5. How to integrate instrumental and/or sensorial evaluations?. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

(e.g. storage conditions) (Kilcast & Subramaniam, 2000). New shelf-life estimations will be needed at every stage of new product development as well as when changes in formulation, processing technology, packaging and/or storage are applied (Nicoli, 2012). When the determination of the best before date is done inappropriately, several drawbacks could arise, such as brand damage or food waste.

For a commercial shelf-stable product, shelf-life determination based on a shelf-life study can be a time-consuming task. Consequently, food industries often conduct an accelerated shelf-life test (ASLT) in which degradation reactions are expected to be accelerated (Calligaris, Manzocco, & Lagazio, 2012; Taoukis, Labuza, & Saguy, 1997). In practice, many determinations of a product shelf-life are based on past experience, product competitor data and/or using trial-and-error methods. Such procedures pose a risk that the shelf-life of the product is being overestimated or underestimated. This is more likely for new products with no or low company historical experience (Calligaris, Manzocco, Anese, & Nicoli, 2016). When shelf-life is overestimated, it could be that the product has lost its quality and acceptability. Consumers can file a complaint and this consequently could lead to the damage of the company's brand and reputation. Another drawback can be related to unnecessary food waste in the case that shelf-life is underestimated. Usually food manufacturers declare the product expiration dates at earlier date than the actual dates to avoid brand damage. Many studies found misconception about shelf-life dates among consumers, particularly on the differences between ‘best before’ and ‘use by’ dates, resulting in spoiling food which pasts its ‘best before’ date, but is still perfect for consumption. This cause of food waste has been identified as a major contributor to household food waste (Leib et al., 2017; Priefer, Jörissen, & Bräutigam, 2013; WRAP, 2011; Williams, Wikström, Otterbring, Löfgren, & Gustafsson, 2012).

Consequently, there is a pressing need to estimate shelf-life dates more adequately, preferentially using a science-based approach. For many years already, researchers have made use of kinetic models to describe major quality changes in foods. By extrapolating the kinetic parameters data, including acceleration factors, to normal storage conditions, shelf-life of the products can be estimated. In ASLT, the validity of the model should be verified at the actual condition (Kilcast & Subramaniam, 2000; Labuza & Schmidl, 1985; Robertson, 1999).

Many studies until now followed a conventional targeted approach which focused on known reactions, specific quality attributes or compounds. However, because the degradation reactions determining a food shelf-life are very complex, it is possible that multiple reaction pathways and compounds which are responsible for quality changes may have not been explored yet. Also, in the context of developments of new technologies or new packaging materials it could be that other reactions become more important and unexpected changes are overlooked. Therefore, giving the complexity, but also the unexpectancy of the behaviour, from an analytical point of view, investigating food quality changes should consider multiple variables. Looking at recent advances in analytical methods and data analysis, many studies have reported the use of untargeted approaches and multivariate data analysis in the area of food quality research (Castro-Puyana, Pérez-Míguez, Montero, & Herrero, 2017; Grauwet, Vervoort, Colle, Van Loey, & Hendrickx, 2014; Kebede et al., 2015; Liu et al., 2014a; Vaclavik, Schreiber, Lacina, Cajka, & Hajslova, 2012; Vervoort et al., 2012). In this context, the analytical platform usually consists of separation methods such as liquid chromatography (LC) and gas chromatography (GC) and detection methods such as nuclear magnetic resonance (NMR) and mass spectrometry (MS). Concerning statistical data tools, the large quantities of data generated by chromatographic techniques and