Testo Food Solutions
Whitepaper
First Expired – First Out

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First Expired – First Out:
Improve food quality and reduce costs with the FEFO method.

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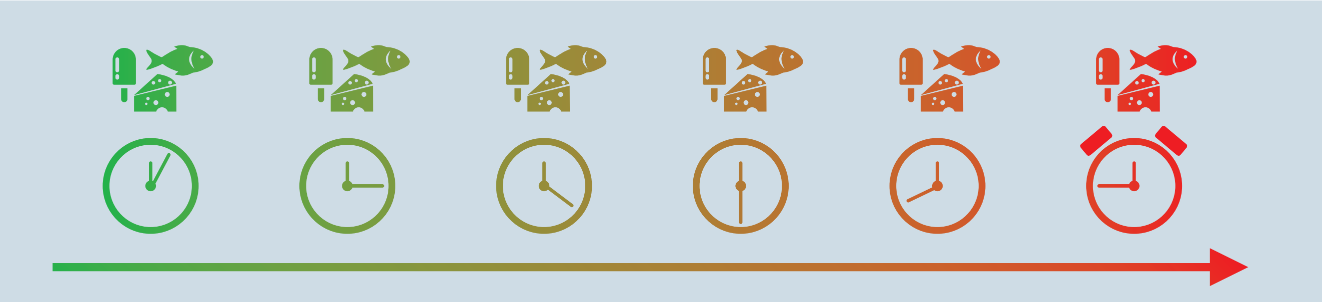

A loss of 30% of all food produced worldwide occurs along the value-added chain "from farm to fork" every year. This corresponds to approx. 1.3 billion tonnes.[1] When it comes to fruit and vegetables, the loss rate is particularly high, amounting to almost 50%.

In order to meet the food requirements of an ever-growing global population, the focus in terms of perishable and processed food must be on intelligent logistics, so as to minimize existing food losses.[2]

The most frequently used method up to now was the First In – First Out (FIFO) method. as far as possible, stocks stored first are used first. However, perishable foods such as fruit and vegetables are less well suited to this procedure, since just because something was harvested earlier, does not mean that it will stay fresh longer.

We can only ensure efficient optimization of food logistics processes and an appreciable reduction of food losses when we understand exactly how foods behave along the value-added chain and how they react to outside influences. One method that makes it possible to achieve this is First Expired – First Out (FEFO).

This document explains what factors affect the ripening process of fruit, vegetables and plant products, what exactly FEFO is and what benefits are derived from it.

1. Influencing product quality

The quality of fruit, vegetables and plant products comprises many characteristics, such as colour, texture and taste. It also depends on specific product properties, such as the sugar content or the cell wall structure.[3,4]

In general, quality always diminishes over time. In spite of every effort, post-harvest handling does not improve the quality of the products. This means that product losses can only be delayed.

The quality of easily perishable foods is therefore a dynamic variable. It changes over time at different speeds. Physiological, physical, microbial and chemical processes are among the factors that initiate ripening processes and are jointly responsible for food losses. However, if there is targeted intervention in the storage, packaging and transport conditions, these processes can be inhibited and/or delayed.

Product quality is influenced by the following factors along the supply chain, which means that these must be taken into account when calculating the remaining shelf life:

- Temperature
- Relative humidity
- O_2 and CO_2 concentration
- Ethylene (phytohormone) concentration
- Light
- Mould contamination

1.1. Temperature

Temperature influences enzymatic and non-enzymatic processes in fresh and processed products. Low storage and transport temperatures extend the shelf life of most products. There are some exceptions: Tropical fruits, for example, are sensitive to temperature. Too low temperatures have a negative influence on their quality. In order to ensure the shelf life and quality of the products, a suitable (usually low) temperature is set during the entire transport.

Ideally, the cold chain starts immediately after harvesting or slaughtering and does not end until the food is on the consumer's fork. As Huelsmann and Brenner showed in a review of the literature, interruptions to the cold chain can have dramatic effects on food quality and losses.[5] The authors found more than 100 reports about problems during storage or transport. What they describe includes faulty temperature management, blocked air circulation in refrigerated rooms or dramatic temperature fluctuations as influencing factors. In terms of transport by ship, it was striking that the refrigerated containers used may need up to two weeks to reach their target temperature.

1.2. Relative humidity

Mechanical refrigeration removes humidity from the air, which means the selling weight falls and the appearance of the product may be affected by shrinkage or wilting.[6] In order to minimize water loss, it is necessary to ensure proper packaging or additional humidification, as well as refrigeration.

On the other hand, if humidity is too high, microbial decay may begin. Humidity is therefore the second most important parameter influencing the quality of food, whether it is dry, fresh with a high water content or processed. This means constant monitoring of this measurement parameter is essential during transport and storage.

1.3. O_2 and CO_2 concentration

After the harvest or minimal processing, many fresh foods continue the active metabolic process, in order to keep the tissue intact. The food's metabolic process can be controlled by exerting appropriate influences on the O_2 and CO_2 content in the storage environment. If the O_2 content is reduced and the CO_2 content increased, the metabolic rate is taken down to the minimum level and the shelf life is thus increased.[7,8] In addition, a higher CO_2 content inhibits microbial growth.[9]

1.4. Ethylene

Ethylene is a phytohormone which specific fruit and plants react to. This means it is also an indicator of the ripening process of fruits, amongst other things. If climacteric fruits are exposed to a specific ethylene concentration, their ripening process starts. This involves them producing ethylene. The amount of ethylene produced by the fruits varies depending on the degree and type of ripeness. The ethylene concentration inside a container for climacteric fruits therefore correlates directly with its degree of ripeness, which means it is of significant importance in terms of quality monitoring.

2. Shelf life models

The effect of temperature deviations on the quality and remaining shelf life of goods can be estimated using shelf life models.[10] These are based on Arrhenius's law of reaction kinetics (1.1). It describes the quantitative dependence of the reaction rate constant k_N on the temperature.

$$k_N = k_{RN} \cdot e^{\frac{E_N}{R_{gas}} \cdot \left(\frac{1}{T_R} - \frac{1}{T}\right)} \qquad (1.1)$$

k_N= Reaction speed constant
k_{RN}= Arrhenius factor
EN= Activation energy
R_{Gas}= universal gas constant
T= Temperature

By combining several Arrhenius terms, the shelf life or sensitivity of different fruits can be approximated (fig. 1).

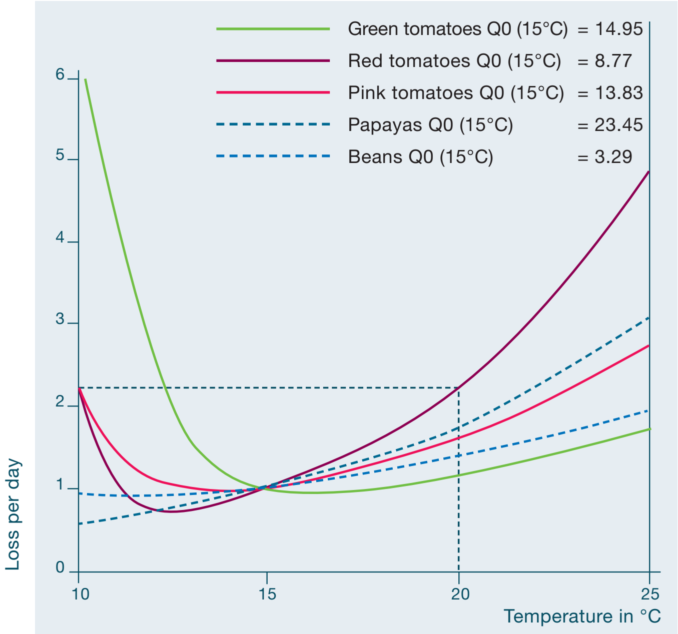

Fig. 1. Loss per day for typical tropical fruits.[11]

Shelf life models firstly describe the changes in quality which products face during processing or transport and secondly how this information can be implemented in warehouse management systems. This involves shifting the emphasis from the classic First In – First Out (FIFO) to the First Expired – First Out (FEFO) approach. This enables losses extending over the entire supply chain to be prevented and means that customers always get products which meet their requirements.[12]

Variance in terms of food quality and remaining shelf life are automatically calculated based on data collected regarding the ambient conditions (e.g. temperature). The different shelf lives are then used by warehouse management to align the shelf-life with any inventories, route plans and possible special treatments of specific products.
Because there have so far not been any automated systems which record data and calculate shelf lives, FEFO is only very seldom used in practice.[13]

The actual condition of food is often really difficult to measure and cannot be determined externally. A red tomato may for instance be in perfect condition for two more weeks or already be spoilt the next day. Generally speaking, the remaining shelf life cannot be directly measured. However, it can be forecast using biological models. These calculate the effect of cumulative temperature values and other influences.[14]

The challenge lies in the fact that an automated system of this kind for monitoring food quality requires an integrated approach. This means that experts from the sensor systems, communication sciences, predictive biology and food technology fields have to work together with transport companies and supply chain managers.

3. The FEFO principle

FEFO (First Expired – First Out) is a storage method which, in contrast to FIFO (First In – First Out), does not use a fixed, printed date of production as the basis for decision making, but rather the actual quality (also referred to as the dynamic use by date). The crucial criterion for taking goods out of stock is their remaining shelf life. The method serves to minimize risks in storage. This enables a guarantee that products will arrive with the expected quality and food losses during transport will be avoided.[15] In a nutshell, FEFO means that the goods used first are those which have progressed furthest through the ripening process.

Foods are highly sensitive goods. When it comes to fruit and vegetables, losses of up to 30% may occur during transport and storage due to temperature discrepancies. Accurate temperature management and monitoring, along with application of the FEFO method, can significantly reduce the loss rate right along the logistics chain.[16] FEFO assumes that the residual quality or remaining shelf life of each pallet or shipping unit can be assessed by appropriate sensor-based monitoring.

3.1. The method

The goods taken out of stock are always those whose remaining shelf life is consistent with the remaining transport time. Goods with short remaining shelf lives are shipped as soon as possible to purchasers in the immediate vicinity, whereas goods with longer remaining shelf lives are retained for more distant purchasers or later deliveries. This is described by the term dynamic FEFO, first used by Lang et al.[17] Through this, they emphasize that a product's delivery assignment is not fixed, but can be adjusted at any time to new information and shelf life variations.

3.2. Reduction of losses

Harvest conditions are never the same. And the times before refrigeration starts vary, just as the conditions in the refrigerated container/vehicle do. Variations in the quality of fresh foods are therefore unavoidable. By monitoring the quality of the goods and using FEFO, losses can be reduced in transport management and during storage.

The bar chart (Fig. 2) shows comparative losses from three different studies: depending on the type of goods, there may be savings of between 8 and 15%. However, the prerequisite is temperature and quality monitoring at a pallet level.

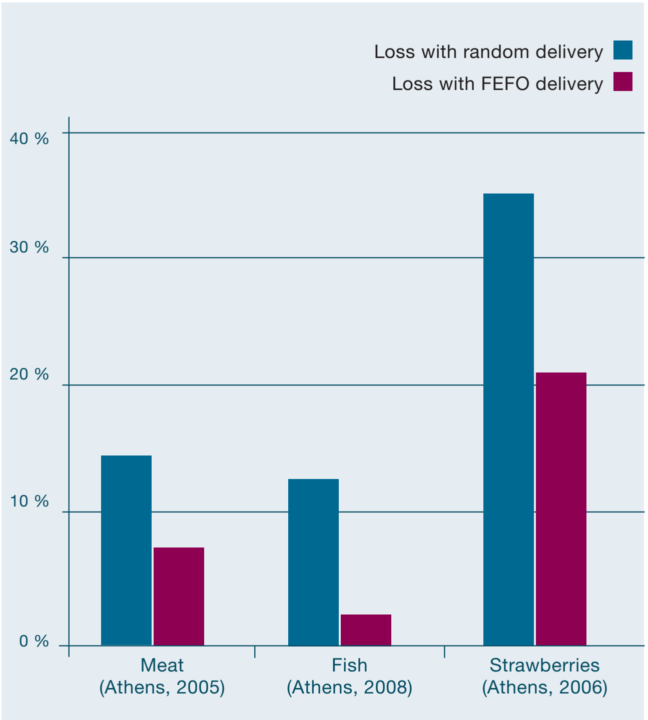

Fig. 2. Comparison of the losses for different foods determined in three studies.[18]

The reduction of losses is based on the fact that the reduction (variance) of quality is minimized with FEFO. On the other hand, in principle the mean value for quality cannot be improved.

However, the lower variance reduces the proportion of goods whose quality is below a critical threshold (red area in Fig. 3).

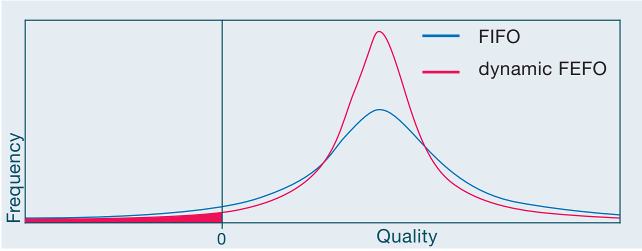

Fig. 3. The effect of dynamic FEFO shows that the proportion of unacceptable products can be significantly reduced.[19]

3.3. The benefits of the FEFO principle

- Lower losses of products during transport
- Lower costs for producers
- Reduced environmental pollution, because there is no longer any transport of decaying goods
- The variance of the quality of the goods is reduced, which enables customers to be provided with higher and more consistent quality
- Less food is thrown away, because it is fresher when it reaches the customer
- More profit for all those involved in the process chain

4. Testo – your food safety expert

For 60 years, Testo has stood for innovative measuring solutions Made in Germany. As a world market leader in portable and stationary measuring technology, we support our customers in saving time and resources, in protecting the environment and human health and in increasing the quality of goods and services.

2,700 employees work in research, development, production and marketing for the high-tech company in 32 subsidiaries all around the world. Testo impresses more than one million customers all over the world with high-precision measuring instruments and innovative solutions for the measurement data management of tomorrow.

In the food area, our comprehensive range of measuring technology, measurement solutions and services is used on a daily basis by producers, supermarkets, restaurants and catering businesses and is indispensable when it comes to food safety and food quality.

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