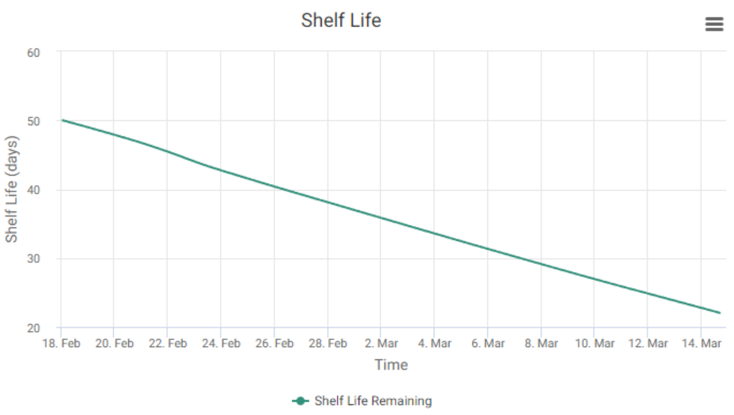
Hemdahl™

Shelf Life Prediction

Ver 1.0

Shelf Life

Product	Grape
Shelf-life Model	Q10
Controlled Atmosphere	No
Product Shelf Life	1 months, 20 days
Reduction due to Trip Length	24.6 days
Reduction due to Storage Conditions	3.3 days
Total Shelf Life Reduction	28 days
Shelf Life Remaining	22 days
Relative Rate of Spoilage	Good (1.14)
Shelf Life Risk	LOW

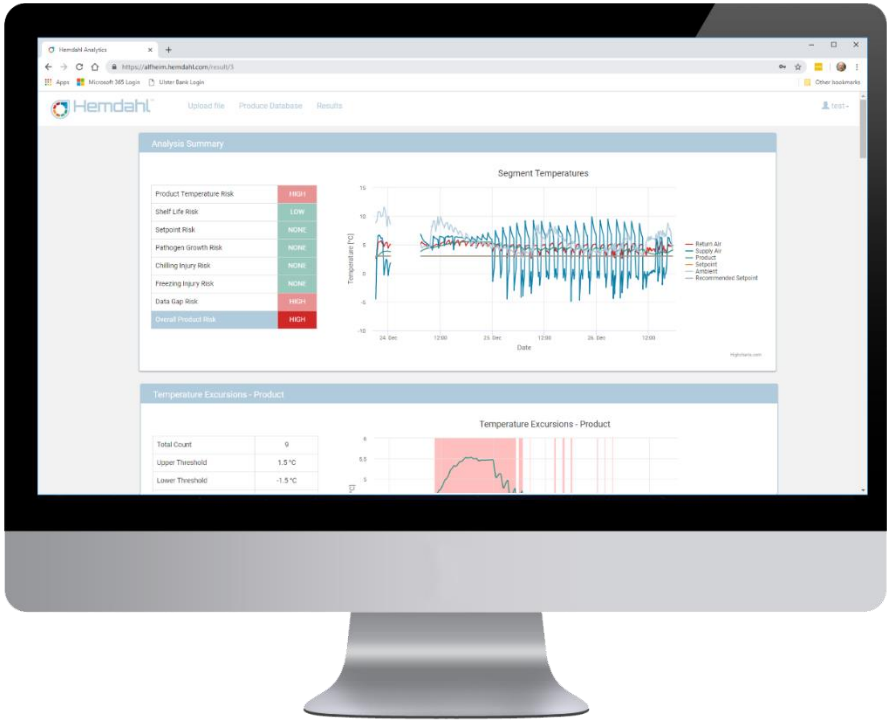


INTRODUCTION

Accurate prediction of remaining shelf life for perishable food products is highly desirable, and allows for better decision-making when temperature excursions have occurred in the cold chain.

Accurate shelf life prediction can allow us to:

- Remove food from the cold chain that could be harmful to humans and animals.
- Remove food from the cold chain that would not meet quality criteria for consumers.
- Reduce waste by not discarding food that is safe to consume.



In this whitepaper, we define what we mean by shelf life, explain the importance of temperature on the shelf life of perishable produce, and consider various data-based approaches to predicting product shelf life using available temperature data.

An accurate data-based model allows for scalable and consistent prediction of remaining shelf life at every stage of the cold chain.

WHAT IS SHELF LIFE?

All food products are composed of biological materials. Biological materials spoil and deteriorate over time. The shelf life of a food product can be defined as:

The time period within which the food product is safe to consume and/or has an acceptable quality to consumers.

From a consumer's point of view, there are three main properties that determine acceptable quality:

- Taste
- Smell
- Appearance

However, there two additional considerations for shelf life which may not be obvious to the consumer:

- Growth of harmful pathogens
- Loss of nutrients, (e.g. Vitamin C in vegetables)

The growth of harmful pathogens is of particular concern for perishable foods, and can render products unfit for human consumption.

FACTORS AFFECTING SHELF LIFE

There are a range of factors that can affect product shelf life. These are normally divided into two groups:

Intrinsic Factors

Intrinsic factors are characteristics of the product itself. These include:

Ingredient quality

Formulation

pH (acidity/alkalinity)

aW (water activity)

Preservatives

Extrinsic Factors

Extrinsic factors are characteristics external to the product. These include:

Processing

Handling

Storage Temperature

Packaging

Oxygen availability

Why Temperature Is Important

Storage temperature and oxygen are the most critical extrinsic factors, as they affect the widest range of food products and have the largest effect on shelf life.

In some cases, it is possible to try and control the oxygen levels in order to extend shelf life. For example, controlled atmosphere shipments in marine containers.

Far more common however, is the control of product temperature to extend shelf life. Controlling product temperature has a greater effect on extending product shelf life, slows the growth of harmful pathogens, and is more cost effective than other strategies.

The important effect of temperature on deterioration rates has long been the subject of scientific research, and a significant number of studies on the deterioration of various quality indices of food (physical, chemical, microbiological or sensory) have been published.

Researchers have found that by analysing the temperatures at which perishable food products have been stored, it is possible to predict the effect of the storage temperatures on product shelf life.

All chemical and biological processes require energy. This includes the spoilage mechanisms for perishable food products. Scientists have long known that higher temperatures (i.e. more energy) leads to faster reactions, and lower temperatures (i.e. less energy) leads to slower reactions.

Several models have been developed that describe the relationship between the rate of these reactions and the storage temperature of the food product.

The two most widely used shelf life prediction models are known as Arrhenius and Q_{10} respectively.

Arrhenius Formula

The Arrhenius formula relates the rate of a chemical reaction to temperature. This formula is widely accepted in the food safety industry as an accurate model for estimating the deterioration of shelf-life over time.

The Arrhenius formula was originally developed for reversible molecular chemical reactions, but has been experimentally shown to hold for a number of more complex chemical and physical phenomena, including the spoilage of perishable food products.

Mathematically, Arrhenius can be expressed as:

$$k = k_a \exp\left[\frac{-E_a}{RT}\right]$$

Where, k is the reaction rate, k_a is the reaction rate constant, E_a is the activation energy, R is the universal gas constant, and T is the absolute temperature (in degrees K).

We can see from the formula that as temperature (T) increases, the reaction rate (k) increases exponentially, and hence the shelf-life decreases exponentially.

We can also see that decreasing temperature results in a reduced reaction rate and a longer shelf life.

Thus, the Arrhenius formula can be used to predict the shelf life of food by providing a mathematical model for how the rate of spoilage of perishable products varies with temperature.

Q_{10} Formula

The Q_{10} formula is used to estimate how changes in temperature affect the rate of chemical reactions in perishable foods, and therefore can be used to predict the shelf life of food products. The Q_{10} formula is widely accepted in the food safety industry as a useful model for estimating the deterioration of shelf-life over time.

The temperature coefficient (Q_{10}) is usually defined as the factor by which the rate of a reaction increases for every 10-degree (C or K) rise in temperature.

The Q_{10} formula can be expressed mathematically as:

$$Q_{10} = \left[\frac{R_2}{R_1}\right]^{\left[\frac{10}{T_2 - T_1}\right]}$$

Where R_1 is the reaction rate at temperature T_1, and R_2 is the reaction rate at temperature T_2.

We can see that for examples where $T_2 > T_1$ the reaction rate R_2 is also greater than R_1 for a given Q_{10}.

The Q_{10} formula can be rewritten as:

$$R_2 = R_1 Q_{10}^{\left[\frac{T_2 - T_1}{10}\right]}$$

Since shelf life is inversely proportional to reaction rate, we can express the relationship between two shelf lives (L_1 and L_2) at different temperatures as:

$$L_2 = L_1 Q_{10}^{\left[\frac{T_1 - T_2}{10}\right]}$$

For a given Q_{10} factor, we can see that as temperature T_2 increases compared to T_1, the shelf life L_2 decreases exponentially with temperature, similar to the Arrhenius formula.

The value of Q_{10} may vary per food product to take into account differences in properties of each product, preparation, packaging, etc.

HEMDAHL SHELF LIFE MODEL

The Hemdahl shelf-life model supports both Arrhenius and Q_{10} formulae. In each case, a proprietary variant of the standard formula has been developed to deliver accurate and reliable shelf life prediction based on varying temperatures.

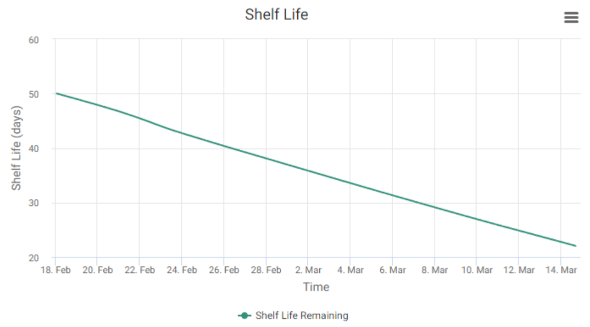
Different values of k_a (Arrhenius) and Q_{10} are used for different food products to take into account different properties of each product.

This results in a choice of models that can be used to give useful shelf-life predictions for a variety of food products in a real-world variable temperature environment.

The Hemdahl shelf-life prediction model (known as Bifrost) was validated against several well-known shelf life prediction tools. The Hemdahl shelf-life prediction models were also validated against measured experimental data.
Several examples of Hemdahl model validation are given in the following pages.

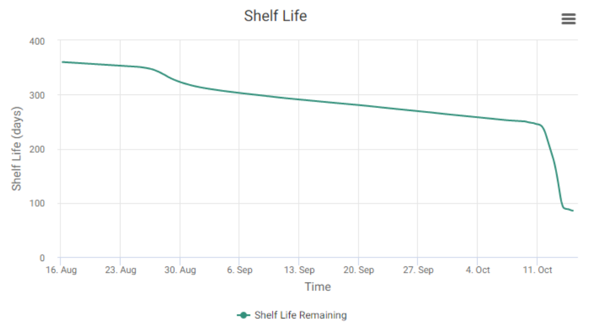
Shelf Life

Product	Grape
Shelf-life Model	Q10
Controlled Atmosphere	No
Product Shelf Life	1 months, 20 days
Reduction due to Trip Length	24.6 days
Reduction due to Storage Conditions	3.3 days
Total Shelf Life Reduction	28 days
Shelf Life Remaining	22 days
Relative Rate of Spoilage	Good (1.14)
Shelf Life Risk	LOW

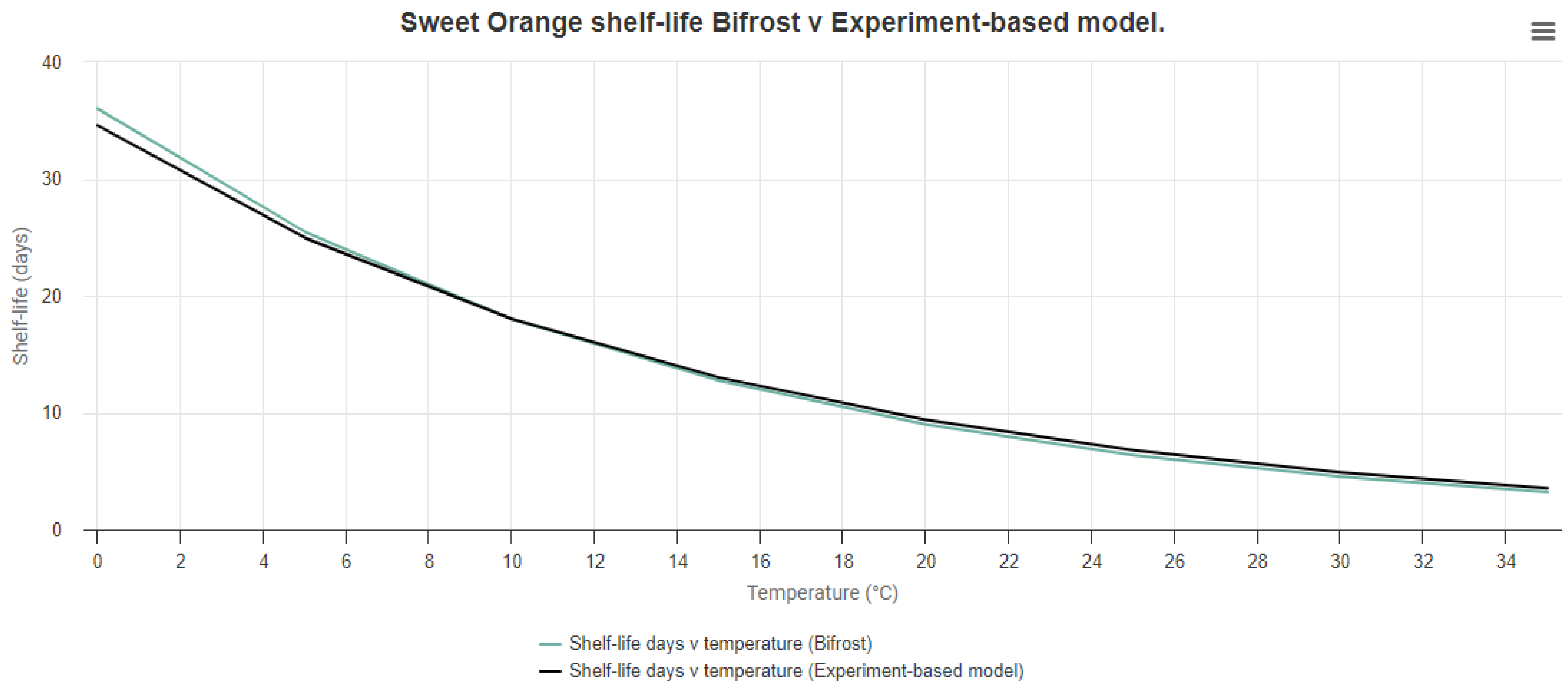


Shelf Life

Product	ULT Tuna
Shelf-life Model	Q10
Controlled Atmosphere	No
Product Shelf Life	12 months
Reduction due to Trip Length	60 days
Reduction due to Storage Conditions	214.5 days
Total Shelf Life Reduction	274.5 days
Shelf Life Remaining	2 months, 26 days
Relative Rate of Spoilage	Poor (4.57)
Shelf Life Risk	HIGH

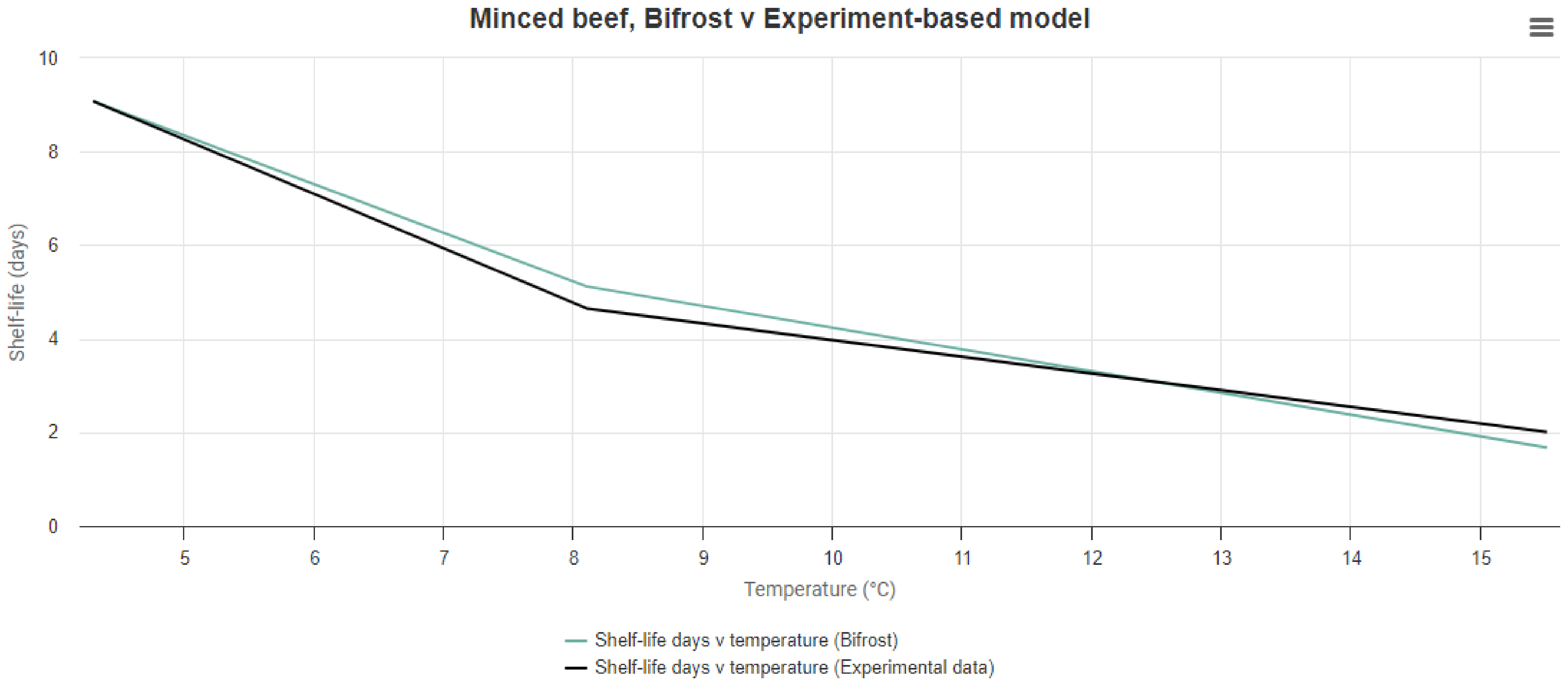


MODEL VALIDATION – SWEET ORANGE



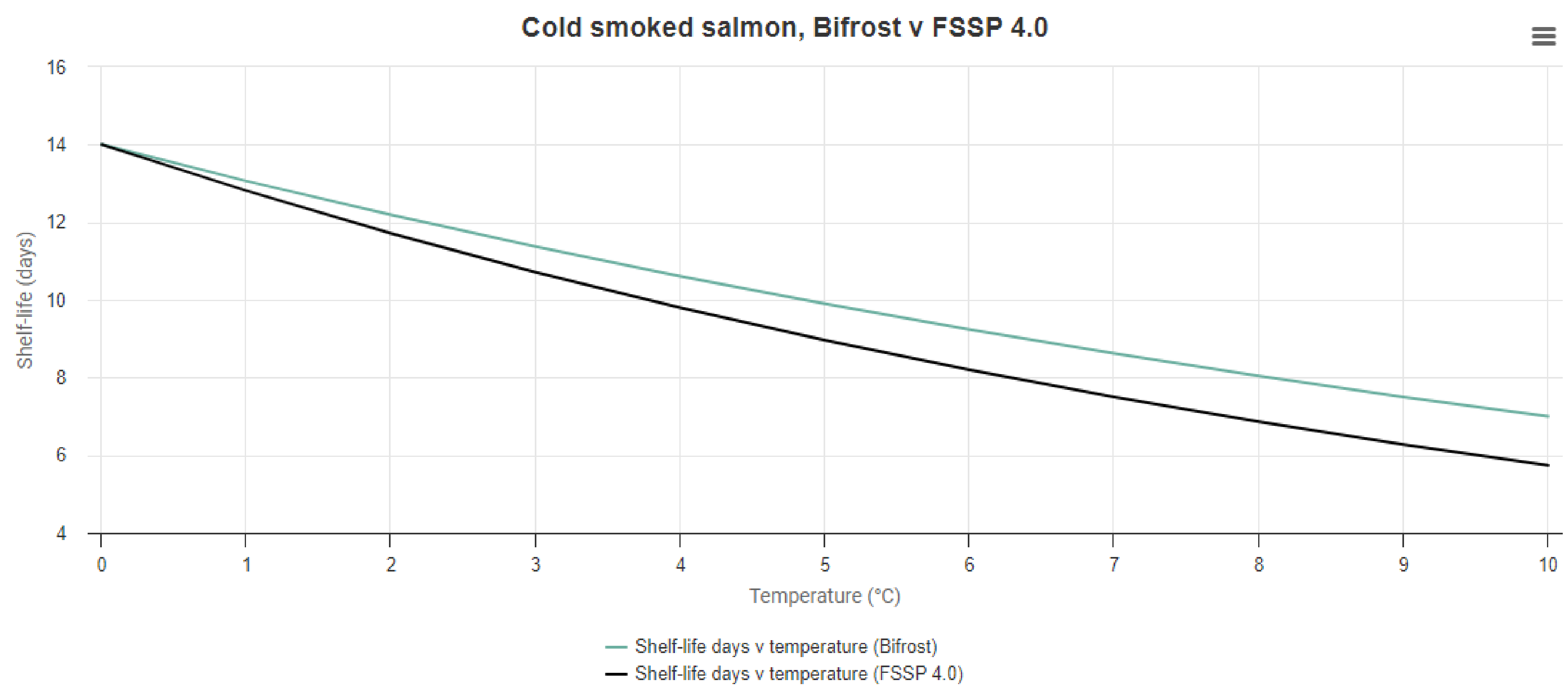
Here we see a comparison between the predicted values of shelf life for sweet orange from the Hemdahl model (Bifrost) and measured values from experimental data. Source: *"The Shelf-life Prediction of Sweet Orange Based on Its Total Soluble Solid by Using Arrhenius and Q10 Approach"*. The Hemdahl shelf life predictions correlate extremely well with the measured data.

MODEL VALIDATION – MINCED BEEF



Here we see a comparison between the predicted values of shelf life for minced beef from the Hemdahl model (Bifrost) and measured values from experimental data. Source: *"Evaluation and predictive modelling of shelf life of minced beef stored in high-oxygen modified atmosphere packaging at different temperatures"*. The Hemdahl shelf life predictions correlate well with the measured data.

MODEL VALIDATION – SMOKED SALMON



Here we see a comparison between the predicted values of shelf life for smoked salmon from the Hemdahl model (Bifrost) and the FSSP 4.0 program "Cold smoked salmon RRS model". The Hemdahl shelf life predictions correlate well with the predicted values from the FSSP program.

CONCLUSIONS

A system to predict the shelf life of perishable food products over a varying temperature range has been developed. The system supports both Arrhenius and Q_{10} models to create accurate shelf-life predictions for a wide variety of temperature-sensitive food products.

The Hemdahl model correlates well with existing shelf life prediction tools such as the FSSP program.

The Hemdahl model also correlates well with actual measured data of the shelf life of various products conducted during scientific experiment.

The use of a data-driven shelf life prediction model provides a scalable means to apply shelf life prediction to food product shipments globally, thus providing a science-based approach to determining the remaining shelf-life of perishable products in the event of temperature excursions in the cold chain.

Hemdahl's predictive algorithms for pathogen growth, product temperature, temperature-related injury, and product shelf life can be used for all transport modes (marine, rail, road, and air) and are independent of the reefer make, datalogger type, telematics system, etc.

ABOUT HEMDAHL

Hemdahl provides a SaaS platform that analyses logged data for perishable products to provide unique, actionable insights into product quality and safety. Our mission is to make the world's perishable products safer, cutting waste and reducing carbon footprints. More information is available at www.hemdahl.com.