Climate change is expected to increase food waste due to spoilage of non-refrigerated foods: Use of risk assessment to identify mitigation strategies

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Keywords: food waste, food spoilage, non-refrigerated food products, climate change.
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Food spoilage contributes greatly to global food waste which is estimated to be about one-third of all food produced. Along the food chain, the distribution and consumption stages contribute almost 35 % of the total food waste (FAO, 2011). Microbiologically stable or shelf-stable foods include products which will not spoil or cause disease when distributed and stored at ambient temperature. They represent a major group in the food market and include products of high consumption, such as canned foods, products processed with Ultra High Temperatures (i.e UHT milk), pasteurized acidic foods (fruit and vegetable juices), dried foods etc. These products undergo a severe heat process, which is primarily designed to destroy spores of pathogenic *Clostridium botulinum* (Membré & van Zuijlen, 2011). However, other spoilage spore-forming bacteria are more heat resistant and can survive the thermal process designed to control this pathogen (Scheldeman et al., 2006). Despite this microbial contamination, these food products are considered shelf-stable because the survivors of the heat process are thermophilic and require a certain storage time at high temperatures in order to grow to spoilage levels. Such time-high temperature conditions are very rare under current distribution and storage conditions prevailing in regions with temperate climate. Considering the regional heterogeneity of temperature increase and the seasonality of warming due to climate change, the increase of global mean surface temperature is expected to have a significant impact on the temperature conditions in which the shelf-stable foods are exposed during distribution and storage with a potential effect in their microbiological stability and subsequently increase the food waste. Therefore, in order to reduce food waste, it is of a great importance to developed appropriate tools which allow for estimating spoilage risk and investigating mitigation strategies.

Hence, in the present work, a quantitative microbial spoilage risk assessment (QMSRA) model was employed to assess the risk of spoilage due to the growth of *Geobacillus stearothermophilus* in canned milk distributed and stored within Europe under current climatic conditions and different climate change scenarios. More specifically, the QMSRA model was developed to assess the effect of 3 global warming projections (temperature increase of 1.5, 3.0 and 4.5 °C) on *G. stearothermophilus* growth and further translate it to risk of canned milk spoilage. The different climate change scenarios were designed based on the latest projection provided by the Intergovernmental Panel on Climate Change (IPCC, 2021). In addition, the impact of insulated non-refrigerated distribution and storage was investigated as a strategy to mitigate the increased risk of spoilage and reduce food waste.

The findings of the study evidence that the current temperature conditions during distribution and storage are marginal in controlling the growth of *G. stearothermophilus* in canned milk. As it is illustrated in Figure 1, a temperature increase above 2 °C, will lead to an increased number of spoilage events during distribution of shelf-stable food products in the Southern European region.

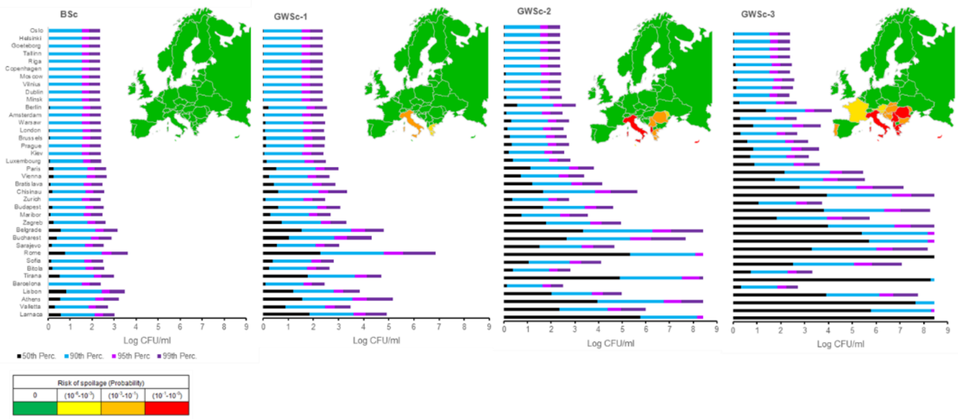

Figure 1. Predicted concentration of *Geobacillus stearothermophilus* at the end of canned milk shelf life in 38 European cities for the baseline scenario (BSc) and the 3 global warming scenarios (GWS) including increases in the mean surface temperature of 1.5 (GWSc-1), 3.0 (GWSc-2) and 4.5 (GWSc-3) °C. Maps translate the concentration of *G. stearothermophilus* at end of the shelf life to risk of spoilage as a probability of exceeding the spoilage level.

Based on the above findings, the effect of insulated transportation and storage as a mitigation strategy to reduce the high risk of spoilage expected from climate change was investigated and led to the elimination of the spoilage risk for the temperature increase scenarios of 1.5 °C (GWSc-1) and 3 °C (GWSc-2) while significantly reducing the risk of spoilage for the extreme scenario of 4.5 °C temperature increase (GWSc-3) (Figure 2).

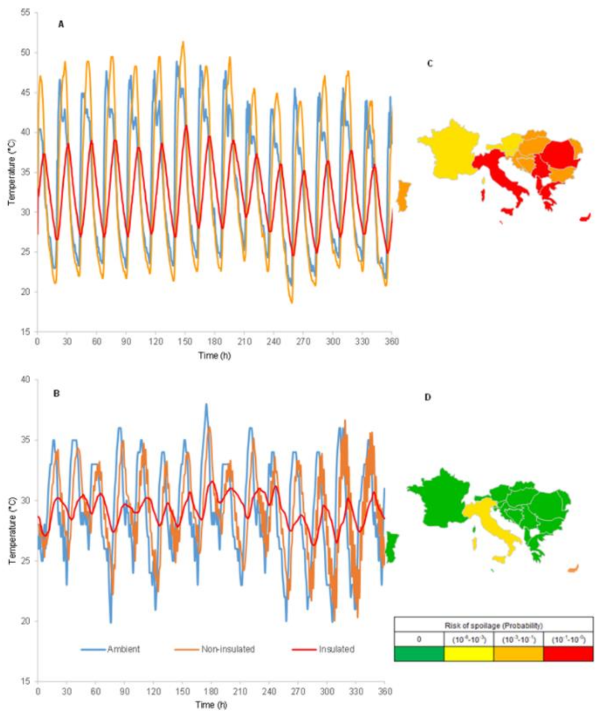

Figure 2. Insulated truck and storage room Representative fitting of insulated transportation and storage. A: Insulated truck B: Insulated storage room inner temperature using an exponential smoothing model (Eq. 6.8). Blue points: recorded external temperature, orange points: recorded inner temperature, red line: fitted inner temperature.

The QMSRA model developed in the present study can be considered as a useful tool for the assessment of the expected impact of climate change on the microbiological stability of shelf-stable food products. The model can be used by both the food industry and the policy makers to eliminate the food waste occurring due to the spoilage of non-refrigerated food products.

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Acknowledgments
This work was supported by the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement [No. 813329].