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Consumer behaviour in the prediction of postharvest losses reduction for fresh strawberries packed in Modified Atmosphere Packaging

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Abstract

MAP can maintain the storage life of products and thereby reduce food losses. However, the benefits of MAP for reducing losses is not well quantified, especially in relation with practices in the postharvest chain. This paper proposes an innovative approach, at the intersection between the domains of food engineering, social sciences and humanities and computer science to quantify the real benefit of using MAP in the postharvest chain of fresh strawberries. To take into account the diversity of postharvest storage conditions and consumer practices on reduction of food losses, 132 scenarios for storage of fresh strawberries were investigated with a numerical model and used as inputs to calculate the losses generated in the postharvest chain as a function of product deterioration. Considering the probability of occurrence of each scenario and consumer practices, the use of MAP instead of commercial macro-perforated packaging, would lead to 17 % reduction of losses on average. The losses reduction is low because 50 % of consumers open the packaging before storing the fruit into the refrigerator, disrupting the benefit of MAP before the fruit is consumed. Losses would be reduced by as much as 74 % if all the consumers stored the strawberries in the fridge and kept the MAP intact.

Keywords

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MAP modelling tool; food loss reduction; consumer behaviour; supermarket; post-harvest scenarios; fresh fruit and vegetables.

1 Introduction

Packaging, was recently identified as an essential element to address the key challenge of sustainable food consumption and as a pillar of the reduction of food losses (Angellier-Coussy et al., 2013; Licciardello, 2017). Among packaging technologies, modified atmosphere packaging (MAP) can maintain storage life of products, and thus contribute to loss reductions (Belay et al., 2016; Chaix et al., 2015; Falagán and Terry, 2018; Peano et al., 2017). The MA is created by the fresh fruit or vegetables (FFV) after packing due to product respiration and permeation through the film. At the steady state, a so-called equilibrium MA (eMA) is reached that should be as close as possible to the optimal recommended storage atmosphere to maintain product quality and safety (Guillaume et al., 2010). An increase of storage life is expected to lead to a significant reduction of FFV losses especially at the consumer stage. FFV losses represent 50%, with no less than 19% for the consumer stage (Gustavsson et al., 2011).

Strawberries have limited storage potential due to their extreme tenderness, vulnerability to mechanical damage, high respiration and transpiration rates, and their susceptibility to fungal spoilage, especially *Botrytis cinerea* (Cagnon et al., 2013; Sousa-Gallagher et al., 2013). They are also subject to high level of losses especially in households (Meyer et al., 2017). Strawberries are mainly sold in plastic or wooden punnets and wrapped in a macro-perforated plastic bag to avoid dehydration and fruit manipulation by the consumer. Macro-holes are necessary to maintain because the plastic film has gas barrier properties that are too high for this type of product. MAP is not used commercially for strawberries but could emerge in the near future with availability of new packaging films suitable for respiring food products (e.g. new green cellulose-based films, starch-based polymers). From a scientific point of view, several studies have highlighted the benefit of using MAP for strawberries (Aday and Caner, 2013; Almenar et al., 2007; Cagnon et al., 2013; Giuggioli et al., 2015; Hertog et al., 1999; Matar et al., 2018a) even if the resulting storage life extension was not always well quantified. The most

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elaborate work is that of Matar et al. (2018a) who proposed integration the dynamic headspace gas concentrations and temperature on quality of fresh strawberries in eMAP. Even if the link between a gain of shelf life and reduction of food losses is not direct, one may expect that an increase of product shelf life thanks to MAP may avoid losses at different stages of the post-harvest chain, especially at the distribution and household stages, contributing to reducing the corresponding negative impact of such losses (Verghese et al., 2015). To the best of our knowledge, none of the available studies focusing on the benefit of MAP on fresh produce storage life attempted to study this link. The main difficulty consists in the apparent nonlinearity of the link between storage life and loss reduction, which is additionally strongly sensitive to the behaviours and practices of the different actors of the post-harvest chain (Muriana, 2017; Porat et al., 2018). It appears thus very important to take into account stakeholder practices, in particular those of consumers, to maximize the positive effect of a process or technology on reduction of food losses.

Yokokawa et al. (2018) linked consumer behaviour and food losses within a framework that aimed to measure the effects of packaging. They found that food loss reduction of highly functionalized packaging may vary from 0 % to 83 % depending on consumer behaviour (time before consumption, storage place, expiry date perception, food preparation). Moreover a survey to a large population in UK (Plumb et al., 2013) shows that most consumers remove or open packaging before storage of produce (apples: 68 %, bananas: 89 %, carrots: 52 %). From this practice, an issue can be anticipated in applying eMAP technology for fresh produce given that the integrity of the packaging is paramount to maintain the benefit of the MA for the product. This highlights the importance of identifying and considering consumer behaviour and practices before quantifying the benefit of post-harvest technologies.

The objective of this study was to build a link between storage life and resulting losses of strawberries while taking into account participants in the postharvest chain, especially in the consumer homes. The case study chosen was the postharvest chain of strawberries as a worst case food model because of its high perishability. The mathematical model developed by Matar et al. (2018a), in which coupling deterioration of the product and gas mass balance in the headspace, was used to numerically explore different realistic post-harvest scenarios built on the basis of distributor and consumer behaviour and

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practices. To collect information about distributor and consumer practices, two surveys were conducted among French distributors and consumers. A mathematical equation was proposed to link the deterioration of the product to the estimation of losses. Finally, based on this equation and the numerical exploration, postharvest losses reduction in the home were estimated using different post-harvest storage strategies to decipher the benefit of eMAP on strawberry loss reduction.

2 Material & Methods

2.1 MAP system studied

'Charlotte' strawberries in their red stage were obtained at a local producer (Mauguio, South of France) and taken to the laboratory around 5 h after harvest and cooled at 5°C. Fruit were sorted to eliminate over ripen, i.e. soft texture, and under ripen, i.e. fruit with green, not fully mature spots. Strawberries were packed and cooled directly after harvest according to the scheme in **Figure 1**

The MAP system is composed of 0.100 ± 0.003 kg of strawberries in a polypropylene (PP, Attitud'Pack, Chatuzange Le Goubet-France) tray, with dimensions of 0.14 m × 0.095 m × 0.025 m, and packed with a pouch of low density polyethylene (LDPE, BBA emballages, Lunel – France), 50×10^{-6} m of thickness and O_2 and CO_2 permeability of $9.57\times10^{-16} \pm 0.43\times10^{-16}$ and $47.85\times10^{-16} \pm 0.43\times10^{-16}$ mol m^{-1} s^{-1} Pa^{-1} respectively (Matar et al., 2018a). The tray is assumed impermeable to mass transfer and gases permeation occurs only through the flexible film. Dimensions of the LDPE pouch were calculated to achieve an internal atmosphere close to the recommended one (5 % O_2 and 15 % CO_2) (Sousa-Gallagher et al., 2013). Quality of stored fruit was assessed using the methodology of Matar et al. (2018b).

The post-harvest chain was divided into three steps. Step 1 consisted in the different stages between packaging and arrival at the supermarket and was called "pre-supermarket", Step 2 was dedicated to the supermarket level and step 3 to the consumer level. To build realistic scenarios of the post-harvest supply chain for fresh strawberries in the south of France, different questionnaires and surveys were conducted.

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Firstly, interviews with French wholesalers (that buy, pack and sell the product) aimed to identify the main stages encountered in the post-harvest chain. Secondly, two surveys were carried out at the distributor and consumer level to have more detailed information about these two stages suspected to generate a high amount of losses.

In addition, a literature review was carried out to gather all available data on strawberry losses at all stages of the post-harvest chain.

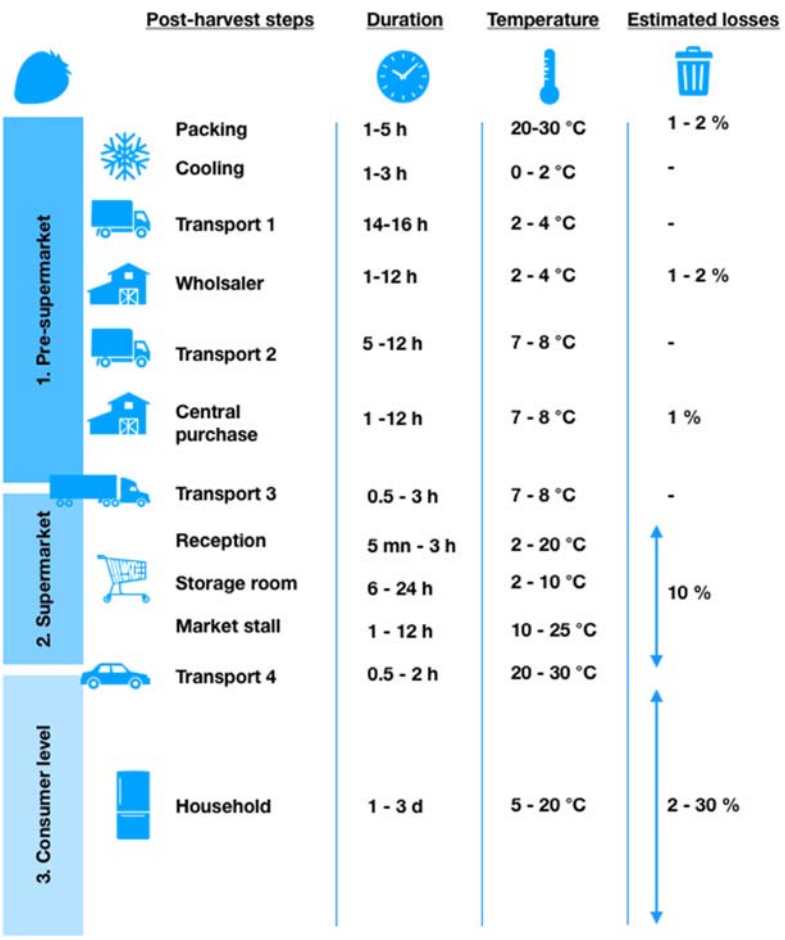

Figure 1: Description of the post-harvest steps considered in this study for fresh strawberries grown in Southern Spain and sold in France with indication of minimal and maximal duration, temperature and percentage of losses when available for each step

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2.1.1 Interviews with French wholesalers: definition of the post-harvest stages and corresponding losses

A typical post-harvest chain for strawberries was constructed based on visits and interviews (detailed in https://doi.org/10.5281/zenodo.1543365) carried out with French wholesalers in the south of the country and using technical reviews from the Interprofessional Technical Centre for fruit and vegetables (CTIFL) dealing with French strawberries supply chain (Moras et al., 2003a, 2003b; Moras and Tamic, 2001; Vaysse et al., 2015). This post-harvest chain is expected to include stages from the packing to the consumer level. The time-temperature history was recorded as well as the average percentages of strawberries losses (regarding weight of product discarded) at each stage, when available. These losses correspond to a visual decay and/or apparent mould development.

2.1.2 Distributor survey: tracking storage conditions and practices at the supermarket level

To build scenarios with realistic storage conditions at the distributor level, operational data are essential. A questionnaire was constructed to understand the organisation of procurement and distribution of strawberries in the French distribution chain. Information on the practices of mass retailing in the fruit and vegetables sector and more particularly for "strawberries" were needed. Then, a typical circuit was built with indication of duration and temperatures of storage, identification of the locations and amount of losses.

The questionnaire (see questions on line at https://doi.org/10.5281/zenodo.1543365) was composed of 57 questions built on LimeSurvey software (LimeSurvey, Hamburg – Germany) and was sent to 89 departments heads working in the fruit and vegetables section of supermarkets. It was constructed based on a report of the CTIFL identifying the brakes and levers for reducing losses for fruit and vegetables including strawberries (Baros and Hongre, 2017).

In addition to questions related to common practices in the fruit and vegetable chain, information about fruit shelf life, storage temperatures, losses (in value and/or percentage) and limits of acceptability were requested.

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2.1.3 Consumer survey: identifying consumer behaviour patterns

The survey conducted at the consumer level aimed at defining purchase and consumption habits. It was based on hypotheses found in the literature (Roty, 2011a, 2011b; Vaysse et al., 2013) and on the results of eight exploratory interviews.

This questionnaire is available online at https://doi.org/10.5281/zenodo.1543365.

The questionnaire begins by a screening question that excluded people who had not bought strawberries within the last month. The first part of the questionnaire concerns the profile of the respondent age, sex and socio professional category. The second part is dedicated to the strawberry purchase habits particularly on the strategy used to select the product during purchase i.e. which of the five senses does the consumer use to evaluate the quality of the fruit. The third part concerns the consumer behaviour after purchase and the identification of storage conditions at home. In fact, strawberries can be consumed immediately or later, whole or cut, stored at ambient temperature or in the fridge, washed and sorted immediately after purchase or right before consumption. The exploratory interviews showed various storage practices included in the questionnaire.

The questionnaire is built on LimeSurvey software and was sent to a consumer panel by email.

2.2 Mathematical prediction of food losses considering stakeholders' practices

In this work, food losses are assumed to be only due to fruit deterioration. At the distribution stage, it was previously demonstrated that a strawberry tray with more than 13 % of the fruit surface spoiled would be rejected by the consumer, therefore entirely discarded by the distributor (Matar et al., 2018a). At the consumer stage, considering that the consumer takes the time to sort spoiled from non-spoiled fruit, the percentage of losses is therefore directly proportional to the percentage of deterioration. In order to predict losses at home, the starting point of this work is consequently to predict the fruit deterioration throughout its storage life.

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2.2.1 Prediction of food deterioration

The mathematical model used to predict deterioration of the fruit is based on the one previously presented and validated (Matar et al., 2018a). The main hypotheses of the model are listed are: external atmosphere has a constant pressure (1.013×10^5 Pa, e.g. atmospheric pressure) and constant gas composition (20.9 % O_2, 0.03 % CO_2 and 79.07 % N_2 (Widory and Javoy, 2003)). The headspace volume and total pressure are assumed to be constant. Heat transfer at atmospheric, packaging material, headspace and food commodity levels are assumed to occur faster than mass transfer and were thus neglected.

The model takes into account the evolution of product quality based on a multi-criteria degradation assessment in MAP conditions (Matar et al., 2018b). The percentage of deteriorated fruit surface depends on the storage temperature and on headspace CO_2 concentration and is modelled using a logistic equation, as follows:

$$\frac{dD}{dt} = k_D\,(T)D\left(1-\frac{D}{D_{max}}\right)\left(1-\frac{x_{CO_2}(t)}{x_{CO_2\,max}}\right) \qquad (1)$$

where D is the percentage of surface deterioration (%) at time t (s), D_{max} is the maximum percentage of deterioration (%), k_D represents the deterioration rate constant (s^{-1}). The latter term is a dimensionless weighting parameter, representing the inhibiting effect of CO_2 on the deterioration rate, $x_{CO_2}(t)$ and $x_{CO_2\,max}$ being respectively the CO_2 concentration (%) in the headspace at time t and the maximal inhibitory CO_2 concentration equal to 30% (Matar et al., 2018a).

For the gas concentrations in the headspace, a mass balance for O_2 and CO_2 was done taking into consideration permeation through the film, respiration of the product and deterioration effect as follows:

$$\frac{dn_{O_2}}{dt} = \frac{P_{O_2}\,A}{e}\left(p_{O_2}^{out}-p_{O_2}^{in}\right)-\frac{R_{O_2max}\quad p_{O_2}^{in}}{\left(Km_{O_2}+p_{O_2}^{in}\right)}\,m \qquad (2)$$

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$$\frac{dn_{CO_2}}{dt} = \frac{P_{CO_2}\,A}{e}\left(p_{CO_2}^{out} - p_{CO_2}^{in}\right) - \; qRQ\;\frac{R_{O_{2max}}\;\;p_{O_2}^{in}}{\left(Km_{O_2} + p_{O_2}^{in}\right)}\;m + \beta_{CO_2}\,D \qquad (3)$$

where A is the surface area of the film (m^2), e the thickness of the film (m), $p_{O_2}^{out}$ and $p_{CO_2}^{out}$ are the atmospheric partial pressure of O_2 and CO_2 respectively (Pa), $p_{O_2}^{in}$ and $p_{CO_2}^{in}$ are the headspace partial pressure of O_2 and CO_2 respectively (Pa), P_{O_2} and P_{CO_2} are the permeability of the film for O_2 and CO_2 respectively (mol m^{-1} Pa^{-1} s^{-1}), $R_{O_{2max}}$ corresponds to the maximum respiration rate per kilogram of food commodity (mol kg^{-1} s^{-1}), Km_{O_2} is the constant of Michaelis and Menten (Pa), m is the weight of the food product (kg), qRQ is the respiratory quotient (dimensionless) and β_{CO_2} represent the rate of carbon dioxide production due to the deterioration (mol s^{-1} $\%^{-1}$). Note that oxygen consumption due to deterioration was found negligible.

In Eq 2 – 3, the first term of the right side refers to the Fick's first law, describing the mass flow of gas species (O_2, CO_2) through the film, in a steady state regime, the second term is the expression of the respiration rate using the classical Michaelis and Menten equation without CO_2 inhibition. In Eq 3, the third and last term is the metabolic deviation (CO_2 production) due to deterioration.

The effect of temperature on the deterioration, k_D, respiration, $R_{O_{2max}}$ and permeation, P_{O_2} and P_{CO_2} is represented through Arrhenius law in Eq 4:

$$k\,(T) \;=\; k_{ref}\;\exp\left(\frac{-\,E_{a,k}}{R}\left(\frac{1}{T} - \frac{1}{T_{ref,k}}\right)\right) \qquad (4)$$

where k is the temperature dependent parameter, k_{ref} the value of reference temperature $T_{ref,k}$ (K), $E_{a,k}$ is the activation energy for parameter k (J mol^{-1}), R is the universal gas constant (8.314 J mol^{-1} K^{-1}). $T_{ref,k}$ (K) considered in this work was the most central value of temperature range investigated, generally 10 °C.

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2.2.2 Prediction of food losses from simulated food deterioration

It was assumed that the area under the deterioration curve is proportional to the percentage of losses. Thus, the percentage of losses is considered linear to the integral of the deterioration curve D_s^p as follows:

$$l_s^p = a \int_{t_i}^{t_j} D_s^p(t)dt + b \quad (5)$$

where p is the type of the packaging, s the number of the scenario tested in a population P of scenarios studied, l_s^p is the percentage of losses (%) of the scenario s using the packaging p, $\int_{t_i}^{t_j} D_s^p(t)dt$ is the integral (dimensionless) of the deterioration curve $(t, D(t))$ for scenario s in the packaging p from t_i to t_j, representing the time at which the post-harvest stage begins and ends respectively (s). a and b (dimensionless) are the estimated parameters of the linear regression.

In **Figure 2** an example of a temperature profile applied for a post-harvest chain scenario is presented. The corresponding deterioration curves and calculations of their integrals are shown for two different types of packaging p = MAP (black hatched area) and p = non MAP (grey hatched area) storage at the consumer level i.e. from 1.4 d to 2.4 d (**Figure 2**).

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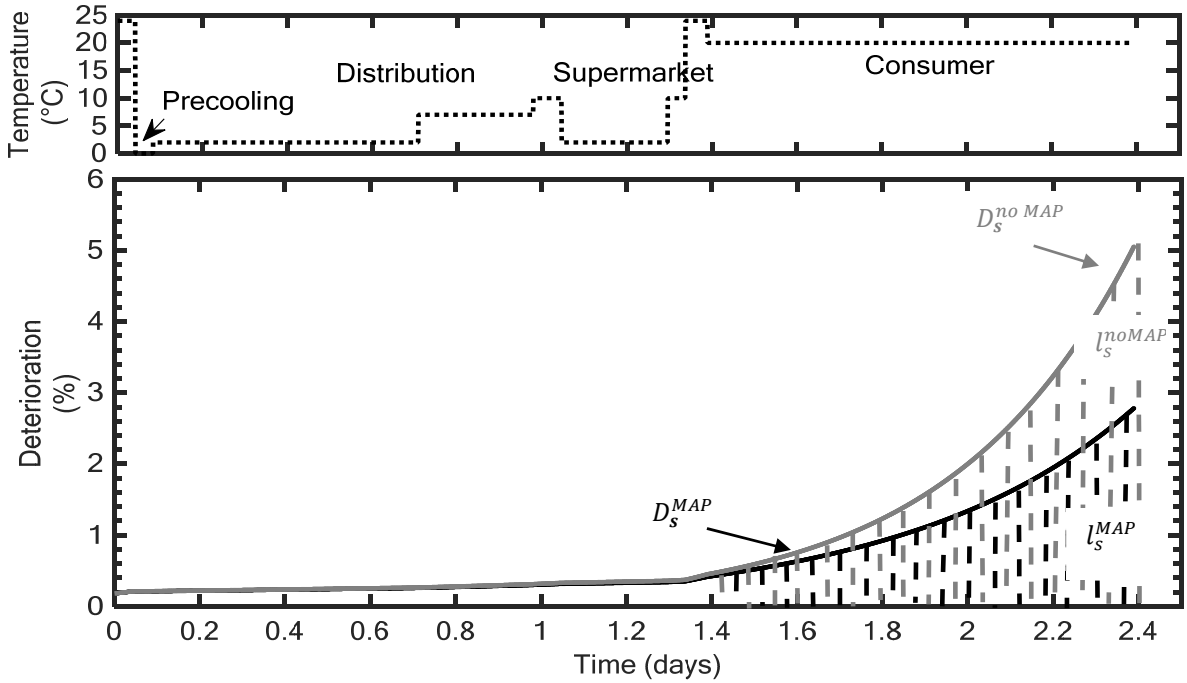

Figure 2: An example of post-harvest chain scenario including precooling, distribution, supermarket and consumer stages with the applied storage temperature in dotted line (…) (a) and predicted $D_s^{no\ MAP}$ and D_s^{MAP} deterioration curves in non MAP (grey curve) and MAP (black curve) conditions (b). Grey and black hatched areas under the deterioration curves are linked respectively to the percentage of losses at the consumer level $l_s^{no\ MAP}$ and $l_s^{no\ MAP}$ respectively calculated using equation (5).

2.2.3 Including consumer behaviour patterns and diversity of post-harvest scenarios in the prediction of food losses

Food losses at the consumer stage are assumed to depend on consumer behaviour regarding storage temperature and duration and preservation of the modified atmosphere. The likelihood of consumer behaviours, w, varying between 0 and 1 (dimensionless), taking into account those three variables all together is calculated using the following equation, assuming that events are independent:

$$w = P_T\, P_d\, P_p \qquad (6)$$

where P_T is the probability related to storage temperatures at home: ambient or refrigerated storage (dimensionless), P_d is the probability related to storage duration at home, before consumption: one day

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or more (dimensionless) and P_p is the probability related to the packaging state: kept or removed packaging at home (dimensionless).

The probability of each practice is supposed to be equal to the frequency of this practice within the sample.

Finally, the cumulated percentage of losses L_{tot}^{P} within the sum of all s_{tot} scenarios participating in the definition of the behaviour of a population P, is expressed as follows:

$$L_{tot}^{p} = \sum_{s=1}^{s=s_{tot}} l_s^p \, w \tag{7}$$

where l_s^p is the percentage of losses for the scenario s in a packaging p (%). p being the state of the packaging i.e. in MAP or non-MAP condition.

2.2.4 Input parameters

The MAP modelling tool was composed of equations (1-4) and required 23 inputs. Firstly, 17 parameters depict the deterioration of fruit, $k_{D_{ref}}$, E_{a,k_D}, T_{ref,k_D}, D_{max}, $x_{CO_{2_{max}}}$, the respiration of fruit, $R_{O_{2max_{ref}}}$, $E_{a,R_{O_{2max}}}$, $T_{ref,R_{O_{2max}}}$, Km_{O_2}, qRQ, β_{CO_2}, and the permeation through the packaging, P_{O_2}, $E_{a,P_{O_2}}$, $T_{ref,P_{O_2}}$, P_{CO_2}, $E_{a,P_{CO_2}}$, $T_{ref,P_{CO_2}}$ including the temperature dependency for the deterioration rate, the gas permeabilities and the maximal respiration rate. Secondly, three parameters depict the geometry of the packaging, A, e and the mass of fruit, m. Finally, three constants were used, $p_{O_2}^{out}$, $p_{CO_2}^{out}$, R (see the nomenclature table for more details about symbol significance and units). Most of them were taken from previous work (Matar et al., 2018a). In addition, to run the MAP modelling tool in dynamic temperature conditions, an activation energy E_{a,k_D} was calculated for k_D representing the deterioration rate constant (s^{-1}). E_{a,k_D} was found equal to 73514 ± 2205 J mol^{-1}. β_{CO_2} was found

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constant whatever the temperature (5 °C, 10 °C and 20 °C) with a mean and standard deviation of $1.32 \times 10^{-9} \pm 2.9 \times 10^{-10}$ mol s^{-1} $\%^{-1}$.

2.2.5 Numerical simulation

Simulations and calculations were performed using Matlab® software (The Mathworks Inc, Natick, Mass., U.S.A) and Microsoft Excel (2016).

2.3 Statistics

The independence of variables (storage temperature, storage duration and packaging practices) in answers to consumer surveys was analysed using Chi-Square tests (performed with SAS 9.3).

Logistic analyses (performed with SAS 9.3, and available upon request) were carried out to determine if variables depend on sex, age and occupation. Results showed that the duration of storage depends on age, and that removing the package depends on age and occupation.

3 Results and discussions

The methodology presented in this work and validated on the typical strawberry supply chain commonly found in South of France, aimed at predicting the benefit of MAP in terms of reduction of product loss, in particular at the consumer stage. The losses considered here are assumed to be directly proportional to the percentage of fruit deterioration. Therefore, all losses estimation relied on the prediction of fruit deterioration (Eq. 1). The consumer step is the step where the storage conditions are the least well controlled and managed, and lead, therefore, to an important amount of losses. As the final step of the supply chain, the deterioration level of the product arriving at consumer homes is strongly dependent on the previous stages (wholesaler, supply and distribution chains). Therefore the first step of this approach was to build realistic scenarios of the strawberry supply chain with determination of storage conditions for each stage.

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3.1 Post-harvest chain scenarios

Setting up of post-harvest scenarios was done based on interviews with wholesalers, from the literature (Mercier et al., 2017), and from the Interprofessional Technical Centre for fruit and vegetables (CTIFL) dealing with the French supply chain of strawberries (Moras et al., 2003a, 2003b; Moras and Tamic, 2001; Vaysse et al., 2015). It was found that a typical pre-supermarket step for packed strawberries could include up to seven stages, such as packaging, precooling, wholesaler, central purchase, and three transport stages. The seven stages were gathered under the same item: "pre-supermarket step" (Figure 1), which is followed by the distribution step (in supermarket), excluding the transport phase and the consumer step, including transport from the supermarket to home, and storage at home until consumption. The transport duration n°1 is rather long, mimicking the case where strawberries are grown far away from the wholesaler location considered as a worst case in the pre-supermarket scenario. Minimal and maximal temperatures applied at each stage are indicated in **Figure 1**.

3.1.1 Distributor behaviour patterns

To collect information about distributor practices, a survey targeted to this stakeholder was carried out. Only 21 answers were obtained on 89 distributors solicited, and among them, only four departments heads answered the whole questionnaire. These distributors belonged to mini-markets and supermarkets and sell strawberries mainly in trays of 0.25 or 0.50 kg. Although few data were obtained, they will be used as guidelines (master data) to confirm information found in the literature.

The results of the questionnaire showed that supermarket step is mainly divided into three stages: the reception, storage room and supermarket display (**Figure 1**). At the reception stage, the product is either refrigerated (2 °C) or kept at ambient temperature (20 °C) for a short duration varying from 5 min to 3 h. In the storage room, the product is stored at low temperature between 2-10 °C for a duration between 6 h and 1 d. Finally, in the supermarket display, products are either stored at 25 °C or in refrigerators at 10 °C from 1 to 12 h. Among the survey respondents, the unsold strawberries are discarded and not kept in stock. The supermarket stock was replenished six times per week.

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3.1.2 Consumers' behaviour patterns

The consumer survey was open for the two last weeks of May 2016, during the strawberry harvest period. A quota method on age and occupation was used. The final sample (749 participants) was close to the French population over 20 years in terms of age and occupation (**Table 1**). The % women of the sample is higher than in the French population (61 % of women in the sample, 52 % in France). However, it reflects the fact that women are more often the main food purchasers than men in French households.

Table 1: Comparison of the sample to the French population over 20 years

	Characteristics	Survey sample (%)	France (%)*
Gender	Male	39	48
	Female	61	52
Age	20-49 years old	49.9	53
	50 years old and more	50.1	47
Occupation	Upper and middle level	27	27
	Lower level	25	29
	Inactive	48	44

* Breakdown of the French population by gender, age and occupation was estimated with the national statistics on employment (in relation with age and gender) published by the "Institut National de la Statistique et des Etudes Economiques", and available online at https://www.insee.fr/fr/statistiques/

Once at home, 14.5 % of the consumers stored the product for a maximum of 3 d, 24.5 % for 2 d while 61 % kept it for a maximum of 1 d before consumption. This can be explained by the very short storage life of strawberries. The fruit were sorted just before the consumption for half of the participants. A majority (79 %) of the consumers removed the packaging just after purchase, systematically or at least every other time. 57 % of the consumers kept the fruit at ambient temperature while 43 % of them kept them in the fridge. These last features are particularly relevant for the present work and are summarized in **Figure 3**. The fact that 79 % of consumers removed the pouch just after purchase means that in the case of MAP, the benefit of the MA is lost as soon as the pack is opened, i.e. in some cases, well before the consumption stage. Two-thirds of the consumers claim that they never throw away the entire tray of strawberries if some of the fruit are damaged, rather discarded damaged strawberries or only the

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damaged parts. This answer confirmed our hypothesis to consider a percentage of losses at the household stage directly proportional to the level of degradation.

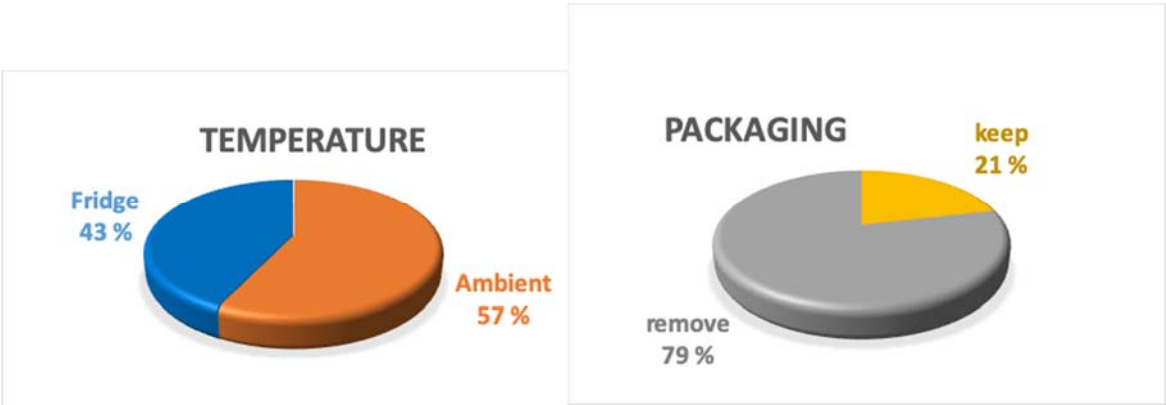

Figure 3: Consumer preferences for post-harvest practices of fresh strawberries; percentage of people using cold chain and removing packaging for storage at home

Within the literature on food loss and waste, only a few papers focus on the link between storage practices and consumer food waste, even if storage is identified as a critical step within food waste drivers (Farr-Wharton et al., 2014; Hebrok and Boks, 2017). The results obtained in the present study confirm previous conclusions of the WRAP final report (Plumb et al., 2013) that many consumers do not recognise that packaging protects food in the home. While there is recognition that packaging is important to keep the product safe on its way to and in the store, the opposite view is prevailing at home. This in turn leads many consumers to adopt unpacking strategies that potentially decrease the longevity of products (i.e. taking products out of their packaging or piercing the packaging to 'let it breathe') (Plumb et al., 2013). Therefore, the importance of consumer behaviours when putting on the market new technologies such as MAP may be significant if these behaviours do not change.

From the survey, three main variables were extracted and were then considered in the prediction of the food losses reduction:

The state of the packaging: "keeping" or "removing" the plastic pouch after purchase;

The temperature of storage: "low temperature" or 'high temperature";

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The time span before consumption: “short duration” or “long duration”, i.e. one or three days of storage as best and worst case scenario.

The independence of storage temperature, storage duration and packaging practices was analysed using Chi-Square tests on dummies (performed with SAS 9.3). Three dummies were considered: fridge, equal to 1 if participant stores strawberries in the refrigerator, 0 otherwise; short, equal to 1 if participant stores strawberries for 1 day (or less), 0 otherwise; remove, equal to 1 if participant removes the packaging before storage, 0 otherwise. Chi-Square tests showed that the three variables are independent (**Table 2**).

Table 2: Chi-Square tests of independence (N=749, DF=1)

	Fridge	Short	Remove
Fridge	-	Chi2 = 1.1596 p = 0.2815	Chi2 = 1.0339 p = 0.3092
Short	-	-	Chi2 = 0.0370 p = 0.8475
Remove	-	-	-

According to the survey results, some likelihood of consumer behaviours, w, could be calculated using Equation 6. For example, the probability that consumers store the strawberries before consumption at low temperature, namely ‘low temperature’ (5 °C), is equal to the rate of participants in the survey who always store their strawberries in the fridge (0.43). Consequently, the rest of the consumers (0.57) store strawberries at ambient temperature, namely ‘high temperature’, i.e. at 20 °C. The same applies for the probability of short/storage duration, where short storage duration means storage of strawberries for 1 d maximum before consumption (61 % of the consumers, so p=0.61). The consumers were considered to remove packaging if they do it at least one time in two, on average (p=0.79 for ‘remove packaging’). Consequently, p=0.21 for keeping packaging, namely ‘keep packaging’. Thereby, the probability of consumers storing the tray 1 day before consumption (short duration), in the refrigerator (low temperature) and keeping the package intact until consumption is equal to 0.61×0.43×0.21=0.05.

In summary, after aggregating the information gained from the consumer surveys, eight behaviours were distinguished at the consumer level that covered all the diversity of practices at home (**Table 3**).

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Table 3: Description of the eight aggregated consumer behaviours based on the temperature, duration of storage and state of the packaging

Number of the behaviour	Probability related to storage temperature T, P_T (dimensionless)	Probability related to storage duration P_d (dimensionless)	Probability related to packaging state the P_p (dimensionless)	Occurrence of each behaviour w (dimensionless)
1	High temperature 0.57	Long duration 0.39	Keep packaging 0.21	0.05
2			Remove packaging 0.79	0.17
3		Short duration 0.61	Keep packaging 0.21	0.07
4			Remove packaging 0.79	0.28
5	Low temperature 0.43	Long duration 0.39	Keep packaging 0.21	0.03
6			Remove packaging 0.79	0.13
7		Short duration 0.61	Keep packaging 0.21	0.06
8			Remove packaging 0.79	0.21

The composition of our sample in terms of sex, age and occupation was slightly different from the composition of the French population (**Table 1**), and therefore, estimating French storage practices with our sample practices might provide biased results if storage practices depend on these factors. Logistic analyses, performed with SAS 9.3, showed that the duration of storage depended on age, and that removing the package depended on age and occupation. By taking into account the composition of the French population rather than the composition of our sample for the calculation of the average frequency, the probability of storing the strawberries more than 1 d is equal to 0.6052 rather than 0.613; and the probability of removing the package is equal to 0.7864 instead of 0.7863. The small differences between these two estimations can be explained by the small difference between our sample and the French population in terms of age breakdown (for storage duration), and by the fact that the bias due to age is offset by the bias due to occupation (for package removing).

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3.1.3 Estimation of strawberry losses

The losses at the different stages of the post-harvest chain are shown in Figure 1. The data were provided by professional experts (technical institutes for the sector such as CTIFL, France AgriMer, inter-branch professional organisation, wholesalers, retailers, distributors) through field surveys and interviews were checked for plausibility and completed by academic experts. The reference year was an "average" year for production/retailing. The difficulty of obtaining reliable estimations of strawberry losses directly from the stakeholders necessitated a thorough cross-checking of the information coming through interviews as well as technical and scientific reviews. For instance, wholesalers and distributors were reluctant to disclose this information.

Losses were about 1-2 %, at the packing step, the wholesale and central purchase (data communicated by the interviewees), 10 % at the distributor stage as recorded by ADEME (ADEME, 2016) and 2 to 30 % at the consumer level identified from interviews with local wholesalers and from literature data (Moras et al., 2003b; Vaysse et al., 2015) (**Figure 1**). These data are in line with those generally quoted for the whole fruit and vegetable sector. For example, Redlingshöfer et al. (2017) found 12 % of losses from primary production to processing for the FFV sector, including food loss at distribution. This value is consistent with the cumulative losses identified in the present work at the packing step, the supply chain up to distributor and including losses at distribution. Porat et al. (2018) also cited FFV losses of 10-11 % from field to retail waste.

While data gathered for the primary losses to retailing were confirmed by different technical and scientific experts, those at the consumer level displayed wide variation and uncertainty. Strawberry losses in the household changes with the season, the place and time of consumption, the cost of the product which is lower in peak strawberry season. Abundance and low price would lead consumers to be more prone to wastage. Thorough cross-checking with scientific literature has revealed that the lower value of 2 % of losses at the consumer level is consistent with the inedible fraction of fresh fruit which would vary from 2 to 6 %, depending on the reference (De Laurentiis et al., 2018). This inedible fraction is directly linked to a physical property of the product, its inedible component (e.g. leaves and stalk of the strawberries), contrary to the generation of avoidable losses that are the consequence of behavioural

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choices of the consumers and poor food conservation. The upper limit of 30 % is consistent with other data: on average 29 % of the mass of FFV purchased by households in the EU28 in 2010 was wasted (De Laurentiis et al., 2018), and 15-30 % of FFV purchases by mass are discarded by consumers (Gustavsson et al., 2011).

The 2-30 % range is considered to correspond to the damaged strawberries thrown away by the consumer (pieces or whole strawberry) and this value is assumed to be directly correlated to the level of deterioration predicted by the mathematical model. In the best case scenario of 2 %, only unavoidable losses corresponding to inedible component, would be discarded in all cases, while in the worst case scenario 30 % of the product is discarded due to unsuitable quality (e.g. apparent spoilage, softening and browning).

3.2 Predicting product deterioration in multiple scenarios of the post-harvest chain

Eq. 1 was used to predict the product deterioration for different post-harvest scenarios based on data gathered in **Figure 1**. The 7 different stages of the "pre-supermarket step" were aggregated in one single step with three different storage conditions: "high temperature and long duration", "low temperature and long duration", "mean temperature and short duration" (**Figure 4**). In the case of "high temperature and long duration", the highest temperature of the range indicated in **Figure 1** for each stage (cooling, packing, etc.) was systematically chosen with the longest duration for building this scenario. In contrast, the lowest temperature and longest time span were chosen for building the "low temperature and long duration" scenario. For the short duration case, preliminary simulations showed that deterioration curves were not significantly different, regardless of the packaging conditions, MAP or non-MAP, and the high or low, or the mean, temperature within each stage. Thus, "high" and "low temperature of storage" for "short duration" in the pre-supermarket step were aggregated in a single scenario "mean storage temperature and short duration" in order to reduce the total number of scenarios. Finally, three different scenarios were considered for the pre-supermarket step.

For the supermarket step, some simplifications were applied. For the reception stage, temperature varies between 2-20 °C (**Figure 1**). However, because of the short duration of this stage and its very weak

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influence on the simulated deterioration, an average temperature (10 °C) and duration (92.5 min) were considered for this storage stage in all simulations. For storage rooms and market stall stages, the combination of "high" and "low temperature" with "long" and "short duration" was considered assuming that the same conditions operate in both storage room and supermarket display stages (**Figure 4**). Finally, four different scenarios were considered for the supermarket step.

For scenarios including high temperature and long duration at the pre-supermarket level followed by high temperature and long duration at the supermarket level, the product deterioration at the end of the supermarket step exceeded the maximal acceptable deterioration of 13 % (Matar et al., 2018a). This means that the consumer was not ready to buy the product anymore. Therefore, these scenarios were not considered in the investigation at the consumer step.

For the consumer step, the first stage was a transport phase between supermarket and the home (transport 4 - shown in **Figure 1**). Due to the very small impact of this stage, a mean temperature and duration was considered (1.25 h at 25 °C). For the household stage, a combination of the highest and lowest temperature of storage combined with longest and shortest storage time was considered with the aim of covering a range of possibilities, i.e. four different scenarios at the consumer level. At this level, combining all the cases represented in the pre-supermarket, supermarket and consumer level, and excluding those that did not pass the supermarket stage, finally, 44 scenarios were obtained (**Figure 4**). These scenarios could be applied for the control packaging (non-MAP).

For the case of MAP, additional scenarios should be added at the consumer level. Indeed, surveys revealed that only 21 % of consumers kept the packages sealed before consumption. 79 % of consumers removed it just after purchase even if they do not immediately consume their strawberries. This practice relies on the belief that it is better to store strawberries without packaging as they are living products. Nearly two-thirds of consumers unpack FFV and therefore reduce the longevity of the product – for example, 64 % take apples out of the pack or do something to the bag (e.g. pierce it) (Plumb et al., 2013). That means that when MAP is used, the benefit of the technology is lost long before FFV consumption. For this reason, the variable related to "the state of the packaging" collected from the surveys will be added to the probability tree drawn in **Figure 4** when MAP packaging is studied. As the

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two possible states of the packaging (keeping packaging sealed until consumption or removing it just after purchase) were considered for each of the 44 pre-scenarios, then 88 additional scenarios were added to the 44 control ones, when MAP packaging is used. In total, 132 scenarios were generated where 88 scenarios were in MAP condition and 44 scenarios were in non-MAP conditions.

The 132 scenarios were used as inputs in the model to calculate the deterioration curve in each case and then, the corresponding losses.

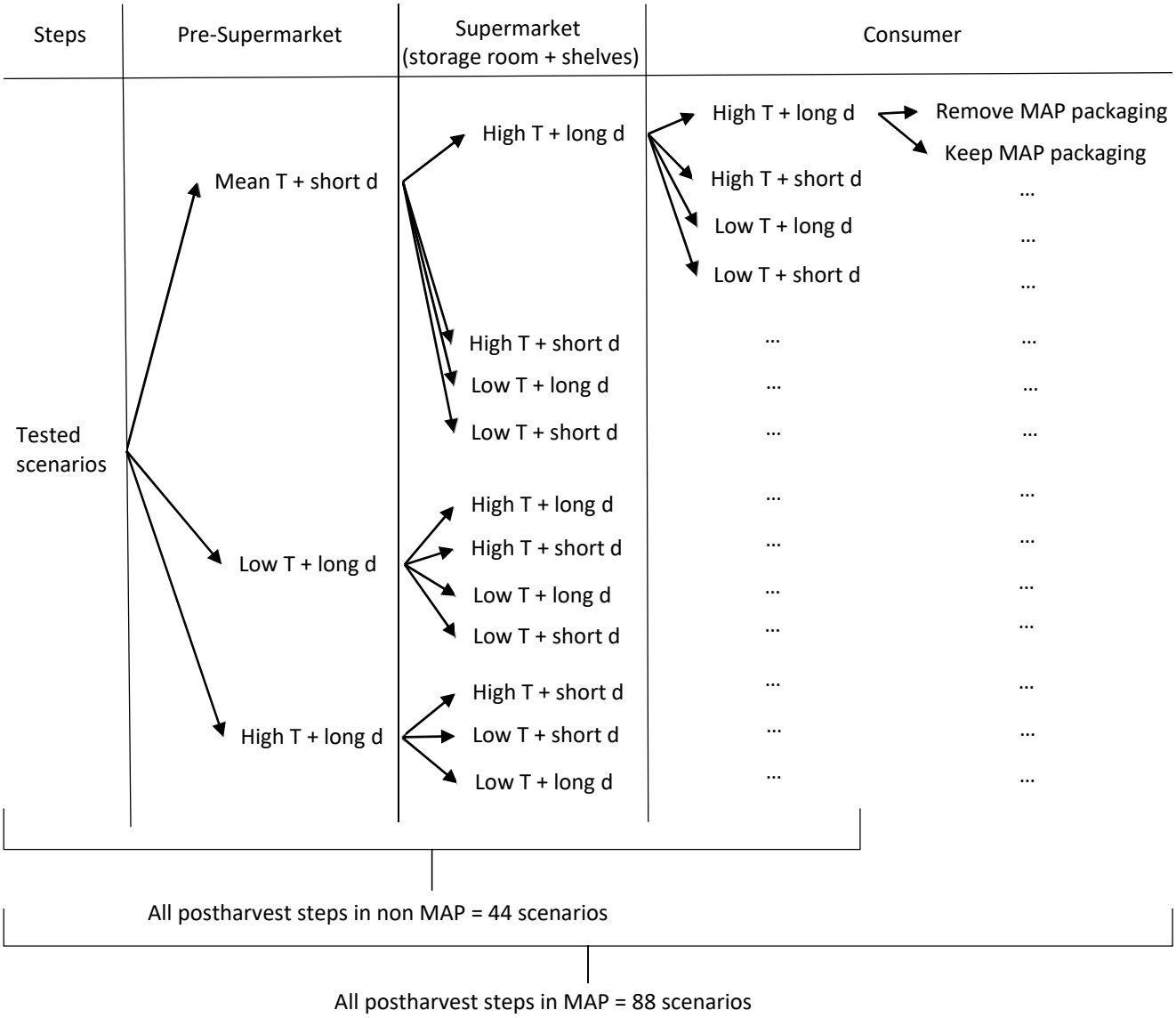

Figure 4: Construction of the 132 scenarios among them 88 in MAP and 44 in non MAP condition according to Pre-supermarket, Supermarket and Consumer storage conditions. T refers to the temperature and d to the duration of the stage

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3.3 Predicting strawberry losses at the consumer stage considering the diversity of French consumers' behaviour

Losses were calculated for each 132 scenarios by using Eq. 5 (see section 2.3.2). Losses were considered proportional to the degradation of the product, degradation that itself depends on the storage conditions (temperature and internal atmosphere composition under MAP conditions). Input parameters for loss calculations are thus all inputs parameters required for predicting the degradation of the fruit during the whole post-harvest chain and the inputs parameters related to losses (see section 3.1.3) used to calibrate Eq. 5. For this purpose, for each of the 132 deterioration curves generated, the corresponding area under the deterioration curves (i.e. the integrals of deterioration curves $\int_{t=i}^{t=j} D_s^p$) was calculated. Then these 132 scenarios were distributed in eight groups corresponding to the main eight behaviours observed at the consumer stage (**Table 3**). A mean value of $\int_{t=i}^{t=j} D_s^p$ was calculated for each aggregated scenario, i.e. eight for each of MAP**,** and non-MAP (**Table 4**).

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Table 4: Percentage of losses, L_s^p, calculated for each aggregated scenario with the associated area of the deterioration, occurrence of each behaviour, percentage of losses, and total percentage of losses affected by French consumer behaviour in MAP and in non-MAP.

		Non-MAP			MAP		
Number of the aggregated scenario	**Occurrence of each behaviour** w *	**Mean of the deterioration curve integrals ***	$l_s^{non-MAP}$ **losses (%)**	L_s^{noMAP} **Losses related to occurrence of the behaviour (%)**	**Mean of deterioration curves Integrals ***	l_s^{MAP} **losses (%)**	L_s^{MAP} **Losses related to the occurrence of the behaviour (%)**
1	0.05	81824.40	30.00	1.41	44967.60	16.98	0.80
2	0.17	81824.40	30.00	5.20	75041.23	27.60	4.79
3	0.07	6378.64	3.35	0.25	3395.70	2.30	0.17
4	0.28	6378.64	3.35	0.93	4494.68	2.69	0.74
5	0.03	12026.07	5.35	0.19	6797.08	3.50	0.12
6	0.13	12026.07	5.35	0.70	7866.65	3.88	0.50
7	0.06	2538.78	2.00	0.11	1517.30	1.64	0.09
8	0.21	2538.78	2.00	0.41	1583.14	1.66	0.34
			$L_{tot}^{non_MAP}$	9.21		L_{tot}^{MAP}	7.57

* dimensionless

In a second step, the % food loss, l_s^p, was calculated using Eq. 5 and the mean value of $\int_{t=i}^{t=j} D_s^p$ for each of the eight aggregated scenarios, in MAP and non-MAP conditions. To do that, a and b values in Eq. 5 must be first calculated. For this purpose, the minimum and maximum losses identified at household, 2 and 30 % respectively (Figure 1), were attributed to the worst case and best case scenarios respectively, s_{min} and s_{max}, i.e. those having the smallest and biggest value of the deterioration integral, in the control situation (non-MAP). In other words, $l_{smin}^{non\,MAP}$ and $l_{smax}^{non\,MAP}$ corresponded to $\int_{t=i}^{t=j} D_{s_{min}}^{non\,MAP}$ and $\int_{t=i}^{t=j} D_{s_{max}}^{non\,MAP}$ respectively. That means that in the best case (optimal storage conditions and moment of consumption), the consumer discards only 2 % of the fruit against 30 % in the worst case. With these two data set ($l_{smin}^{non\,MAP} = 2$ %, $\int_{t=i}^{t=j} D_{s_{min}}^{non\,MAP} = 2538.78$) and ($l_{smax}^{non\,MAP} =$ 30 %, $\int_{t=i}^{t=j} D_{s_{max}}^{non\,MAP} = 81824.40$), the values of a and b can be calculated following a linear function of the form $y = ax + b$ (**Table 4**). The two fitted parameters a and b were found equal to 3.53×10^{-04}

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and 1.10 respectively. Consequently, losses l_s^p corresponding to all other deterioration integrals ranging from the s_{min} to s_{max} values could be interpolated using Eq. 5.

To calculate the overall value for losses in the post-harvest chain, L_{tot}^p, L_s^p values were first calculated using Eq 6 for the eight different behaviour scenarios taking care of their probability of occurrence, w, and then aggregated in a single value, L_{tot}^p, using Eq 7. Finally, eight values of losses were estimated for each of non-MAP conditions, L_s^{nonMAP}, and MAP conditions L_s^{MAP}.

Using this methodology, the average overall losses for the two cases of storage investigated, non-MAP and MAP, considering multiple, realistic post-harvest storage scenarios and consumer practices were 9.2 % (rounded to 9 % in the following) in the case of non-MAP and 7.6 % (rounded to 8 % in the following) in the case of MAP, respectively. Considering uncertainty on the loss estimations at the household stage (about 10 %) according to the results of FUSION EU project (Stenmarck et al., 2016), these two values are not significantly different. This could be ascribed to the fact that only 21 % keep the packaging intact until the consumption time. In that case, the benefit of the modified atmosphere would have been lost quite early during the post-harvest chain. This result confirmed that, if the current storage practices of consumers do not change, the benefit of using MAP for the fresh strawberries would be negligible.

The absolute value of losses found at the household stage must be considered with caution as they are highly dependent on the upper and lower limits they are derived from (2-30 %). Different values could have been obtained considering other limits, especially the upper limit, which could be discussed. In addition, the consumer practices studied here refer only to the case where the consumer consumes all or part of the product. Waste of strawberries due to inappropriate consumer behaviours (e.g. still edible product voluntarily discarded for instance because the consumer forgot it or did not want to eat it anymore) were not considered because it is difficult if not impossible to predict.

3.4 Impact of consumers' behaviour changes on strawberry losses

The objective of this part was to investigate the impact of a change of consumer practices on the post-harvest losses of strawberries. For this purpose, six hypotheses were tested (Figure 5) in addition to the

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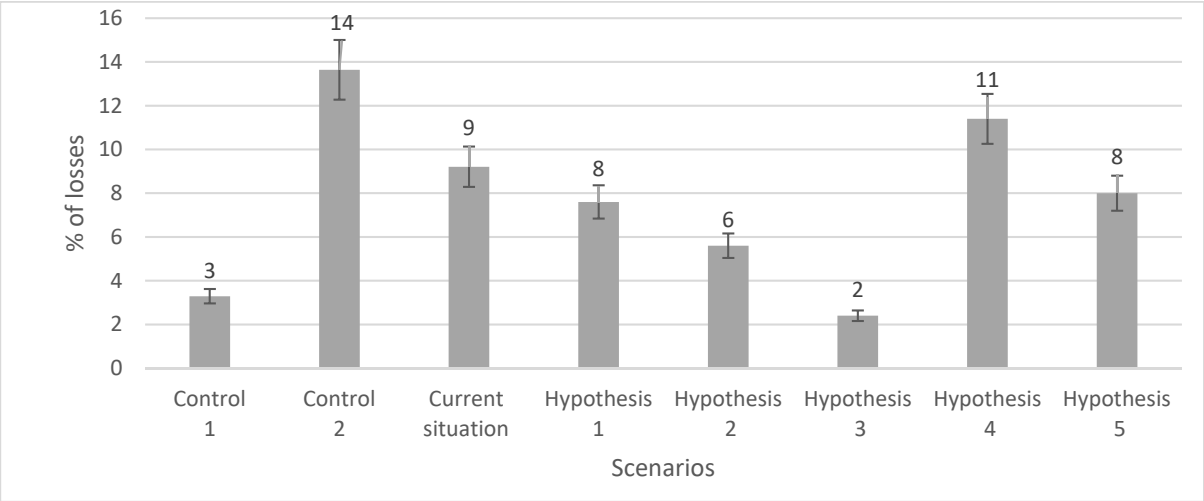
current situation, macro-perforated packaging with 43 % of refrigerator storage and 79 % of packaging removed after purchase and the MAP situation (named hypothesis 1 in Figure 5) corresponding to the case when MAP is applied for all strawberries sold but with the current consumer behaviours. The two first new hypotheses tested represented control situations (100 % of people store the strawberries in the fridge or 100 % of people store them at ambient temperature, all strawberries being packed in macro-perforated packaging, i.e. without any specific modified atmosphere condition). The four other hypotheses corresponded to alternative behaviours for the consumer: for instance, hypothesis 3 assumes that 100 % of consumers store their strawberries in the refrigerator and 100 % of them kept them in MAP until consumption while hypothesis 5 considered that 100 % of consumers kept their fruit at ambient temperature but in MAP, until consumption. The corresponding losses obtained for each of these eight cases were calculated (Figure 5).



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Packaging type	Consumer behaviour	
	Scenario	**Description**
Macro-perforated packaging (non-MAP)	**Control 1**	100% store in refrigerator, 100% of macro-perforated packaging
	Control 2	100 % store at ambient temperature, 100 % of macro-perforated packaging
	Current situation	43 % store in the refrigerator and 100% macro-perforated packaging
Modified atmosphere packaging (MAP)	**Hypothesis 1** Current situation in MAP	43 % store in the refrigerator and 21% keep packaging closed until consumption
	Hypothesis 2	43 % store in the refrigerator and 100% keep packaging closed until consumption
	Hypothesis 3	100 % store in the refrigerator and 100% keep packaging closed until consumption
	Hypothesis 4	100 % store at ambient temperature and 21% keep packaging closed until consumption
	Hypothesis 5	100 % store at ambient temperature and 100% keep packaging closed until consumption

Figure 5: Evaluation of percentage of losses* for 8 different scenarios including the current case, 3 control situations and 5 hypotheses of change of consumer behaviours. The details of all scenarios are given in the table below the graph. The state of the packaging for each situation before its arrival to the household stage is indicated on the left of the table. * rounded values

Figure 5 illustrates that use of MAP reduces losses from 9 % to 8 % (hyp 1), but if the consumers keep the fruit in sealed packages, the loss is reduced to 6 % (hyp 2). This result confirms the benefit of MAP to reduce post-harvest losses (Aday and Caner, 2013; Almenar et al., 2007; Giuggioli et al., 2015; Peano et al., 2017) while quantifying this benefit for the first time. However, benefits are reduced if consumers open the packaging and lose the benefit of MAs. Informing consumers through dedicated front-of-package labelling about the food and packaging innovations, is a major driver to raise awareness of the benefits of the new technology (Hebrok and Boks, 2017; Plumb et al., 2013).

If in addition to MAs, all consumers keep the strawberries in the refrigerator instead of ambient temperature (hyp 3), the losses decrease from 6 % (hyp 2), to 2 % (hyp 3, Fig. 5). As expected, largest loss reductions are achieved when combining cold chain and MA. This is only a bit lower than for the

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theoretical case of macro-perforated packaging combined with 100 % of use of cold chain, for which the calculated losses are equal to 3 % (control 1, Fig. 5). Considering only the percentage of losses in households, the benefit of MAP in addition to cold chain would be negligible compared with the exclusive use of cold chain (hyp 3 versus control 1).

To better highlight the benefit of using MAP for fresh strawberries, only results obtained at ambient temperature were compared. If all consumers stored fruit at ambient temperature, even if only 21 % of them kept the packaging sealed until consumption (hyp 4, Fig. 5), the percentage of losses would be reduced to 11 % compared with the same non-MAP situation where losses are equal to 14 % (control 2, Fig. 5). If 100 % of consumers keep the packaging sealed until consumption, losses would be reduced to 8 % (hyp 5, Fig 5), which corresponds to a relative reduction of loss to 41 %. Comparison of this benefit of MAP at ambient temperature (41 % of relative losses with MAP; hyp 5 versus control 2) with benefit of MAP at cold temperatures (28% reduction of losses; hyp 3 versus control 1), revealed that the benefit of MAP is much higher at ambient temperature than at chilled temperature.

Previous results highlight that above all, consumers should use refrigerated storage to maintain strawberry quality at home. However, systematic use of refrigeration is not feasible because: more than 55 % consumers will not put their strawberries in the refrigerator because they consider that refrigeration negatively changes the taste of the product. For these consumers, MAP could be a benefit for strawberry providing that these consumers also keep package integrity until the moment of consumption (not in 79 % of cases). Consumer education is needed to increase benefit of MAP.

The positive impact of the cold chain should also be put into balance with its environmental cost. In spite of upcoming advances in energy production techniques that reduce costs and environmental impacts of the cold chain, refrigeration still has environmental and economic implications for the food industry. The use of refrigeration is, indeed, still a major contributor to global energy consumption, accounting for 15 % of the electricity consumed worldwide (Camanzi et al., 2017; Coulomb, 2008; Matarolo, 1990). However, MAP technology also carries financial costs and environmental impacts that must be put into balance with its environmental benefit. In a general manner, the benefit for the full

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chain of loss reduction could be hampered by the economic and environmental cost of the technology used to reduce these losses.

4 Conclusion

In this paper, 132 post-harvest scenarios representing the diversity of distributor and consumer practices have been simulated for the strawberry supply chain. Percentage of fruit losses were calculated for each scenario with the objective of quantifying the benefit of MAP in the strawberry supply chain compared to the current standard situation (macro perforated pouches). It was found that, considering the current consumer habits for strawberry storage and consumption at home, the use of MAP technology would decrease losses by 18 %. Higher benefits would be expected by changing consumer behaviours: indeed, 79 % of them remove the packaging just after purchase before product storage which limits the benefit of MAs and more than half of them stored the strawberries at ambient temperature and not in the refrigerator. If the best storage conditions were maintained at home (i.e. all the consumers stored fruit in the fridge and under MAP), strawberry losses would be reduced by more than 70 %. At ambient temperature, if the MAP is maintained until consumption, loss reduction would be about 40 %. The results obtained here confirmed the need to couple the cold chain and MAP technology, but it also highlighted that the benefit of MAP was greater at ambient temperature than at refrigeration temperature. Even if these results have to be confirmed by in vivo tests, the numerical exploration presented here permitted for the first time to explore the impact of consumer practices on the benefit of MAP for the strawberry post-harvest chain. One important conclusion is that the benefit of MAP will remain very low if consumers are not informed that the packages should not be disrupted until the moment of consumption.

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5 Nomenclature

Parameter	Definition	Unit
D_{max}	Maximum percentage of deterioration	%
$E_{a,k}$	Activation energy for parameter k	J mol^{-1}
k_D	Deterioration rate constant	s^{-1}
Km_{O_2}	Constant of Michaelis and Menten	Pa
x_{CO_2}	CO_2 concentration in the headspace at time t	%
$x_{CO_2 max}$	Maximal inhibitory CO_2 concentration (%) in the headspace	%
k_{ref}	Value of parameter k at reference temperature T_{ref}	
l_{max}	Minimum percentage of losses	%
l_{min}	Maximum percentage of losses	%
l_s^p	Percentage of losses of the scenario s using the packaging p	%
L_s^p	Percentage of losses affected by stakeholder's storage behaviour	%
L_{tot}^P	Total percentage of losses affected by actor's storage behaviour for all the scenarios of a population	%
P_{O_2}	Permeability of the film to O_2	mol m^{-1} Pa^{-1} s^{-1}
P_{CO_2}	Permeability of the film to CO_2	mol m^{-1} Pa^{-1} s^{-1}
$p_{O_2}^{in}$	Partial pressure of O_2 in the headspace	Pa
$p_{CO_2}^{in}$	Partial pressure of CO_2 in the headspace	Pa
$p_{O_2}^{out}$	Atmospheric partial pressure of O_2	Pa
$p_{CO_2}^{out}$	Atmospheric partial pressure of CO_2	Pa
$R_{O_2 max}$	Maximum respiration rate per kilogram of food commodity	mol kg^{-1} s^{-1}
$T_{ref,k}$	Reference temperature for the parameter k.	K
β_{CO_2}	Rate of carbon dioxide production due to the deterioration	mol s^{-1} %$^{-1}$
A	Surface area of the film	m^2
a	Estimated parameters	dimensionless
b	Estimated parameters	dimensionless
D	Percentage of surface deterioration	%
D_{acc}	Maximal acceptable deterioration	%
e	Thickness of the film	m
k	Temperature dependent parameter	
m	Weight of the food product	kg
p	State of the packaging: MAP or non MAP	
P_d	Probability related to storage duration: one or three days at the consumer	dimensionless
P_p	Probability related to packaging state: kept or removed packaging at the consumer level	dimensionless
P_T	Probability related to storage temperatures: ambient or fridge storage at the consumer level	dimensionless
qRQ	Respiratory quotient	dimensionless
R	Universal gas constant	J mol^{-1} K^{-1}
s	Scenario	
s_{max}	Scenario having the highest value of deterioration integral	
s_{min}	Scenario having the smallest value of deterioration integral	
t	Time	s
w	Occurrence of a stakeholder's storage behaviour in the postharvest chain, w can vary between 0 and 1	dimensionless

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