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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

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

27 1 Introduction

28 Packaging, was recently identified as an essential element to address the key challenge of sustainable
29 food consumption and as a pillar of the reduction of food losses (Angellier-Coussy et al., 2013;
30 Licciardello, 2017). Among packaging technologies, modified atmosphere packaging (MAP) can
31 maintain storage life of products, and thus contribute to loss reductions (Belay et al., 2016; Chaix et al.,
32 2015; Falagán and Terry, 2018; Peano et al., 2017). The MA is created by the fresh fruit or vegetables
33 (FFV) after packing due to product respiration and permeation through the film. At the steady state, a
34 so-called equilibrium MA (eMA) is reached that should be as close as possible to the optimal
35 recommended storage atmosphere to maintain product quality and safety (Guillaume et al., 2010). An
36 increase of storage life is expected to lead to a significant reduction of FFV losses especially at the
37 consumer stage. FFV losses represent 50%, with no less than 19% for the consumer stage (Gustavsson
38 et al., 2011).

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

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

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

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

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

83 2 Material & Methods

84 2.1 MAP system studied

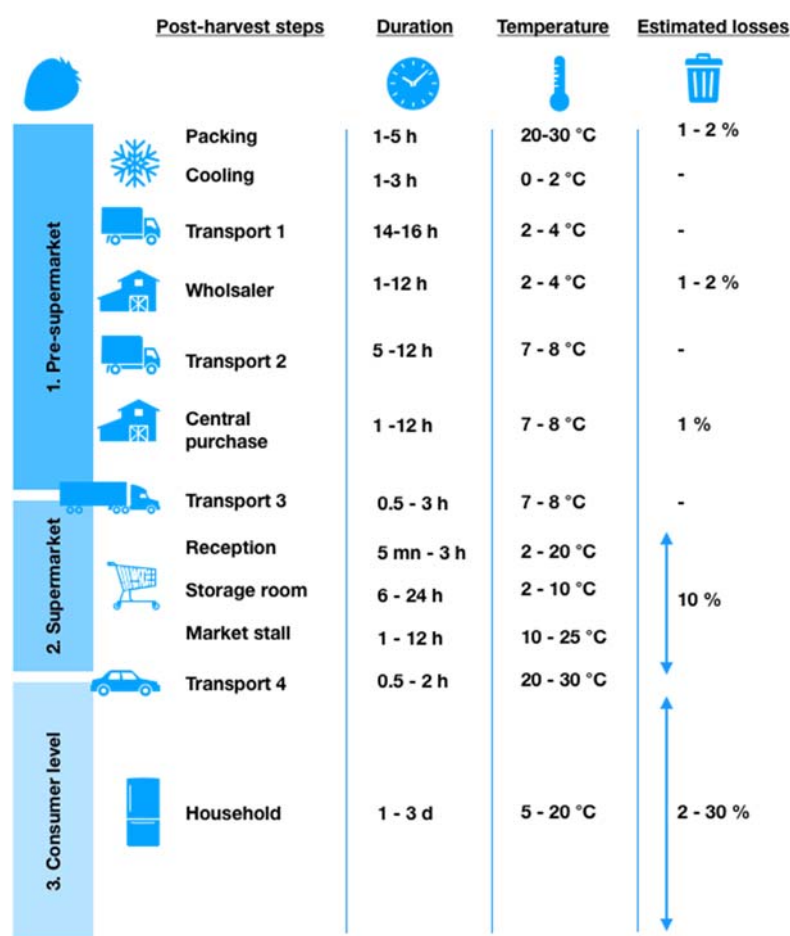
85 ‘Charlotte’ strawberries in their red stage were obtained at a local producer (Mauguio, South of France)
86 and taken to the laboratory around 5 h after harvest and cooled at 5°C. Fruit were sorted to eliminate
87 over ripen, i.e. soft texture, and under ripen, i.e. fruit with green, not fully mature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

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

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

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

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



108
 109 **Figure 1: Description of the post-harvest steps considered in this study for fresh strawberries grown in**
 110 **Southern Spain and sold in France with indication of minimal and maximal duration, temperature and**
 111 **percentage of losses when available for each step**

112 2.1.1 Interviews with French wholesalers: definition of the post-harvest stages and
113 corresponding losses

114 A typical post-harvest chain for strawberries was constructed based on visits and interviews (detailed
115 in <https://doi.org/10.5281/zenodo.1543365>) carried out with French wholesalers in the south of the
116 country and using technical reviews from the Interprofessional Technical Centre for fruit and vegetables
117 (CTIFL) dealing with French strawberries supply chain (Moras et al., 2003a, 2003b; Moras and Tamic,
118 2001; Vaysse et al., 2015). This post-harvest chain is expected to include stages from the packing to the
119 consumer level. The time-temperature history was recorded as well as the average percentages of
120 strawberries losses (regarding weight of product discarded) at each stage, when available. These losses
121 correspond to a visual decay and/or apparent mould development.

122 2.1.2 Distributor survey: tracking storage conditions and practices at the supermarket level

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

129 The questionnaire (see questions on line at <https://doi.org/10.5281/zenodo.1543365>) was composed of
130 57 questions built on LimeSurvey software (LimeSurvey, Hamburg – Germany) and was sent to 89
131 departments heads working in the fruit and vegetables section of supermarkets. It was constructed based
132 on a report of the CTIFL identifying the brakes and levers for reducing losses for fruit and vegetables
133 including strawberries (Baros and Hongre, 2017).

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

137 2.1.3 Consumer survey: identifying consumer behaviour patterns

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

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

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

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

152 2.2 Mathematical prediction of food losses considering stakeholders' practices

153 In this work, food losses are assumed to be only due to fruit deterioration. At the distribution stage, it
154 was previously demonstrated that a strawberry tray with more than 13 % of the fruit surface spoiled
155 would be rejected by the consumer, therefore entirely discarded by the distributor (Matar et al., 2018a).

156 At the consumer stage, considering that the consumer takes the time to sort spoiled from non-spoiled
157 fruit, the percentage of losses is therefore directly proportional to the percentage of deterioration. In
158 order to predict losses at home, the starting point of this work is consequently to predict the fruit
159 deterioration throughout its storage life.

160 2.2.1 Prediction of food deterioration

161 The mathematical model used to predict deterioration of the fruit is based on the one previously
162 presented and validated (Matar et al., 2018a). The main hypotheses of the model are listed are: external
163 atmosphere has a constant pressure (1.013×10^5 Pa, e.g. atmospheric pressure) and constant gas
164 composition (20.9 % O₂, 0.03 % CO₂ and 79.07 % N₂ (Widory and Javoy, 2003)). The headspace
165 volume and total pressure are assumed to be constant. Heat transfer at atmospheric, packaging material,
166 headspace and food commodity levels are assumed to occur faster than mass transfer and were thus
167 neglected.

168 The model takes into account the evolution of product quality based on a multi-criteria degradation
169 assessment in MAP conditions (Matar et al., 2018b). The percentage of deteriorated fruit surface
170 depends on the storage temperature and on headspace CO₂ concentration and is modelled using a
171 logistic equation, as follows:

172

$$\frac{dD}{dt} = k_D(T)D \left(1 - \frac{D}{D_{max}}\right) \left(1 - \frac{x_{CO_2}(t)}{x_{CO_2max}}\right) \quad (1)$$

173 where D is the percentage of surface deterioration (%) at time t (s), D_{max} is the maximum percentage
174 of deterioration (%), k_D represents the deterioration rate constant (s⁻¹). The latter term is a dimensionless
175 weighting parameter, representing the inhibiting effect of CO₂ on the deterioration rate, $x_{CO_2}(t)$ and
176 x_{CO_2max} being respectively the CO₂ concentration (%) in the headspace at time t and the maximal
177 inhibitory CO₂ concentration equal to 30% (Matar et al., 2018a).

178 For the gas concentrations in the headspace, a mass balance for O₂ and CO₂ was done taking into
179 consideration permeation through the film, respiration of the product and deterioration effect as follows:

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

180

$$\frac{dn_{CO_2}}{dt} = \frac{P_{CO_2} A}{e} (p_{CO_2}^{out} - p_{CO_2}^{in}) - qRQ \frac{R_{O_2max} p_{O_2}^{in}}{(Km_{O_2} + p_{O_2}^{in})} m + \beta_{CO_2} D \quad (3)$$

181 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
 182 atmospheric partial pressure of O_2 and CO_2 respectively (Pa), $p_{O_2}^{in}$ and $p_{CO_2}^{in}$ are the headspace partial
 183 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
 184 respectively ($mol\ m^{-1}\ Pa^{-1}\ s^{-1}$), R_{O_2max} corresponds to the maximum respiration rate per kilogram of food
 185 commodity ($mol\ kg^{-1}\ s^{-1}$), Km_{O_2} is the constant of Michaelis and Menten (Pa), m is the weight of the
 186 food product (kg), qRQ is the respiratory quotient (dimensionless) and β_{CO_2} represent the rate of carbon
 187 dioxide production due to the deterioration ($mol\ s^{-1}\ \%^{-1}$). Note that oxygen consumption due to
 188 deterioration was found negligible.

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

193 The effect of temperature on the deterioration, k_D , respiration, R_{O_2max} and permeation, P_{O_2} and P_{CO_2} is
 194 represented through Arrhenius law in Eq 4:

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

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

199

200 2.2.2 Prediction of food losses from simulated food deterioration

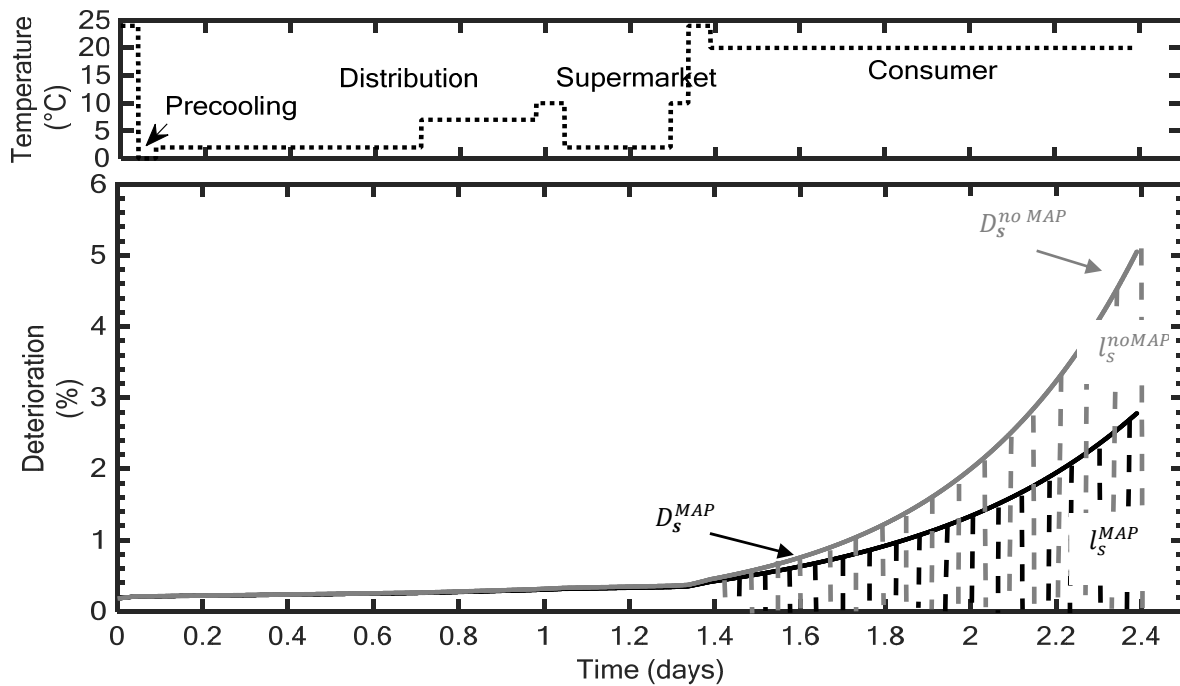
201 It was assumed that the area under the deterioration curve is proportional to the percentage of losses.
202 Thus, the percentage of losses is considered linear to the integral of the deterioration curve D_s^p as
203 follows:

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

204 where p is the type of the packaging, s the number of the scenario tested in a population P of scenarios
205 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
206 integral (dimensionless) of the deterioration curve ($t, D(t)$) for scenario s in the packaging p from t_i
207 to t_j , representing the time at which the post-harvest stage begins and ends respectively (s). a and b
208 (dimensionless) are the estimated parameters of the linear regression.

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

213



214

215 **Figure 2: An example of post-harvest chain scenario including precooling, distribution, supermarket and**
 216 **consumer stages with the applied storage temperature in dotted line (...) (a) and predicted D_s^{noMAP} and**
 217 **D_s^{MAP} deterioration curves in non MAP (grey curve) and MAP (black curve) conditions (b). Grey and black**
 218 **hatched areas under the deterioration curves are linked respectively to the percentage of losses at the**
 219 **consumer level l_s^{noMAP} and l_s^{MAP} respectively calculated using equation (5).**

220 2.2.3 Including consumer behaviour patterns and diversity of post-harvest scenarios in the
 221 prediction of food losses

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

$$w = P_T P_d P_p \quad (6)$$

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

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

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

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

$$L_{tot}^P = \sum_{s=1}^{s=s_{tot}} l_s^p w \quad (7)$$

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

236

237 2.2.4 Input parameters

238 The MAP modelling tool was composed of equations (1-4) and required 23 inputs. Firstly, 17
239 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
240 fruit, $R_{O_2_{max_{ref}}}$, $E_{a,R_{O_2_{max}}}$, $T_{ref,R_{O_2_{max}}}$, Km_{O_2} , qRQ , β_{CO_2} , and the permeation through the packaging,
241 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
242 deterioration rate, the gas permeabilities and the maximal respiration rate. Secondly, three parameters
243 depict the geometry of the packaging, A , e and the mass of fruit, m . Finally, three constants were used,
244 $p_{O_2}^{out}$, $p_{CO_2}^{out}$, R (see the nomenclature table for more details about symbol significance and units). Most
245 of them were taken from previous work (Matar et al., 2018a). In addition, to run the MAP modelling
246 tool in dynamic temperature conditions, an activation energy E_{a,k_D} was calculated for k_D representing
247 the deterioration rate constant (s^{-1}). E_{a,k_D} was found equal to $73514 \pm 2205 \text{ J mol}^{-1}$. β_{CO_2} was found

248 constant whatever the temperature (5 °C, 10 °C and 20 °C) with a mean and standard deviation of
249 $1.32 \times 10^{-9} \pm 2.9 \times 10^{-10} \text{ mol s}^{-1} \%^{-1}$.

250 2.2.5 Numerical simulation

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

253 2.3 Statistics

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

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

259 3 Results and discussions

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

270 3.1 Post-harvest chain scenarios

271 Setting up of post-harvest scenarios was done based on interviews with wholesalers, from the literature
272 (Mercier et al., 2017), and from the Interprofessional Technical Centre for fruit and vegetables (CTIFL)
273 dealing with the French supply chain of strawberries (Moras et al., 2003a, 2003b; Moras and Tamic,
274 2001; Vaysse et al., 2015). It was found that a typical pre-supermarket step for packed strawberries
275 could include up to seven stages, such as packaging, precooling, wholesaler, central purchase, and three
276 transport stages. The seven stages were gathered under the same item: “pre-supermarket step” (Figure
277 1), which is followed by the distribution step (in supermarket), excluding the transport phase and the
278 consumer step, including transport from the supermarket to home, and storage at home until
279 consumption. The transport duration n°1 is rather long, mimicking the case where strawberries are
280 grown far away from the wholesaler location considered as a worst case in the pre-supermarket scenario.
281 Minimal and maximal temperatures applied at each stage are indicated in **Figure 1**.

282 3.1.1 Distributor behaviour patterns

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

288 The results of the questionnaire showed that supermarket step is mainly divided into three stages: the
289 reception, storage room and supermarket display (**Figure 1**). At the reception stage, the product is either
290 refrigerated (2 °C) or kept at ambient temperature (20 °C) for a short duration varying from 5 min to 3
291 h. In the storage room, the product is stored at low temperature between 2-10 °C for a duration between
292 6 h and 1 d. Finally, in the supermarket display, products are either stored at 25 °C or in refrigerators at
293 10 °C from 1 to 12 h. Among the survey respondents, the unsold strawberries are discarded and not
294 kept in stock. The supermarket stock was replenished six times per week.

295 3.1.2 Consumers' behaviour patterns

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

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

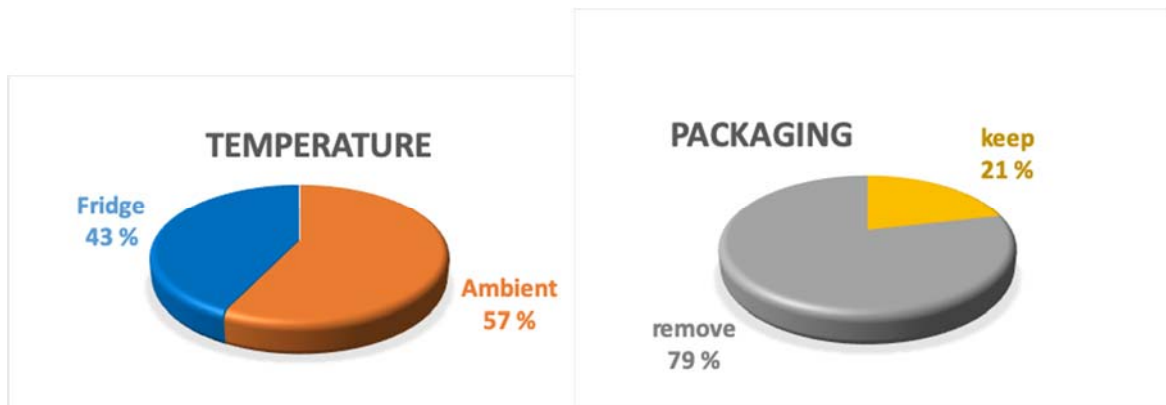
	Characteristics	Survey sample (%)	France (%)*
Gender	Male	39	48
	Female	61	52
Age	20-49 years old	49.9	53
	50 years old and more	50.1	47
Occupation	Upper and middle level	27	27
	Lower level	25	29
	Inactive	48	44

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

306

307 Once at home, 14.5 % of the consumers stored the product for a maximum of 3 d, 24.5 % for 2 d while
 308 61 % kept it for a maximum of 1 d before consumption. This can be explained by the very short storage
 309 life of strawberries. The fruit were sorted just before the consumption for half of the participants. A
 310 majority (79 %) of the consumers removed the packaging just after purchase, systematically or at least
 311 every other time. 57 % of the consumers kept the fruit at ambient temperature while 43 % of them kept
 312 them in the fridge. These last features are particularly relevant for the present work and are summarized
 313 in **Figure 3**. The fact that 79 % of consumers removed the pouch just after purchase means that in the
 314 case of MAP, the benefit of the MA is lost as soon as the pack is opened, i.e. in some cases, well before
 315 the consumption stage. Two-thirds of the consumers claim that they never throw away the entire tray
 316 of strawberries if some of the fruit are damaged, rather discarded damaged strawberries or only the

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



319

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

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

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

334 The state of the packaging: “keeping” or “removing” the plastic pouch after purchase;

335 The temperature of storage: “low temperature” or ‘high temperature’;

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

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

344 **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	-	-	-

345
 346 According to the survey results, some likelihood of consumer behaviours, w , could be calculated using
 347 Equation 6. For example, the probability that consumers store the strawberries before consumption at
 348 low temperature, namely ‘low temperature’ (5 °C), is equal to the rate of participants in the survey who
 349 always store their strawberries in the fridge (0.43). Consequently, the rest of the consumers (0.57) store
 350 strawberries at ambient temperature, namely ‘high temperature’, i.e. at 20 °C. The same applies for the
 351 probability of short/storage duration, where short storage duration means storage of strawberries for 1
 352 d maximum before consumption (61 % of the consumers, so $p=0.61$). The consumers were considered
 353 to remove packaging if they do it at least one time in two, on average ($p=0.79$ for ‘remove packaging’).
 354 Consequently, $p=0.21$ for keeping packaging, namely ‘keep packaging’. Thereby, the probability of
 355 consumers storing the tray 1 day before consumption (short duration), in the refrigerator (low
 356 temperature) and keeping the package intact until consumption is equal to $0.61 \times 0.43 \times 0.21 = 0.05$.

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

359 **Table 3: Description of the eight aggregated consumer behaviours based on the temperature, duration of**
 360 **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

361

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

373 3.1.3 Estimation of strawberry losses

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

382 Losses were about 1-2 %, at the packing step, the wholesale and central purchase (data communicated
383 by the interviewees), 10 % at the distributor stage as recorded by ADEME (ADEME, 2016) and 2 to 30
384 % at the consumer level identified from interviews with local wholesalers and from literature data
385 (Moras et al., 2003b; Vaysse et al., 2015) (**Figure 1**). These data are in line with those generally quoted
386 for the whole fruit and vegetable sector. For example, Redlingshöfer et al. (2017) found 12 % of losses
387 from primary production to processing for the FFV sector, including food loss at distribution. This value
388 is consistent with the cumulative losses identified in the present work at the packing step, the supply
389 chain up to distributor and including losses at distribution. Porat et al. (2018) also cited FFV losses of
390 10-11 % from field to retail waste.

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

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

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

410 3.2 Predicting product deterioration in multiple scenarios of the post-harvest chain

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

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

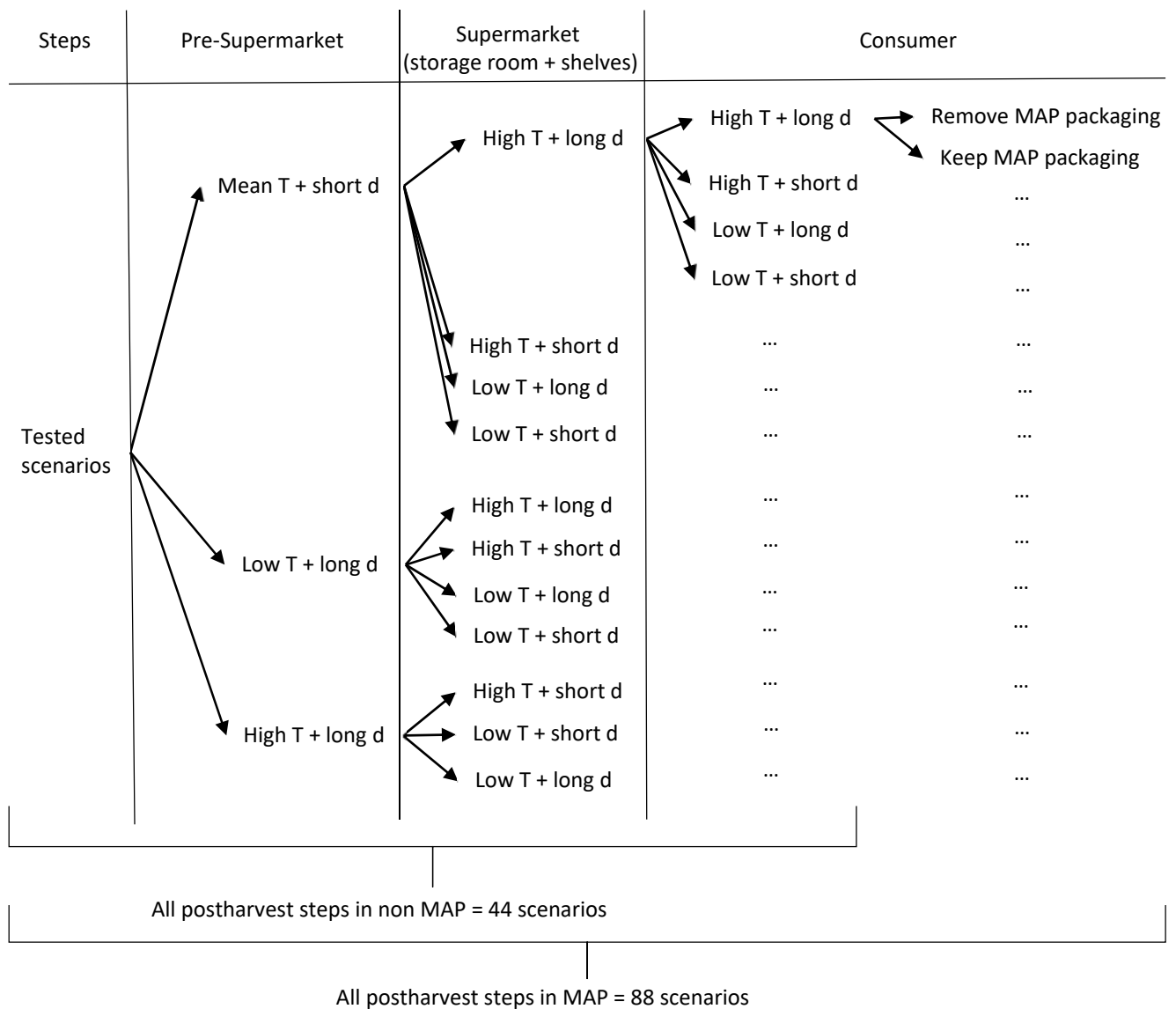
426 influence on the simulated deterioration, an average temperature (10 °C) and duration (92.5 min) were
427 considered for this storage stage in all simulations. For storage rooms and market stall stages, the
428 combination of “high” and “low temperature” with “long” and “short duration” was considered
429 assuming that the same conditions operate in both storage room and supermarket display stages (**Figure**
430 **4**). Finally, four different scenarios were considered for the supermarket step.

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

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

444 For the case of MAP, additional scenarios should be added at the consumer level. Indeed, surveys
445 revealed that only 21 % of consumers kept the packages sealed before consumption. 79 % of consumers
446 removed it just after purchase even if they do not immediately consume their strawberries. This practice
447 relies on the belief that it is better to store strawberries without packaging as they are living products.
448 Nearly two-thirds of consumers unpack FFV and therefore reduce the longevity of the product – for
449 example, 64 % take apples out of the pack or do something to the bag (e.g. pierce it) (Plumb et al.,
450 2013). That means that when MAP is used, the benefit of the technology is lost long before FFV
451 consumption. For this reason, the variable related to “the state of the packaging” collected from the
452 surveys will be added to the probability tree drawn in **Figure 4** when MAP packaging is studied. As the

453 two possible states of the packaging (keeping packaging sealed until consumption or removing it just
 454 after purchase) were considered for each of the 44 pre-scenarios, then 88 additional scenarios were
 455 added to the 44 control ones, when MAP packaging is used. In total, 132 scenarios were generated
 456 where 88 scenarios were in MAP condition and 44 scenarios were in non-MAP conditions.
 457 The 132 scenarios were used as inputs in the model to calculate the deterioration curve in each case and
 458 then, the corresponding losses.



459
 460 **Figure 4: Construction of the 132 scenarios among them 88 in MAP and 44 in non MAP condition according**
 461 **to Pre-supermarket, Supermarket and Consumer storage conditions. T refers to the temperature and d to**
 462 **the duration of the stage**

463 3.3 Predicting strawberry losses at the consumer stage considering the diversity of 464 French consumers' behaviour

465 Losses were calculated for each 132 scenarios by using Eq. 5 (see section 2.3.2). Losses were considered
466 proportional to the degradation of the product, degradation that itself depends on the storage conditions
467 (temperature and internal atmosphere composition under MAP conditions). Input parameters for loss
468 calculations are thus all inputs parameters required for predicting the degradation of the fruit during the
469 whole post-harvest chain and the inputs parameters related to losses (see section 3.1.3) used to calibrate
470 Eq. 5. For this purpose, for each of the 132 deterioration curves generated, the corresponding area under
471 the deterioration curves (i.e. the integrals of deterioration curves $\int_{t=i}^{t=j} D_s^p$) was calculated. Then these
472 132 scenarios were distributed in eight groups corresponding to the main eight behaviours observed at
473 the consumer stage (**Table 3**). A mean value of $\int_{t=i}^{t=j} D_s^p$ was calculated for each aggregated scenario,
474 i.e. eight for each of MAP, and non-MAP (**Table 4**).

475

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

Number of the aggregated scenario	Occurrence of each behaviour w^*	Non-MAP			MAP		
		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

479 * dimensionless

480 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
 481 each of the eight aggregated scenarios, in MAP and non-MAP conditions. To do that, a and b values in
 482 Eq. 5 must be first calculated. For this purpose, the minimum and maximum losses identified at
 483 household, 2 and 30 % respectively (Figure 1), were attributed to the worst case and best case scenarios
 484 respectively, s_{min} and s_{max} , i.e. those having the smallest and biggest value of the deterioration integral,
 485 in the control situation (non-MAP). In other words, $l_{smin}^{non-MAP}$ and $l_{smax}^{non-MAP}$ corresponded to
 486 $\int_{t=i}^{t=j} D_{smin}^{non-MAP}$ and $\int_{t=i}^{t=j} D_{smax}^{non-MAP}$ respectively. That means that in the best case (optimal storage
 487 conditions and moment of consumption), the consumer discards only 2 % of the fruit against 30 % in
 488 the worst case. With these two data set ($l_{smin}^{non-MAP} = 2\%$, $\int_{t=i}^{t=j} D_{smin}^{non-MAP} = 2538.78$) and ($l_{smax}^{non-MAP} =$
 489 30% , $\int_{t=i}^{t=j} D_{smax}^{non-MAP} = 81824.40$), the values of a and b can be calculated following a linear function
 490 of the form $y = ax + b$ (Table 4). The two fitted parameters a and b were found equal to 3.53×10^{-04}

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

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

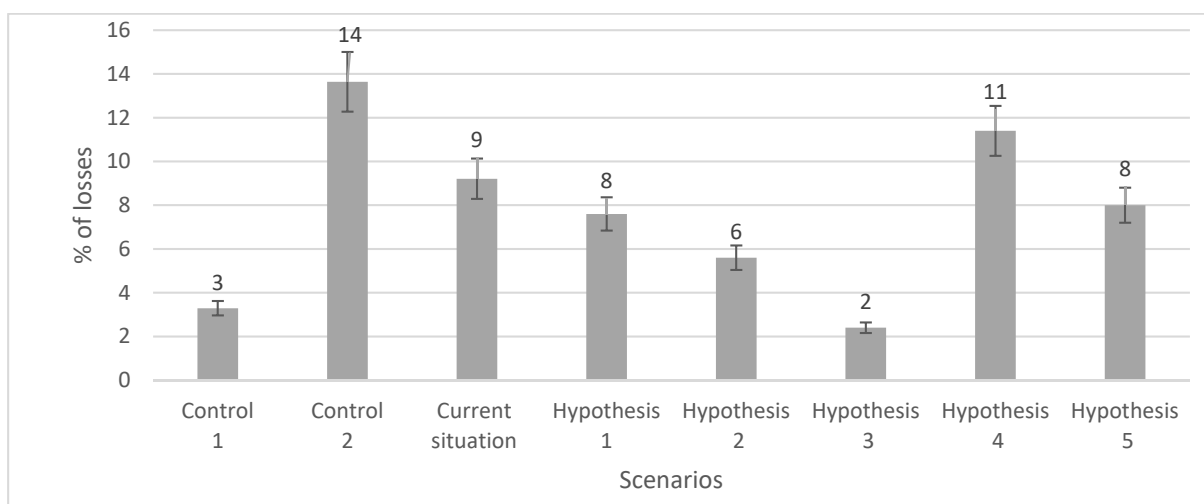
497 Using this methodology, the average overall losses for the two cases of storage investigated, non-MAP
498 and MAP, considering multiple, realistic post-harvest storage scenarios and consumer practices were
499 9.2 % (rounded to 9 % in the following) in the case of non-MAP and 7.6 % (rounded to 8 % in the
500 following) in the case of MAP, respectively. Considering uncertainty on the loss estimations at the
501 household stage (about 10 %) according to the results of FUSION EU project (Stenmarck et al., 2016),
502 these two values are not significantly different. This could be ascribed to the fact that only 21 % keep
503 the packaging intact until the consumption time. In that case, the benefit of the modified atmosphere
504 would have been lost quite early during the post-harvest chain. This result confirmed that, if the current
505 storage practices of consumers do not change, the benefit of using MAP for the fresh strawberries would
506 be negligible.

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

514 3.4 Impact of consumers' behaviour changes on strawberry losses

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

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



528

529

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

530

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

535

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

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

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

550 To better highlight the benefit of using MAP for fresh strawberries, only results obtained at ambient
551 temperature were compared. If all consumers stored fruit at ambient temperature, even if only 21 % of
552 them kept the packaging sealed until consumption (hyp 4, Fig. 5), the percentage of losses would be
553 reduced to 11 % compared with the same non-MAP situation where losses are equal to 14 % (control
554 2, Fig. 5). If 100 % of consumers keep the packaging sealed until consumption, losses would be reduced
555 to 8 % (hyp 5, Fig 5), which corresponds to a relative reduction of loss to 41 %. Comparison of this
556 benefit of MAP at ambient temperature (41 % of relative losses with MAP; hyp 5 versus control 2) with
557 benefit of MAP at cold temperatures (28% reduction of losses; hyp 3 versus control 1), revealed that
558 the benefit of MAP is much higher at ambient temperature than at chilled temperature.

559 Previous results highlight that above all, consumers should use refrigerated storage to maintain
560 strawberry quality at home. However, systematic use of refrigeration is not feasible because: more than
561 55 % consumers will not put their strawberries in the refrigerator because they consider that
562 refrigeration negatively changes the taste of the product. For these consumers, MAP could be a benefit
563 for strawberry providing that these consumers also keep package integrity until the moment of
564 consumption (not in 79 % of cases). Consumer education is needed to increase benefit of MAP.

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

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

574 4 Conclusion

575 In this paper, 132 post-harvest scenarios representing the diversity of distributor and consumer practices
576 have been simulated for the strawberry supply chain. Percentage of fruit losses were calculated for each
577 scenario with the objective of quantifying the benefit of MAP in the strawberry supply chain compared
578 to the current standard situation (macro perforated pouches). It was found that, considering the current
579 consumer habits for strawberry storage and consumption at home, the use of MAP technology would
580 decrease losses by 18 %. Higher benefits would be expected by changing consumer behaviours: indeed,
581 79 % of them remove the packaging just after purchase before product storage which limits the benefit
582 of MAs and more than half of them stored the strawberries at ambient temperature and not in the
583 refrigerator. If the best storage conditions were maintained at home (i.e. all the consumers stored fruit
584 in the fridge and under MAP), strawberry losses would be reduced by more than 70 %. At ambient
585 temperature, if the MAP is maintained until consumption, loss reduction would be about 40 %. The
586 results obtained here confirmed the need to couple the cold chain and MAP technology, but it also
587 highlighted that the benefit of MAP was greater at ambient temperature than at refrigeration
588 temperature. Even if these results have to be confirmed by in vivo tests, the numerical exploration
589 presented here permitted for the first time to explore the impact of consumer practices on the benefit of
590 MAP for the strawberry post-harvest chain. One important conclusion is that the benefit of MAP will
591 remain very low if consumers are not informed that the packages should not be disrupted until the
592 moment of consumption.

593

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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_2max}	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	$\text{mol m}^{-1} \text{Pa}^{-1} \text{s}^{-1}$
P_{CO_2}	Permeability of the film to CO_2	$\text{mol m}^{-1} \text{Pa}^{-1} \text{s}^{-1}$
$p_{O_2}^{in}$	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_2max}	Maximum respiration rate per kilogram of food commodity	$\text{mol kg}^{-1} \text{s}^{-1}$
$T_{ref,k}$	Reference temperature for the parameter k .	K
β_{CO_2}	Rate of carbon dioxide production due to the deterioration	$\text{mol s}^{-1} \%^{-1}$
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	$\text{J mol}^{-1} \text{K}^{-1}$
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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