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Authors(s)	Ktenioudaki, Anastasia, O'Donnell, C. P. (Colm P.), Nascimento Nunes, Maria Cecilia do
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1 **Modelling the biochemical and sensory changes of strawberries during storage under diverse**
2 **relative humidity conditions**

3
4 Anastasia Ktenioudaki¹, Colm P. O'Donnell¹, M. Cecilia do Nascimento Nunes²

5
6 ¹UCD School of Biosystems and Food Engineering, University College Dublin, Belfield, Dublin
7 4, Ireland

8 ²Food Quality Laboratory, Department of Cell Biology, Microbiology and Molecular Biology,
9 University of South Florida, 4202 E. Fowler Ave., Tampa, FL 33620, USA

10
11 **Abstract**

12 Many studies stress the importance of keeping strawberries at high relative humidity conditions
13 during postharvest storage. However, the effect of deviations occurring across the supply chain on
14 the appearance, acceptability and biochemical properties of strawberries has not been adequately
15 explored or quantified to date using kinetic modelling applications. This study investigated the
16 effect of relative humidity (RH) on degradation kinetics of quality and biochemical properties of
17 'Strawberry Festival', during 7 days of storage at 2 °C, using zero, first-order and Weibull models.
18 The strawberries were stored at 40, 60, 70, 80 or 90 % RH and were evaluated using subjective
19 quality evaluation, weight loss monitoring and biochemical analysis. The shelf life was established
20 based on current industry practices using subjective quality evaluation, namely shrivelling and
21 colour scores. The Weibull model was found to better fit the experimental chemical analysis data
22 compared to zero and first order kinetics models. The analysis of the rate constants quantified the
23 significant effect of RH conditions on the weight loss and degradation rate of chemical
24 components. Storage at low RH conditions accelerated the loss of ascorbic acid, and anthocyanins
25 and negatively affect the in vitro antioxidant activity. The overall appearance of strawberries was
26 modelled with zero-order kinetic model and the results revealed that lower RH conditions can limit
27 the remaining shelf life of fresh strawberries by increasing the rate of appearance deterioration.
28 Using RH and time as predictors in a logistic regression model, the waste occurring due to
29 unacceptable strawberry quality, was predicted; highlighting the importance of using RH in
30 predictive modelling when designing supply chains with the view to minimise losses.

31 1. Introduction

32 Fresh fruits and vegetables are among the most perishable food products. Due to their high
33 perishability, they are also amongst the most frequently wasted foods (Kelly et al., 2018). Food
34 waste has a devastating impact on food security affecting all people regardless of geography or social
35 groupings. With a predicted increase of 1.7 billion in world population between now and 2050,
36 mankind is placing more and more pressure on the shrinking finite resources used to produce our
37 food (McCarthy et al., 2018). Yet it is estimated that globally 30–50% of all food produced never
38 reaches its intended destination, i.e. the consumer. Under-addressed supply chain issues are a key
39 cause of commercial food waste (White, 2007). Emphasis has been placed over the years on
40 temperature management that often deviates from optimum during storage, handling and
41 distribution, as one of the major causes of fresh fruit and vegetable overall quality deterioration
42 (van Boekel, 2008, Taoukis et al., 1997; Nunes et al., 2003; Lai et al., 2011; .

43 Strawberry is a popular fruit around the world due its physical characteristics and its sweet
44 flavour; but is also considered an important source of bioactive compounds such as vitamin C and
45 diverse phenolic compounds such as phenolic acids, flavonoids and tannins (Cayo et al., 2016;
46 Kelly et al., 2016b, Flores-Felix et al., 2018) for human nutrition. At the same time, strawberries
47 are one of the fruits most often discarded throughout the supply chain, due to their short shelf life
48 and high perishability and due to poor management during distribution (Kelly et al., 2018; Nunes
49 et al., 2009, Pan et al., 2014). As the strawberry fruit is metabolically active after harvest, the rate
50 at which its quality will deteriorate depends on both genetic factors and on pre- and post-harvest
51 conditions (Castro et al., 2002). The recommended storage conditions for strawberries are 0 °C
52 and 90-95 % Relative Humidity (RH). However, Nunes et al. (2009) found that during retail
53 storage strawberries are kept at temperatures ranging from 5.8 °C to 7.1 °C and RH conditions
54 ranging from 56 % to 93 %. This range does not consider the common practice of storing and
55 displaying strawberries outside refrigerated compartments or displays at open markets where
56 temperatures and RH conditions can deviate at a larger scale from the optimum conditions.
57 Furthermore, Lai et al. (2011) studied real strawberry supply chain conditions and their effect on
58 quality and found that RH varies from 33.8 % to 87.2 % along the different supply chain stages
59 (harvest to retail). Many studies stress the importance of keeping strawberries at 90-95 % RH but
60 the effect of the deviations occurring during the supply chain on the appearance, acceptability and
61 nutritional value of strawberries has not been adequately explored to date. Shin et al. (2007) studied
62 the effect of three RH conditions (75 %, 85 %, and 95 %) and the effect of temperature (0.5 °C, 10
63 °C, and 20 °C) on the quality and nutritional properties of strawberries and found no effect of RH

64 on these properties. In a later study, Shin et al. (2008) looked at a lower RH condition (65 %) and
65 found that weight loss increased, whereas total flavonoids and total phenols decreased in fruit
66 stored at 65 % compared to samples stored at 95 % RH. Both studies evaluated their nutritional
67 analysis results in fresh weight basis, which could fail to consider the concentration effect due to
68 water loss and hence obscure the effect of RH on these properties.

69 To better define the effect of storage conditions on deterioration of quality, the kinetics of
70 sensory and chemical properties should be examined. Traditionally, degradation of nutrients and
71 quality characteristics are modelled by 0, 1st or 2nd order kinetic models (Amodio et al., 2013;
72 Oms-Oliu et al., 2009). Also studies have emerged that used the Weibull model, the cumulative
73 form of the Weibull distribution function, to study several degradation reactions (Ong et al., 2011;
74 Odriozola-Serrano et al., 2009; Oms-Oliu et al., 2009; Amodio et al., 2013). The Weibull model
75 is flexible due to the inclusion of a shape constant in addition to the rate constant (Oms-Oliu et al.,
76 2009). Odriozola-Serrano et al. (2009) studied the degradation kinetics anthocyanins, total phenols
77 and ascorbic acid in fresh cut strawberries using the Weibull model and used it to explain the
78 changes occurring in anthocyanins and antioxidant capacity of the fruits under storage.

79 The present study focuses on a broad range of RH conditions (40 % - 90 %) that can be
80 encountered along the supply chain of strawberries. The main objective is to examine the effect of
81 the different RH conditions during storage on the shelf life, sensory and nutritional quality of
82 strawberries; emphasising on properly describing the changes occurring in both physical and
83 chemical properties of the fruit. This paper aims: i) to examine the effect of RH conditions on the
84 shelf life of strawberries including both the sensory and nutritional quality, ii) to study the kinetics
85 of sensory and chemical changes occurring in strawberries during storage by comparing three
86 kinetic models; and iii) to examine and predict through modelling the waste that would occur
87 depending on the storage conditions.

88

89 2. Materials & Methods

90 2.1. Plant material and experimental setup

91 ‘Strawberry Festival’ strawberries were harvested twice during 2012 and 2013 (March 2012 and
92 February 2013) from a commercial field in Florida, USA. The samples were brought to the USF-
93 Food Quality Laboratory in Tampa, Florida, USA, with minimal delay after harvest (Max delay of
94 30 minutes). The fruit were then sorted by colour, size, and absence of defects and packed into
95 clamshells (capacity \approx 0.453 kg). In total, 210 clamshells (containing 10 fruit each) were prepared

96 and distributed equally to five RH-controlled chambers (Forma Environmental Chambers Model
97 3940 Series, Thermo Electron Corporation, OH, USA) at 2 °C and 40, 60, 70, 80, and 90 % RH.
98 Three clamshells were removed daily from each chamber and used for sensory quality evaluation
99 and weigh loss monitoring. Three additional clamshells were used for chemical analysis.
100 Temperature and RH were monitored throughout storage using battery-powered data loggers
101 (Hobo® U10 Temp/RH data logger, Onset Computer Corporation, Pocasset, MA, USA).

102 One the day of harvest (day 0) three replicates of 10 fruit each, were used for sensory
103 quality evaluation (30 fruits in total) and weight loss (3 clamshells of 10 fruits each). Three
104 replicates of 10 fruit each were immediately frozen to preserve their biochemical properties and
105 used later for chemical analysis.

106

107 2.2. Sensory quality evaluation

108 Sensory quality evaluation was performed every day during a 7-day storage period, always by the
109 same trained personnel. Colour, shrivelling, decay severity, firmness, taste, and aroma were
110 determined subjectively using 1–5 rating scales (where 1 = very poor, 3 = acceptable and 5 =
111 excellent) (Nunes, 2015; Nunes and Delgado, 2014). A score of 3 was considered as the lower
112 limit of acceptability for sale.

113

114 2.3. Weight loss

115 Weight loss was calculated from the initial weight of each of the three clamshells containing 15
116 fruits each, and every day during a seven-day storage period. The following formula was used for
117 water loss corrections: [chemical components (fresh weight) × 100 g/(dry weight) + weight loss
118 during storage (g)]. The dry weight was determined by drying three weighed aliquots of
119 homogenized fruit tissue at 80 °C, until weight stabilized. All chemical components were
120 expressed on a dry weight basis to compensate for water loss during storage.

121

122 2.4. Biochemical analysis

123 Three replicated samples of fifteen individual fruit per treatment were homogenized in a laboratory
124 blender at high speed for 120 s and the resulting puree immediately frozen and kept at -30 °C until
125 used. The samples were evaluated on days 0, 2, 3, 4, 5, 6, and 7. The following analyses were
126 performed:

127 2.4.1. Total ascorbic acid

128 Total ascorbic acid (AA) analysis was conducted using a Hitachi LaChromUltra UHPLC system
129 with a diode array detector and a LaChromUltra C18 2 μm column (2 \times 50 mm) (Hitachi, Ltd.,
130 Tokyo, Japan), as described in Kelly et al. (2016b). The retention time of AA peak was 0.35 min.
131 After comparison of retention time with the AA standard, the peak was identified. The amount of
132 total AA in strawberry was quantified using calibration curves obtained from different
133 concentrations of AA standards. The total ascorbic acid content was expressed in g kg^{-1} on a dry
134 weight basis.

135

136 2.4.2. Total anthocyanin content

137 Total anthocyanins (ANC) were extracted in 0.5% (v/v) HCl methanol and measured using the
138 procedure described by Nunes et al. (2005). Total anthocyanin content (ANC) is expressed as g
139 kg^{-1} pelargonidin 3-glucoside equivalents on dry weight basis.

140

141 2.4.3. Total phenolic content

142 In vitro antioxidant activity of the samples was determined using the total phenols assay by Folin–
143 Ciocalteu reagent as described by Nunes et al. (2005). The total phenolic content (TPC) of the
144 samples was measured and expressed as g kg^{-1} gallic acid equivalents (GAE) on dry weight basis.

145

146 2.4.4. Sugar analysis

147 Quantification of sucrose, fructose and glucose was conducted using a Hitachi HPLC with a
148 refractive index detector and a 300 mm \times 8 mm Shodex SP0810 column (Shodex, Colorado
149 Springs, CO) with an SP-G guard column (2 mm \times 4 mm) as described by Kelly et al. (2016b).
150 Total sugars were calculated as the sum of the individual sugars (sucrose and glucose) values and
151 expressed as g kg^{-1} on a dry weight basis.

152

153 2.4.5. Titratable acidity and soluble solids content

154 Titratable acidity (TA) and soluble solids content (SSC) were determined according to (Nunes et
155 al., 2006a) and expressed in g kg^{-1} on a dry weight basis.

156

157 2.5. Mathematical Modelling

158 2.5.1. Kinetics modelling

159 Three kinetic models were evaluated to relate and explain the changes in appearance (colour and
 160 shrivelling) and the changes in chemical properties that occurred to the strawberries during storage
 161 under different RH. Zero (eq.1) and first order (eq.2) kinetics models have been applied to describe
 162 degradation reactions in foods and the Weibull model (eq.3) has been shown to fit the degradation
 163 of chemical compounds in strawberries (Odriozola-Serrano et al., 2009), sensory and ascorbic acid
 164 changes in melon (Amodio et al., 2013), and also colour changes in dried salak fruit (Ong et al.,
 165 2011).

166 $Q = Q_0 - kt$ eq.1

167 $Q = Q_0 e^{-kt}$ eq.2

168 $Q(t)$ is the value/concentration of the quality index at time t , Q_0 is the intercept of the curve, and k
 169 is the rate constant.

170 The cumulative distribution of the Weibull distribution function may be re-written as follows
 171 (Amodio et al., 2013):

172 $Q = Q_0 [1 - \exp(-\frac{t}{a})^\beta]$ eq.3

173 Where $Q(t)$ is the value/concentration of the quality index at time t , Q_0 is value/concentration of
 174 the quality index at initial time, and a and β are the scale factor and the shape parameter,
 175 respectively. The inverse of a ($1/a$) may be considered as the kinetic constant of the process
 176 (Corradini and Peleg, 2004). The β parameter indicates concavity or convexity of the curve when
 177 it takes values below and above 1 respectively (Odriozola-Serrano et al., 2009). The constants a
 178 and β were estimated and the initial value of the samples was used for Q_0 .

179 Statistical parameters such as root mean square error (RMSE), Akaike information criterion
 180 (AIC), and the regression coefficient (R^2) were the criteria for goodness of fit of the models. The
 181 models with the highest R^2 and lowest RMSE and AIC were chosen as the best fit for the data.

182

183 2.5.2 Classification models

184 The average of the shriveling and the colour scores, was used to evaluate the acceptability of the
 185 strawberries. A score of 3 was the lower limit of acceptability for sale. Samples were divided in
 186 two categories (Pass/Fail) depending on that score (score > 3 = Pass, score ≤ 3 = Fail). Data from
 187 both harvests were merged and the following classification models were fitted to the experimental
 188 data: binary logistic regression model, decision tree, support vector machine, and k-nearest
 189 neighbours. The independent variables were Time (days) and RH (%). The models were evaluated

190 using the k-fold cross validation method. The model with the highest average accuracy and the
 191 lowest standard deviation of the accuracies between the folds was the binary logistic regression
 192 model. Therefore, it was considered the best fit for our data (see Results and Discussion section).
 193 The general formula for the binary logistic regression model can be written as in eq.4:

194

$$195 \quad \ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 \quad \text{eq.4}$$

196

197 Where p is the probability that the sample is a “Pass”, 1-p is the probability that a sample is a
 198 “Fail”, logit(p) is the odds ratio of the two probabilities, β are logistic coefficients, RH is the
 199 relative humidity, and Time is the days after harvest.

200

201 2.6. Statistical and Data Analysis

202 One-way ANOVA analysis was carried out using Minitab (Minitab version 16, Minitab Inc.,
 203 USA). Where ANOVA indicated significant differences were present, the Tukey pairwise
 204 comparison of the means (and 95% confidence intervals) was used to identify where the sample
 205 differences occurred. Significant differences were identified between the two harvests and the
 206 results were treated separately. The kinetic models were fitted to the data using non-linear
 207 regression procedures in R version 3.4.4 (R Core Team, 2017). The following packages were used
 208 to perform the data analysis in R: Caret (Kuhn, 2018), e1071 (Meyer et. al, 2017), caTools
 209 (Tuszynski, 2014), ElemStatLearn (Halvorsen, 2015), ROCR (Sing et al., 2005), Metrics (Hammer
 210 & Frasco, 2017), writexl (Ooms, 2018), class (Venables, 2002), and rpart (Therneau & Atkinson,
 211 2018).

212

213 3. Results and Discussion

214 3.1. Effect of RH and time on weight loss

215 Weight loss is an important parameter in determining the shelf life of fresh fruits and vegetables,
 216 because it is responsible not only for visual appearance deterioration (discolouration, shrivelling
 217 etc) but also for objectionable changes in texture, flavour and nutritional value (Nunes and Emond,
 218 2007, Nunes et al., 1998). Robinson et al. (1975) reported previously that the maximum acceptable
 219 weight loss in strawberries is 6 %, before they become unacceptable for sale. A more recent study
 220 (Nunes and Emond, 2007) found that a loss of 2.5 %-3 % in weight of strawberries was the
 221 maximum acceptable loss when kept at 20 °C and occurred within 2-3 days. In our study, weight

222 loss increased with storage time and it was dependant on the RH conditions during storage. The
223 total weight loss from harvest to day 7 of storage, varied from 7.2 % (90 % RH) to 19 % (40 %
224 RH) in 2012; and from 5.7 % (90 % RH) to 15.5 % (40 % RH) in 2013 (Figure 1).

225 Both the zero-order model and the Weibull model fit the data. The Weibull model was
226 chosen to interpret the changes in weight loss because of the highest coefficient of determination
227 (R^2) and lower RMSE and AIC in both harvests. Table 1 shows the rate constants and the goodness
228 of fit of the Weibull model for the weight loss data. Strawberries kept at lower RH conditions,
229 were found to have higher rate constants; proving that weight loss occurred faster when fruit was
230 kept at 40, 60 and 70 % RH compared to 80 and 90 %. Water vapor pressure deficit (VPD) will
231 increase at any given temperature as RH of air decreases (Hosahalli, 2015). Exposure of fruits and
232 vegetables to conditions that lead to an increase in the VPD, will increase the transpiration rate
233 and can result in increased water loss (Laurin et al., 2005). In 2012, higher rates of water loss were
234 observed than in 2013 and hence the total weight loss in 2012 was overall higher in all storage RH.
235 The shape factor γ is less than 1 in all cases indicating that water loss is more intense during the
236 first days of storage.

237 If we adopt the more conservative approach of 6 % being the maximum acceptable weight
238 loss, it can be observed that shelf life of strawberries harvested in 2012 would be limited to 1.5, 2,
239 3, 4, and 5.5 days for fruit kept at 40, 60, 70, 80 and 90 % respectively (Figure 1). Keeping
240 strawberries nearer optimum RH conditions (i.e., 80-90 %) can extend the shelf life by 1- 4 days
241 compared to fruit kept to sub-optimum RH conditions (40-60 %).

242

243 3.2. Effect of RH and time on sensory quality

244 Colour became less acceptable (darker and less vibrant) with time and significant differences were
245 observed between day 0 and day 7 at all RHs (results not shown). However, colour was not
246 considered a limiting factor of strawberry shelf life (i.e., rating score was always higher than 3).

247 Shrivelling increased with time, and it was more intense for strawberries kept at 40 % and
248 60 % RH (Figure 2). In 2012, shrivelling was more pronounced on the day of harvest (average
249 score of 4.5) than in 2013 (average score of 5). Shrivelling increased more rapidly in strawberries
250 stored at 40 % RH for both harvests, limiting the shelf life to approximately 2.5 days in 2012 and
251 to 4 days in 2013. Strawberries kept at 60, 70 and 80 % RH had a shelf life of approximately 5.5
252 days in 2012 based on shrivelling scores; whereas for fruit kept at 90 % RH, shrivelling was not a
253 limiting shelf life factor. In 2013, shrivelling was not a limiting shelf life factor for strawberries

254 kept at 70, 80 and 90 % RH; whereas fruit kept at 60 % RH received a score below 3 just after day
255 6. The differences between harvests are due to the initial significant differences in shrivelling
256 scores (2012 samples received a lower score on the day of harvest) and to the higher rate of weight
257 loss observed during storage at all RHs in 2012 (Table 1). Nunes (2015) studied the correlation
258 between subjective measurements (such as sensory quality evaluation) and physicochemical
259 attributes, and found strong correlation between shrivelling and weight loss ($R^2=0.92$) for
260 strawberries when kept at different RH regimes.

261 The average score between colour and shrivelling was used as the overall appearance score.
262 To better understand the changes in the overall appearance, the three kinetic models were fitted to
263 the data. All models fitted the data well (Table 2). In most cases the zero-order model had the
264 highest coefficient of determination and the smallest AIC and it was chosen as the best fit in both
265 harvest years. The rate constant shows that the rate of appearance degradation increased as the
266 storage RH decreased. For example, in 2013, the rate of appearance score decrease, for samples
267 kept at 40 % RH, is 0.44 per day, double the rate for samples kept at 90 % RH (0.22 /day). This
268 can be linked to the higher rate of weight loss at lower RHs, which affects the discolouration and
269 drying rates and hence the shrivelling and colour scores. One-way ANOVA analysis showed that
270 the score of strawberries kept at 90 % RH was significantly higher on most days (and on day 7)
271 for both harvests, than the scores of fruit kept at the lower RHs (40-80%). As a result, based on
272 the acceptability scores, shelf life as being evaluated to date in the industry based on visual
273 appearance will be significantly shorter when samples are kept at RH conditions lower than 90 %.

274

275 3.3. Biochemical Analysis

276 Significant differences were observed on the initial values of all the chemical compounds studied
277 between the two harvests. Most of the differences can be attributed to the difference in temperature
278 at the time of harvest observed in 2012 and 2013 (Table 3). To better understand the effect of RH
279 during storage on chemical properties of strawberries, the three kinetic models mentioned earlier
280 were applied. The Weibull model was the most suitable for fitting the changes in the chemical
281 properties described below. The goodness of fit of the model was judged based on the coefficient
282 of determination, RMSE and AIC. Table 4 shows the results of the goodness of fit for all the
283 models applied to the sugar retention data. The Weibull model had the highest coefficient of
284 determination, lowest RMSE and lowest AIC. The same was observed for all chemical properties

285 and hence the results for the AA, ANC, TPC, SSC and TA only show the goodness of fit
286 parameters for the Weibull model.

287

288 3.3.1. Total Ascorbic Acid

289 Significant differences were observed between the initial concentrations of AA for the two
290 harvests. The concentration of AA varied from 8.25 g kg⁻¹ in 2012 to 10.92 g kg⁻¹ in 2013.
291 Concentration of AA is influenced by environmental factors such as temperature, light intensity,
292 and maturity at harvest (Cayo et al., 2016). Wang and Camp (2000) found that strawberry cultivars
293 grown at cooler temperatures had higher concentration of AA possibly due to decreased
294 metabolism. The higher temperatures observed in 2012 (Table 3) could explain the lower content
295 of ascorbic acid that year. In general, AA decreased with storage time for all RH conditions.
296 Strawberries kept at higher RHs showed better retention of AA throughout storage. For example,
297 the concentration of AA on day 7 for strawberries kept at 40 % RH was 1.68 g kg⁻¹ compared to
298 3.55 g kg⁻¹ for samples kept at 90 % RH in 2012.

299 The Weibull model was the most suitable model to describe the changes in AA retention
300 during storage (Table 5). The degradation constant decreased as the RH increased, indicating the
301 significant effect RH has on degradation kinetics of AA. In 2012, the degradation rate varied
302 between 0.15 (80 % RH) to 0.66 (40 % RH) per day. These results show that the retention rate
303 decreased 4 times faster for strawberries kept at 40 % RH compared to samples kept at 80 % RH.
304 The γ parameter was below 1 indicating that AA degraded during the first days of storage at all
305 RH conditions. Similar results were observed for strawberries harvested in 2013. Loss of AA in
306 fresh fruit and vegetables during storage has been attributed to various causes, such as tissue
307 degradation as the product becomes overripe, cell wall damage and enzymatic oxidation caused
308 by bruising, but also due to water loss which can intensify AA oxidation (Nunes et al., 1998; Klein,
309 1987). Many other studies have also reported the loss of AA during storage of strawberries (Kelly
310 et al., 2018; Cayo et al., 2016; Kelly et al., 2016a; Kelly et al., 2016b; Odriozola-Serrano et al.,
311 2009). Our results show that the rate of AA degradation is linked to water loss and highlight the
312 fast deterioration than can occur when fruit are stored in suboptimal RH conditions.

313

314 3.3.2. Total Anthocyanin Content

315 Strawberries harvested in 2012 had significantly higher ANC (4.04 g kg⁻¹) compared to
316 strawberries harvested in 2013 (1.69 g kg⁻¹), possibly due to the higher temperatures in 2012 on

317 the week before harvest. Differences in ANC between years were reported by Cayo et al. (2016),
318 also observing that higher temperatures around time of harvest led to higher accumulation of
319 anthocyanins. Total anthocyanins content decreased with time with significant differences among
320 the different RH conditions. At the end of storage (day 7), strawberries stored at 40 % RH had the
321 lowest ANC both in 2012 (0.72 g kg^{-1}) and 2013 (0.48 g kg^{-1}). On the contrary, strawberries stored
322 at 90 % RH had nearly double the concentration of ANC on day 7.

323 To better demonstrate the effect of RH on the retention of anthocyanins, the kinetics models
324 were used on the retention data. The degradation rate constants obtained from the Weibull model,
325 for the different RH conditions for both harvests are shown in Table 5. Consistent with the results
326 of AA, the rate of ANC degradation was lower for samples kept at higher RH. In 2013, the rate of
327 decrease was lower than in 2012 for most RHs, leading to the higher retentions observed. In 2012,
328 the retention of ANC varied from 18.3 % (at 40 % RH) to 46.4 % (at 80 % RH), compared to 28.6
329 % (at 40 % RH) to 64.6 % (at 80 % RH), in 2013. The differences in the rate constants among the
330 RH conditions and between the harvests can be explained by the highest rate of weight loss
331 observed under the same conditions. Nunes et al. (2005) have reported a decrease in ANC in
332 strawberries kept uncovered at 1°C and 90-95 % RH over storage. The authors explained how
333 water loss in combination with oxidative mechanisms can contribute to degradation and changes
334 in the anthocyanin pigments. Water loss is not the only reason for ANC degradation during storage
335 (other factors such as ascorbic acid oxidation, pH changes, changes in sugar content and presence
336 of other phenolics also contribute to loss of ANC (Kader et al., 1999; Holcroft and Kader, 1999);
337 however as Nunes et al. (2005) mentions water loss can make the degradation more prominent.
338 Despite the higher degradation rate observed in 2012 the concentration of ANC was still higher at
339 the end of storage than the content measured in 2013, due the higher ANC in strawberries on the
340 day of harvest.

341

342 3.3.4. Total phenol content

343 Significant differences were observed in TPC between the two harvests. The total phenolic content
344 varied between 26.92 g kg^{-1} GAE, in 2012 to 23.72 g kg^{-1} GAE in 2013. The higher temperatures
345 observed in 2012, could have assisted in the accumulation of compounds with antioxidant activity
346 (i.e., anthocyanins) and hence contribute to the higher antioxidant activity of the samples as
347 measured with the TPC assay. Also the strawberry plants from the two harvests were most likely
348 exposed to different levels of stress, leading to different levels of bioactive compounds (i.e.,

349 polyphenols) to be present as a response to that stress (Kelly et al., 2016b). Total phenols content
350 decreased with time of storage. Strawberries stored at 90 % RH had the highest TPC on all days
351 of storage in 2013 whereas in 2012, strawberries stored at 80 % and 90%, both had the highest
352 content. An increase in TPC was observed on days 2 and 3 in samples harvested in 2013 and stored
353 at 90 % RH. According to Van de Velde et al. (2017), an increase in TPC at specific periods during
354 storage can attributed to de novo synthesis as a result to stress. This has also been reported before
355 (Oms-Oliu et al., 2009). However, such an increase in TPC on those days was not consistently
356 observed in all strawberry samples.

357 The Weibull model was the best fit to describe the retention of total phenols data (Table
358 5). The degradation constants varied from 0.09 (in 2012) and 0.1 (in 2013) per day for samples
359 stored at 90 % RH, to 0.30 (in 2012) and 0.26 (in 2013) per day for samples stored at 40 % RH
360 (Table 5). The constants increased as the RH decreased, indicating that the degradation of bioactive
361 compounds is faster at lower RH conditions, indicating a possible link to the faster rate of weight
362 loss. Shin et al. (2008) found a decrease in TPC in strawberries after 12 days of storage at 10 °C,
363 and observed a simultaneously increase in water loss and decrease in anthocyanins content. The
364 loss of water leads to membrane collapse which allows for enzymes like PPO to come in contact
365 with polyphenols and hence a reduction in TPC is observed (Nunes et al., 2005). This in
366 combination with the degradation of anthocyanins will lead to the decrease in antioxidant activity
367 measured with the TPC assay.

368

369 3.3.5. Total sugar content

370 Total sugar content was significantly higher in strawberries harvested in 2013 (1068 g kg⁻¹) than
371 in 2012 (865 g kg⁻¹), most likely due to the lower temperatures at the time of harvest in 2013.
372 Lower temperatures result in lower metabolic rate and higher accumulation of soluble
373 carbohydrates and starch (Wang and Camp, 2000). Loss of sugars in strawberries postharvest has
374 been reported elsewhere (Kelly et al., 2016b; Kelly et al., 2018) and the degradation occurs
375 regardless of harvest or genotype effects (Cayo et al., 2016). Caleb et al. (2016) also observed a
376 depletion of sucrose and glucose in strawberries during storage; highlighting that the role of
377 sucrose, postharvest, is to sustain the energy demand during respiration and support fruit
378 maintenance and metabolic processes. In our study, total sugar content decreased with storage time
379 for all RH conditions, with significant differences in sugar content on day 7 among strawberries
380 kept at 80 and 90 % RH and the lower RH conditions (Figure 4).

381 The Weibull model was the best fit for the retention of total sugars data, considering the
382 high coefficient of determination (R^2), low RMSE and low AIC (Table 4). Based on the rate
383 constants shown in Table 4, sugar content reduced faster for strawberries kept at 40 and 60 % RH
384 in both harvests. Kader and Salveit (2003) stated that water stress caused by low storage RH
385 conditions can stimulate the rate of respiration. The higher rate of weight loss experienced in these
386 RH conditions, attributed to water loss, could potentially have increased the rate of respiration,
387 consequently increasing the rate of simple sugars depletion. In both years the parameter γ was
388 below 1 indicating that degradation takes place the first days of storage. Sweetness intensity has
389 been linked to consumers' acceptance of strawberries (Schwieterman et al., 2014), hence a higher
390 rate of decrease in sugar content during storage under low RH conditions, will become a limiting
391 shelf life factor in strawberries at consumer level.

392

393 3.3.6. Titratable Acidity

394 Titratable acidity (TA) was significantly higher in fruit harvested in 2012 (22.7 %) than in 2013
395 (16.9 %). These results cannot be attributed to the weather conditions during harvests, as it has
396 been shown that higher temperatures during harvest (as observed in 2012) will lead to lower TA
397 values (Wang and Camp, 2000). These differences could be due to possible differences in maturity
398 at harvest or due to differences in the growing conditions between the two harvests. A reduction
399 in TA during storage was observed for all RH conditions in both years. Conflicting results have
400 been reported in the literature regarding TA during storage. A reduction in TA with time was
401 observed by Kelly et al. (2016b) and Cayo et al. (2016), whereas an increase in TA was reported
402 during storage by (Nunes et al. (2006a) and Caleb et al. (2016). Shin et al. (2007) found no effect
403 of RH in TA of strawberries over a storage period of 4 days. The RH conditions in their study
404 varied from 75 % to 95 %. Using the Weibull model to fit our data, it was found that higher rates
405 of TA degradation were observed when strawberries were kept at lower RHs and varied between
406 0.08 to 0.23 per day (Table 6). The reduction in TA observed in our study is possibly due to the
407 use of organic acids as substrates in respiration (Wang and Camp, 2000); and as mentioned earlier
408 a relationship exists between the respiration rate and the weight loss rate.

409

410 3.3.6. Soluble Solids Content

411 Soluble solids content (SSC) is considered a good indicator of sweetness (Jouquand et al., 2008).
412 The SSC in strawberries harvested in 2013 was significantly higher than that of strawberries

413 harvested in 2012 (1370 g kg^{-1} and 1300 g kg^{-1} respectively), possibly due to the variation in
414 temperature at the time of harvest observed between the two years. A reduction in SSC during
415 storage was observed for all RH conditions and the rate of reduction was modelled using the
416 Weibull model. The rate of decrease in SSC increased as the storage RH decreased (Table 6). The
417 same was observed for both harvests and varied between 0.12 and 0.51 per day depending on the
418 harvest and the RH conditions. Higher rates of decrease were observed in 2012 for samples stored
419 in 40 % and 60 % RH due to the higher rate of weight loss also taking place.

420

421 3.4. Classification model

422 The logistic regression model was the best fit to the experimental data when compared to other
423 classification models as mentioned earlier. The results of the K-fold validation showed that the
424 logistic regression had the highest mean accuracy when compared to other classification models
425 (0.93 ± 0.02). Data from both harvests were merged and the dataset was split to a training set and
426 a test set and these were used to train and validate the model respectively. The results of the logistic
427 regression on the test set showed that both RH and time and their interaction had a significant
428 effect on the score (Pass/Fail) of the strawberry samples. The confusion matrix produced by the
429 model is shown in Table 7.

430 Table 7 shows that the model predicted 488 samples (out of 600) in the test set would pass
431 and 112 samples would fail based on the acceptability criterion. The actual number of samples that
432 passed or failed was 508 and 92 respectively., resulting in a 96.6 % accuracy in prediction. The
433 accuracy calculated from the confusion matrix tables can sometimes be misleading due to what is
434 known as the accuracy paradox (a model with higher accuracy has less predictive power than a
435 model with lower accuracy). To better estimate the accuracy of the model the Receiving Operating
436 Characteristic (ROC) curve was constructed (Figure 5) and the area under the curve was calculated.
437 A ROC curve is commonly plotted to illustrate the diagnostic ability of a binary classifier. It shows
438 the sensitivity (the proportion of correctly classified positive observations) and specificity (the
439 proportion of correctly classified negative observations) as the output threshold is moved over the
440 range of all possible values (Robin et al., 2011). A popular way of summarizing the discrimination
441 ability of a model is to report the area under the ROC curve (AUC) (Prasad, 2016). The AUC value
442 for the model was 0.97, showing that the logistic regression using the RH and time after harvest
443 as predictors, has a strong discriminating power between strawberry samples that would score
444 above or below the acceptability threshold.

445 4. Conclusions

446 Strawberries are metabolically active during postharvest storage, and their quality and shelf life is
447 influenced among other things by the storage conditions they experience. Temperature and RH are
448 environmental factors with major impact on strawberries postharvest quality. However, the RH
449 effect on strawberries sensory and nutritional properties has not been explored sufficiently. This
450 study emphasised on studying the kinetics of the physicochemical changes occurring during
451 storage under RH conditions experienced by strawberries under simulated commercial situations.
452 The results provided a comprehensive description and explanation of these changes, information
453 which is useful when designing supply chain aiming at minimising food losses. One of the most
454 significant impacts of RH on strawberry quality during storage, was on weight loss. Weight loss
455 significantly increased when the storage RH decreased. In turn, the weight loss was correlated with
456 the changes that occurred in visual appearance and chemical properties.

457 Commercially, strawberry quality and shelf life are determined by visual inspection. Overall
458 appearance (i.e., average score of colour and shrivelling), was modelled with a zero-order kinetics
459 model for the various RH conditions. It was found that the lower RH increased the rate of
460 appearance deterioration and hence limited the remaining shelf life of strawberries. The Weibull
461 model was the best fit for the data related to the chemical properties and it was found to be an
462 important tool in explaining the changes occurring and the effect of the various RH conditions
463 during storage. Our results showed that improper RH storage conditions have a significant impact
464 on the rate of degradation of chemical components and affects negatively nutritional and
465 biochemical properties such as retention of AA, TPC, and ANC. In addition, sugar content, a major
466 quality attribute in strawberries that determines acceptability by the consumer, was negatively
467 affected by lower RH storage conditions. Overall, the Weibull model showed the rate of
468 deterioration was the highest when strawberries were kept at 40 or 60 % RH.

469 Furthermore, significant differences in quality were observed between harvests. Higher
470 contents of ANC and TPC were found in strawberries from the 2012 harvest possibly due to the
471 higher temperatures occurring around the time of harvest. On the contrary, the higher temperatures
472 in 2012, may have affected negatively the sugar content and the ascorbic acid contents. Arising
473 from the Weibull model the degradation rate of many chemical properties was different between
474 the two harvests, following the same pattern as the rate of weight loss for these harvests. Pre-
475 harvest conditions can affect postharvest quality and shelf life. This study showed the significant
476 interaction between pre-harvest and postharvest conditions on the overall concentration of

477 nutritional properties over storage. Higher initial concentrations due to favourable conditions,
478 resulted in higher concentrations after 7 days of storage even when the degradation rate was higher
479 compared to a harvest with lower initial concentrations. Similarly, the study showed that higher
480 RH storage ($RH \geq 80\%$) can extend the shelf life and aid in the retention of overall quality even
481 in strawberries with lower initial levels of AA, TPC, ANC and sugars due to pre-harvest
482 conditions.

483 Finally, using the logistic regression classification method, our results showed that RH and
484 time after harvest have a strong predictive power in forecasting the number of samples that would
485 be unacceptable based on the visual appearance. This highlighted the importance of RH in
486 determining the shelf life of fresh strawberries and therefore it be considered when predictive
487 modelling is used for designing the supply chain with the view to minimising unnecessary losses.

488

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494

495 **References**

- 496 Amodio, M. L., Derossi, A., & Colelli, G. (2013). Modelling sensorial and nutritional changes to better
497 define quality and shelf life of fresh-cut melons. *Journal of Agricultural Engineering*, 43(4), 6-e6.
498 <https://doi:10.4081/jae.2013.e6>
- 499 Caleb, O. J., Wegner, G., Rolleczeck, C., Herppich, W. B., Geyer, M., & Mahajan, P. V. (2016). Hot water
500 dipping: Impact on postharvest quality, individual sugars, and bioactive compounds during storage
501 of 'Sonata' strawberry. *Scientia Horticulturae*, 210, 150-157.
502 <https://doi.org/10.1016/j.scienta.2016.07.021>
- 503 Castro, I., Gonçalves, O., Teixeira, J. A., & Vicentesc, A. A. (2002). Comparative Study of Selva and
504 Camarosa Strawberries for the Commercial Market. *Journal of Food Science*, 67(6), 2132-2137.
505 <https://doi.org/10.1111/j.1365-2621.2002.tb09515.x>
- 506 Cayo, Y. P., Sargent, S., Nunes, C. D., & Whitaker, V. (2016). Composition of Commercial Strawberry
507 Cultivars and Advanced Selections as Affected by Season, Harvest, and Postharvest Storage.
508 *Hortscience*, 51(9), 1134-1143. <https://doi.org/10.21273/HORTSCI10996-16>
- 509 Corradini, M. G., & Peleg, M. (2004). A model of non-isothermal degradation of nutrients, pigments and
510 enzymes. *Journal of the Science of Food and Agriculture*, 84(3), 217-226.
511 <https://doi.org/10.1002/jsfa.1647>
- 512 Flores-Felix, J. D., Velazquez, E., Garcia-Fraile, P., Gonzalez-Andres, F., Silva, L. R., & Rivas, R.
513 (2018). Rhizobium and Phyllobacterium bacterial inoculants increase bioactive compounds and
514 quality of strawberries cultivated in field conditions. *Food Research International*, 111, 416-422.
515 <https://doi.org/10.1016/j.foodres.2018.05.059>

516 Halvorsen, B. K. (2015). Material from the book's webpage, R port and packaging. ElemStatLearn: Data
517 Sets, Functions and Examples from the Book: "The Elements of Statistical Learning, Data Mining,
518 Inference, and Prediction" by Trevor Hastie, Tibshirani, R. and Friedman, J. R package version
519 2015.6.26. <https://CRAN.R-project.org/package=ElemStatLearn>

520 Hamner, B. and Frasco M. (2017). Metrics: Evaluation Metrics for Machine Learning. R package version
521 0.1.3. <https://CRAN.R-project.org/package=Metrics>

522 Holcroft, D. M., & Kader, A. A. (1999). Controlled atmosphere-induced changes in pH and organic acid
523 metabolism may affect color of stored strawberry fruit. *Postharvest Biology and Technology*, 17(1),
524 19-32. [https://doi.org/10.1016/S0925-5214\(99\)00023-X](https://doi.org/10.1016/S0925-5214(99)00023-X)

525 Hosahalli, S. R. (2015). Post Harvest Physiology of Fruits and Vegetables: Transpiration. In *Post-harvest*
526 *Technologies of Fruits & Vegetables*. Pennsylvania, USA: DEStech Publications Inc.

527 Jouquand, C., Chandler, C., Plotto, A., & Goodner, K. (2008). A sensory and chemical analysis of fresh
528 strawberries over harvest dates and seasons reveals factors that affect eating quality. *Journal of the*
529 *American Society for Horticultural Science*, 133(6), 859-867.
530 <https://doi.org/10.21273/JASHS.133.6.859>

531 Kader, A. A., & Salveit, M. E. (2003). Respiration and gas exchange. In J. A. Bartz & J. K. Brecht (Eds.),
532 *Postharvest physiology and pathology of vegetables, second edition, revised and expanded*, (pp.
533 7-31). New York, USA: Marcel Dekker, Inc.

534 Kader, F., Nicolas, J.-P., & Metche, M. (1999). Degradation of pelargonidin 3-glucoside in the presence of
535 chlorogenic acid and blueberry polyphenol oxidase. *Journal of the Science of Food and*
536 *Agriculture*, 79(4), 517-522. [https://doi.org/10.1002/\(SICI\)1097-0010\(19990315\)79:4<517::AID-](https://doi.org/10.1002/(SICI)1097-0010(19990315)79:4<517::AID-JSFA212>3.0.CO;2-N)
537 [JSFA212>3.0.CO;2-N](https://doi.org/10.1002/(SICI)1097-0010(19990315)79:4<517::AID-JSFA212>3.0.CO;2-N)

538 Kelly, K., Madden, R., Emond, J. P., & do Nascimento Nunes, M. C. (2018). A novel approach to determine
539 the impact level of each step along the supply chain on strawberry quality. *Postharvest Biology and*
540 *Technology*, 147, 78-88. <https://doi.org/10.1016/j.postharvbio.2018.09.012>

541 Kelly, K., Nunes, C., & Whitaker, V. M. (2016). A comparison of physical and chemical attributes of
542 strawberry cultivars and advanced breeding selections from the university of florida. In
543 *Proceedings of the Florida State Horticultural Society*, vol. 129 (pp. 185-189).

544 Kelly, K., Whitaker, V. M., & Nunes, M. C. d. N. (2016). Physicochemical characterization and
545 postharvest performance of the new Sensation ® ‘Florida127’ strawberry compared to
546 commercial standards. *Scientia Horticulturae*, 211, 283-294.
547 <https://doi.org/10.1016/j.scienta.2016.09.012>

548 Klein, B. P. (1987). Nutritional consequences of minimal processing of fruits and vegetables. *Journal of*
549 *Food Quality*, 10(3), 179-193. <https://doi.org/10.1111/j.1745-4557.1987.tb00857.x>

550 Kuhn, M. Contributions from Jed Wing, J., Weston, S., Williams, A. Keefer, C., Engelhardt, A., Cooper,
551 T., Mayer, Z., Kenkel, B., R Core Team, Benesty, M., Lescarbeau, R., Ziem, A., Scrucca, L., Tang, Y.,
552 Candan, C. and Hunt, T. (2018). caret: Classification and Regression Training. R package version 6.0-79.
553 <https://CRAN.R-project.org/package=caret>

554 Lai, Y.P., Emond, J. P., & Nunes, M. C. N. (2011). Environmental Conditions Encountered during
555 Distribution from the Field to the Store Affect the Quality of Strawberry (‘Albion’). *Proceedings*
556 *of the Florida State Horticultural Society*, 124, 213-220.

557 Laurin, E., Nunes, M. C. N., Brecht, J. K., & Emond, J. P. (2005). Vapor pressure deficit and water loss
558 patterns during simulated air shipment and storage of Beit Alpha cucumbers. In F. Mencarelli & P.
559 Tonutti (Eds.), *Proceedings of the 5th International Postharvest Symposium, Vols 1-3*, (pp. 1697-
560 1703).

561 Mc Carthy, U., Uysal, I., Badia-Melis, R., Mercier, S., O'Donnell, C., and Ktenioudaki, A. (2018). Global
562 food security – Issues, challenges and technological solutions. *Trends in Food Science &*
563 *Technology*, 77, 11-20. <https://doi.org/10.1016/j.tifs.2018.05.002>

564 Meyer D., Dimitriadou, E., Hornik, K., Weingessel, A. and Leisch, F.(2017). e1071: Misc Functions of the
565 Department of Statistics, Probability Theory Group (Formerly: E1071), TU Wien. R package
566 version 1.6-8. <https://CRAN.R-project.org/package=e1071>.

- 567 Nunes, M. C. N. (2015). Correlations between subjective quality and physicochemical attributes of fresh
568 fruits and vegetables. *Postharvest Biology and Technology*, 107, 43-54.
569 <https://doi.org/10.1016/j.postharvbio.2015.05.001>
- 570 Nunes, M. C. N., Å-mond, J. P., & Brecht, J. K. (2003). Predicting shelf life and quality of raspberries
571 under different storage temperatures. In 628 ed., (pp. 599-606): International Society for
572 Horticultural Science (ISHS), Leuven, Belgium.
- 573 Nunes, M. C. N., Brecht, J. K., Morais, A. M. M. B., & Sargent, S. (1998). Controlling temperature and
574 water loss to maintain ascorbic acid levels in strawberries during postharvest handling. *Journal of*
575 *Food Science*, 107, 1033-1036. <https://doi.org/10.1111/j.1365-2621.1998.tb15848.x>
- 576 Nunes, M. C. N., Brecht, J. K., Morais, A. M. M. B., & Sargent, S. A. (2005). Possible Influences of
577 Water Loss and Polyphenol Oxidase Activity on Anthocyanin Content and Discoloration in Fresh
578 Ripe Strawberry (cv. OsoGrande) During Storage at 1 °C. *Journal of Food Science*, 70(1), 79-84.
579 <https://doi.org/10.1111/j.1365-2621.2005.tb09069.x>
- 580 Nunes, M. C. N., Brecht, J. K., Morais, A. M. M. B., & Sargent, S. A. (2006). Physicochemical changes
581 during strawberry development in the field compared with those that occur in harvested fruit during
582 storage. *Journal of the Science of Food and Agriculture*, 86(2), 180-190.
583 <https://doi.org/10.1002/jsfa.2314>
- 584 Nunes, M. C. N., & Delgado, A. (2014). Quality of organic compared to conventionally grown strawberries
585 at the retail level. In 1049 ed., (pp. 723-730): International Society for Horticultural Science
586 (ISHS), Leuven, Belgium.
- 587 Nunes, M. C. N., & Emond, J. P. (2007). Relationship between Weight Loss and Visual Quality of Fruits
588 and Vegetables. *Proceedings of the Florida State Horticultural Society*, 120, 235-245.
- 589 Nunes, M. C. N., Emond, J. P., Rauth, M., Dea, S., & Chau, K. V. (2009). Environmental conditions
590 encountered during typical consumer retail display affect fruit and vegetable quality and waste.
591 *Postharvest Biology and Technology*, 51(2), 232-241.
592 <https://doi.org/10.1016/j.postharvbio.2008.07.016>
- 593 Odriozola-Serrano, I., Soliva-Fortuny, R., & Martín-Belloso, O. (2009). Influence of storage temperature
594 on the kinetics of the changes in anthocyanins, vitamin C, and antioxidant capacity in fresh-cut
595 strawberries stored under high-oxygen atmospheres. *J Food Sci*, 74(2), C184-191. <https://doi.org/10.1111/j.1750-3841.2009.01075.x>.
- 596
- 597 Oms-Oliu, G., Odriozola-Serrano, I., Soliva-Fortuny, R., & Martín-Belloso, O. (2009). Use of Weibull
598 distribution for describing kinetics of antioxidant potential changes in fresh-cut watermelon.
599 *Journal of Food Engineering*, 95(1), 99-105. <https://doi.org/10.1016/j.jfoodeng.2009.04.016>
- 600 Ong, S. P., Law, C. L., & Hii, C. L. (2011). Effect of Pre-treatment and Drying Method on Colour
601 Degradation Kinetics of Dried Salak Fruit During Storage. *Food and Bioprocess Technology*, 5(6),
602 2331-2341. <https://doi.org/10.1007/s11947-011-0647-y>
- 603 Ooms, J. (2018). writexl: Export Data Frames to Excel 'xlsx' Format. R package version 1.0.
604 <https://CRAN.R-project.org/package=writexl>
- 605 Pan, L., Zhang, W., Zhu, N., Mao, S., & Tu, K. (2014). Early detection and classification of pathogenic
606 fungal disease in post-harvest strawberry fruit by electronic nose and gas chromatography–mass
607 spectrometry. *Food Research International*, 62, 162-168.
608 <https://doi.org/10.1016/j.foodres.2014.02.020>
- 609 Prasad, Y.L. (2016) Big Data Analytics Made Easy. Notion Press, Chennai, India
- 610 R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical
611 Computing, Vienna, Austria. URL <https://www.R-project.org/>.
- 612 Robin, X., Turck N., Hainard A., Tiberti N., Lisacek F., Sanchez J.C. & Muller M. (2011). pROC: an
613 open-source package for R and S+ to analyze and compare ROC curves. *BMC Bioinformatics*.
614 12, 77.
- 615 Robinson, J. E., Browne, K. M., & Burton, W. G. (1975). Storage characteristics of some vegetables and
616 soft fruits. *Annals of Applied Biology*, 81(3), 399-408.
- 617 Schwieterman, M. L., Colquhoun, T. A., Jaworski, E. A., Bartoshuk, L. M., Gilbert, J. L., Tieman, D. M.,
618 Odabasi, A. Z., Moskowitz, H. R., Folta, K. M., Klee, H. J., Sims, C. A., Whitaker, V. M., & Clark,

619 D. G. (2014). Strawberry Flavor: Diverse Chemical Compositions, a Seasonal Influence, and
620 Effects on Sensory Perception. *PLOS ONE*, 9(2), e88446.
621 <https://doi.org/10.1371/journal.pone.0088446>

622 Shin, Y., Liu, R. H., Nock, J. F., Holliday, D., & Watkins, C. B. (2007). Temperature and relative humidity
623 effects on quality, total ascorbic acid, phenolics and flavonoid concentrations, and antioxidant
624 activity of strawberry. *Postharvest Biology and Technology*, 45(3), 349-357.
625 <https://doi.org/10.1016/j.postharvbio.2007.03.007>

626 Shin, Y., Ryu, J.-A., Liu, R. H., Nock, J. F., & Watkins, C. B. (2008). Harvest maturity, storage temperature
627 and relative humidity affect fruit quality, antioxidant contents and activity, and inhibition of cell
628 proliferation of strawberry fruit. *Postharvest Biology and Technology*, 49(2), 201-209.
629 <https://doi.org/10.1016/j.postharvbio.2008.02.008>

630 Sing, T., Sander, O., Beerenwinkel, N. and Lengauer, T. (2005). "ROCR: visualizing classifier performance
631 in R." *Bioinformatics*, 21 (20), pp. 7881. <URL: <http://rocr.bioinf.mpi-sb.mpg.de>>

632 Taoukis P, Labuza T, Saguy I. 1997. Kinetics of food deterioration and shelf-life prediction. In Handbook
633 of Food Engineering Practice, ed. K Valentas, E Rotstein, R Singh, pp. 361–403. Boca Raton: CRC
634 Press

635 Therneau, T. and Atkinson, B. (2018). rpart: Recursive Partitioning and Regression Trees. R package
636 version 4.1-13. <https://CRAN.R-project.org/package=rpart>

637 Tuszynski, J. (2014). caTools: R package version 1.17.1. <https://CRAN.R-project.org/package=caTools>

638 Van de Velde, F., Fenoglio C., Piagentini A.M. & Pirovani M.E. (2017). Modeling the Impact of the Type
639 of Cutting and Storage Temperature on the Bioactive Compound Content, Phenylpropanoid
640 Metabolism Enzymes and Quality Attributes of Fresh-Cut Strawberries. *Food and Bioprocess
641 Technology*, 11(1), 96-109. <https://doi.org/10.1007/s11947-017-1996-y>

642 Venables, W.N. and Ripley, B.D. (2002). *Modern Applied Statistics with S*. Fourth Edition. Springer, New
643 York.

644 Wang, S.Y. & Camp M.J. (2000). Temperatures after bloom affect plant growth and fruit quality of
645 strawberry. *Scientia Horticulturae*, 85, 183-199. [https://doi.org/10.1016/S0304-4238\(99\)00143-0](https://doi.org/10.1016/S0304-4238(99)00143-0)

646 White, J. (2007). How Cold Was It? Know the Whole Story. *Frozen Food Age*, 56, 38-40. ISSN
647 00162191

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Figure Captions

654 Figure 1 Effect of storage under various RH conditions on the weight loss (%) of fresh strawberries
655 harvested (a) in 2012 and (b) in 2013. Error bars represent the standard deviation of the mean, plotted
656 lines correspond to the values estimated by the Weibull model

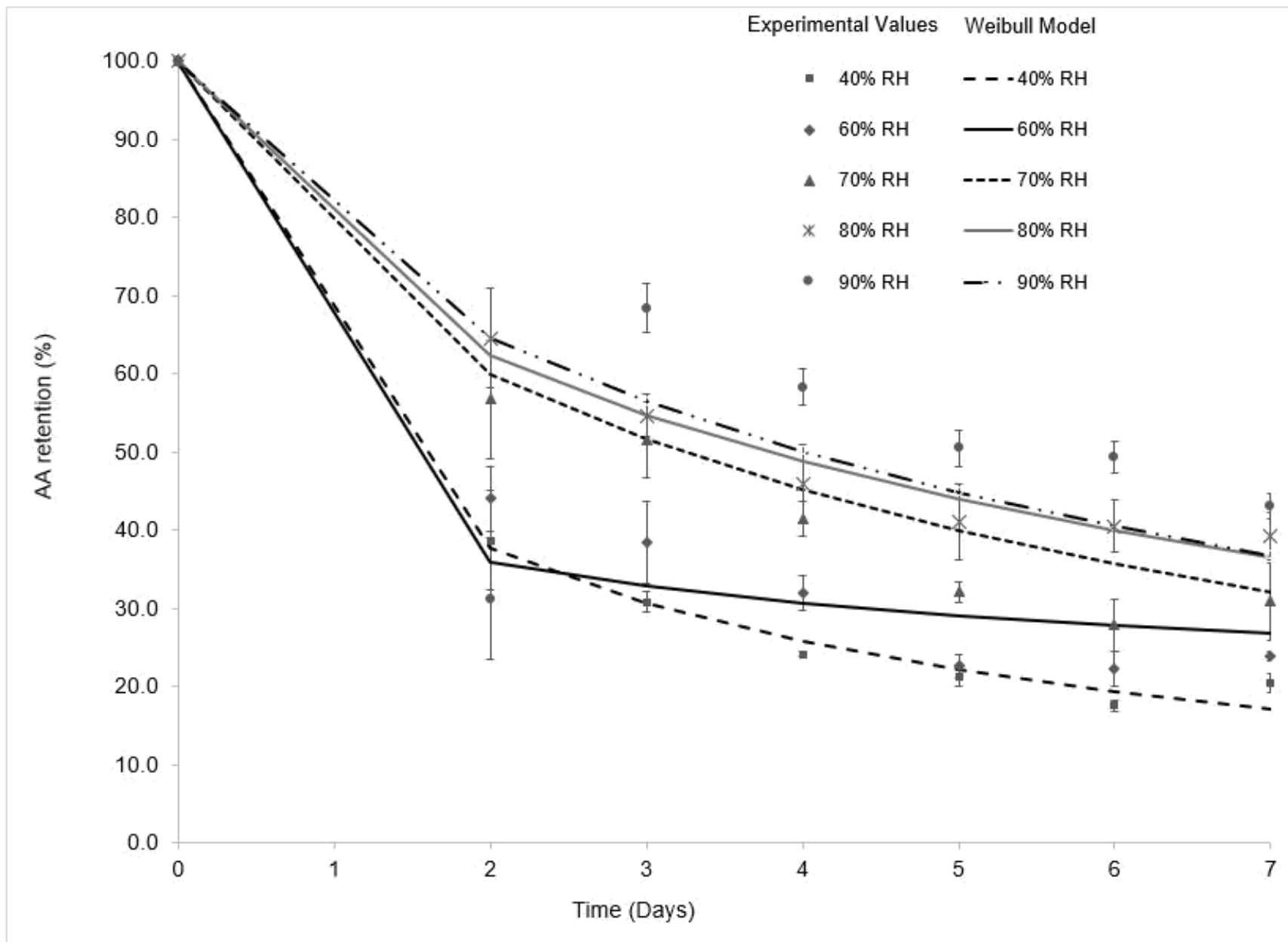
657 Figure 2 Changes observed in shrivelling of fresh strawberries during storage under various RH
658 conditions (a-2012 harvest, b-2013 harvest). Error bars represent the standard deviation of the mean
659 score. Dashed straight line represents the minimum acceptable quality before strawberries become
660 unmarketable (rating 3).

661 Figure 3 Effect of storage under various RH conditions on the AA retention (%) of fresh strawberries
662 harvested in 2012. Error bars represent the standard deviation of the mean, plotted lines correspond to
663 the values estimated by the Weibull model.

664 Figure 4 Effect of storage under various RH conditions on the total sugar retention (%) of fresh
665 strawberries harvested (a) in 2012 and (b) in 2013. Error bars represent the standard deviation of the
666 mean, plotted lines correspond to the values estimated by the Weibull model

667 Figure 5 Receiver operating characteristic (ROC) curve of logistic regression model predicting “ Pass-Fail”
668 score of fresh strawberries kept under various RH conditions. The area under the ROC curve, is 0.97
669 ($p=0$).

670



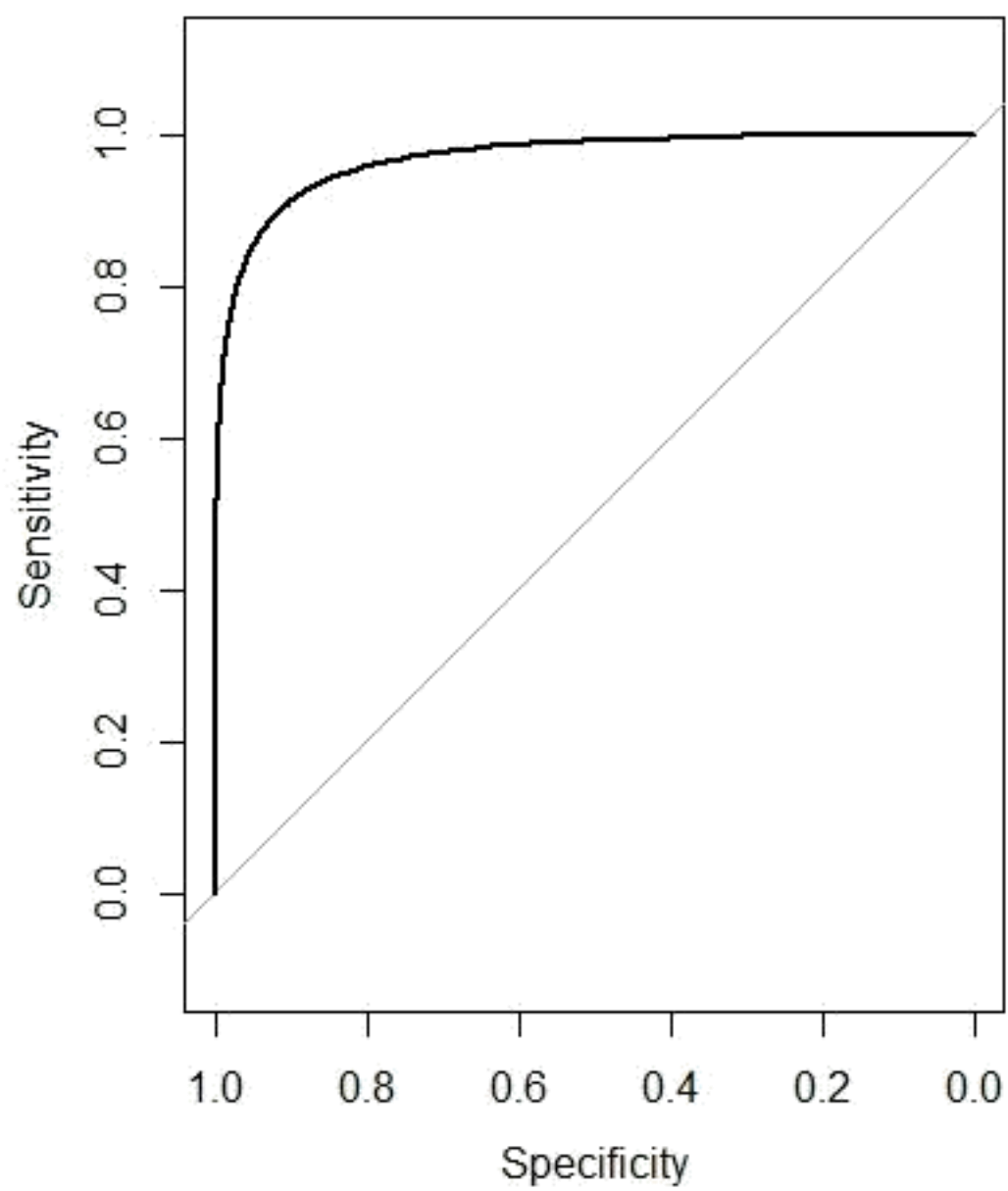


Table 1 Kinetic constants and goodness of fit parameters of zero-order, 1st-order and Weibull models of weight loss (%) in fresh strawberries kept at various RH conditions

Harvest	Model	RH	Rate constants (per day)	R ²	RMSE	AIC
2012	M0	40	-2.66	0.98	0.83	65
	M0	60	-2.54	0.99	0.59	49
	M0	70	-1.83	0.99	0.46	37
	M0	80	-1.40	0.97	0.58	48
	M0	90	-1.03	0.99	0.19	-4
	M1	40	-0.23	0.90	1.99	107
	M1	60	-0.24	0.91	1.84	103
	M1	70	-0.25	0.91	1.28	86
	M1	80	-0.24	0.88	1.14	80
	M1	90	-0.26	0.93	0.67	55
	MW	40	0.03, $\gamma=-0.37$	0.99	0.74	60
	MW	60	0.03, $\gamma=-0.38$	0.99	0.49	40
	MW	70	0.02, $\gamma=-0.35$	0.99	0.47	38
	MW	80	0.01, $\gamma=-0.32$	0.97	0.55	45
	MW	90	0.01, $\gamma=-0.30$	0.99	0.22	2
2013	M0	40	-2.15	0.99	0.5	41
	M0	60	-1.80	0.99	0.4	35
	M0	70	-1.34	0.99	0.3	17
	M0	80	-1.29	0.99	0.2	4
	M0	90	-0.87	0.94	0.5	43
	M1	40	-0.24	0.91	1.5	93
	M1	60	-0.24	0.91	1.3	85
	M1	70	-0.25	0.92	0.9	68
	M1	80	-0.25	0.92	0.9	67
	M1	90	-0.25	0.85	0.8	64
	MW	40	0.022, $\gamma=-0.35$	0.99	0.5	41
	MW	60	0.015, $\gamma=-0.33$	0.99	0.4	34
	MW	70	0.009, $\gamma=-0.31$	0.99	0.4	26
	MW	80	0.008, $\gamma=-0.31$	0.99	0.2	6
	MW	90	0.004, $\gamma=-0.28$	0.94	0.5	41

M0 = Zero-order (eq. 1), M1 = 1st-order (eq. 2), MW = Weibull model (eq. 3)

Table 2 Kinetic constants and goodness of fit parameters of zero-order, 1st-order and Weibull models of the overall appearance of fresh strawberries kept at various RH conditions

Harvest	Model	RH	Rate constants (per day)	R ²	RMSE	AIC
2012	M0	40	0.39	0.94	0.23	-17
	M0	60	0.24	0.89	0.19	-109
	M0	70	0.23	0.80	0.27	52
	M0	80	0.26	0.78	0.31	129
	M0	90	0.21	0.88	0.18	-137
	M1	40	0.14	0.94	0.22	-30
	M1	60	0.07	0.91	0.17	-168
	M1	70	0.06	0.80	0.27	52
	M1	80	0.07	0.77	0.32	133
	M1	90	0.05	0.88	0.18	-145
	MW	40	0.16, $\gamma=0.82$	0.92	0.34	162
	MW	60	0.06, $\gamma=0.58$	0.90	0.23	-15
	MW	70	0.06, $\gamma=0.67$	0.76	0.34	168
	MW	80	0.07, $\gamma=0.80$	0.75	0.35	184
	MW	90	0.05, $\gamma=0.78$	0.86	0.21	-65
2013	M0	40	0.44	0.93	0.27	58
	M0	60	0.31	0.85	0.30	114
	M0	70	0.26	0.83	0.28	70
	M0	80	0.23	0.83	0.24	-3
	M0	90	0.22	0.78	0.26	44
	M1	40	0.13	0.91	0.31	130
	M1	60	0.08	0.86	0.30	105
	M1	70	0.07	0.81	0.29	89
	M1	80	0.06	0.83	0.24	3
	M1	90	0.05	0.78	0.26	49
	MW	40	0.14, $\gamma=1.26$	0.93	0.28	82
	MW	60	0.09, $\gamma=0.97$	0.85	0.30	107
	MW	70	0.07, $\gamma=0.99$	0.81	0.30	102
	MW	80	0.05, $\gamma=0.77$	0.81	0.27	56
	MW	90	0.05, $\gamma=0.91$	0.77	0.28	72

M0 = Zero-order (eq. 1), M1 = 1st-order (eq. 2), MW = Weibull model (eq. 3)

Table 3 Daily mean temperatures for the week of harvest during 2012 and 2013 periods in Floral City, Florida (data from weather underground <https://www.wunderground.com>)

Harvest	Temperature °C		
	Mean	Max	Min
March 2012	20.5	28.8	13.8
February 2013	12.1	21.6	6.8

Table 4 Kinetic constants and goodness of fit parameters of zero-order, 1st-order and Weibull models of sugar retention in fresh strawberries kept at various RH conditions

Harvest	Model	RH	Rate constants (per day)	R ₂	RMSE	AIC
2012	M0	40	9.70	0.69	14.55	178
	M0	60	9.99	0.72	13.90	176
	M0	70	10.75	0.86	9.58	160
	M0	80	8.14	0.81	8.71	156
	M0	90	8.62	0.76	10.83	166
	M1	40	0.31	0.92	7.89	152
	M1	60	0.32	0.94	6.88	147
	M1	70	0.26	0.96	4.93	133
	M1	80	0.16	0.91	6.20	142
	M1	90	0.19	0.88	7.73	151
	MW	40	0.50, $\gamma=0.37$	1.00	1.04	67
	MW	60	0.44, $\gamma=0.45$	1.00	0.97	64
	MW	70	0.28, $\gamma=0.72$	0.98	3.59	119
	MW	80	0.14, $\gamma=0.51$	0.98	3.04	112
	MW	90	0.20, $\gamma=0.41$	0.98	3.15	114
2013	M0	40	9.94	0.84	9.69	161
	M0	60	8.77	0.62	15.48	181
	M0	70	8.79	0.72	12.15	171
	M0	80	8.29	0.84	8.1	154
	M0	90	7.97	0.88	6.59	145
	M1	40	0.23	0.96	5.10	134
	M1	60	0.27	0.84	10.38	164
	M1	70	0.22	0.88	8.08	153
	M1	80	0.16	0.92	5.8	140
	M1	90	0.14	0.94	4.52	129
	MW	40	0.25, $\gamma=0.6$	0.99	2.38	102
	MW	60	0.45, $\gamma=0.3$	0.97	4.57	129
	MW	70	0.24, $\gamma=0.4$	0.98	3.21	115
	MW	80	0.14, $\gamma=0.5$	0.97	3.2	114
	MW	90	0.12, $\gamma=0.7$	0.97	3.3	115

M0 = Zero-order (eq. 1), M1 = 1st-order (eq. 2), MW = Weibull model (eq. 3)

Table 5 Kinetic constants and goodness of fit parameters of the Weibull model of ascorbic acid, anthocyanins, and total phenol retention in fresh strawberries kept at various RH conditions

Retention %	RH	2012				2013			
		Rate constants (per day)	R ²	RMSE	AIC	Rate constants (per day)	R ²	RMSE	AIC
Ascorbic acid	40	0.66, $\gamma=0.31$	0.98	3.48	172.92	0.66, $\gamma=0.31$	0.92	7.93	173
	60	0.34, $\gamma=0.42$	0.98	3.69	193.08	0.57, $\gamma=0.20$	0.82	11.53	168
	70	0.17, $\gamma=0.48$	0.95	5.95	177.06	0.17, $\gamma=0.64$	0.78	11.26	167
	80	0.15, $\gamma=0.61$	0.96	3.88	122.56	0.24, $\gamma=0.47$	0.77	12.76	173
	90	0.13, $\gamma=1.02$	0.42	17.95	112.23	0.14, $\gamma=0.66$	0.55	17.91	187
Anthocyanins	40	0.73, $\gamma=0.37$	0.99	3.27	115.35	0.17, $\gamma=0.95$	0.96	4.22	126
	60	0.80, $\gamma=0.34$	0.99	3.14	113.63	0.10, $\gamma=0.81$	0.93	4.70	131
	70	0.14, $\gamma=0.48$	0.81	9.57	160.48	0.09, $\gamma=0.85$	0.84	6.74	146
	80	0.12, $\gamma=0.91$	0.85	7.62	150.90	0.02, $\gamma=0.33$	0.83	5.67	138
	90	0.003, $\gamma=0.12$	0.67	10.94	166.06	0.10, $\gamma=1.66$	0.72	8.48	155
Total Phenols	40	0.30, $\gamma=0.56$	0.97	4.34	127.29	0.26, $\gamma=0.52$	0.99	1.79	90
	60	0.33, $\gamma=0.40$	0.99	2.84	109.44	0.20, $\gamma=0.56$	0.99	1.64	86
	70	0.26, $\gamma=0.51$	1.00	1.61	85.69	0.10, $\gamma=1.31$	0.84	6.71	146
	80	0.12, $\gamma=0.75$	0.91	5.94	140.40	0.07, $\gamma=1.42$	0.71	6.81	146
	90	0.09, $\gamma=0.76$	0.89	5.58	137.83	0.11, $\gamma=4.45$	0.60	12.52	172

Table 6 Kinetic constants and goodness of fit parameters of the Weibull model of SSC and TA contents in fresh strawberries kept at various RH conditions

Composition	RH	2012				2013			
		Rate constants (per day)	R ²	RMSE	AIC	Rate constants (per day)	R ²	RMSE	AIC
SSC	40	0.51, $\gamma=0.39$	1.00	3.01	111.92	0.21, $\gamma=0.42$	0.98	3.97	124
	60	0.46, $\gamma=0.45$	1.00	2.89	110.23	0.18, $\gamma=0.64$	0.99	3.37	117
	70	0.26, $\gamma=0.54$	0.99	3.50	118.18	0.15, $\gamma=0.64$	0.98	4.24	126
	80	0.18, $\gamma=0.47$	0.96	6.11	141.61	0.13, $\gamma=0.63$	0.98	4.03	124
	90	0.14, $\gamma=0.54$	0.99	3.89	122.60	0.12, $\gamma=0.95$	0.93	6.73	146
TA (%)	40	0.32, $\gamma=0.44$	0.99	2.20	98.73	0.23, $\gamma=0.44$	0.99	0.35	21
	60	0.25, $\gamma=0.58$	0.99	2.20	98.64	0.17, $\gamma=0.55$	0.99	0.36	23
	70	0.19, $\gamma=0.80$	0.97	2.21	98.88	0.12, $\gamma=0.58$	0.98	0.45	32
	80	0.15, $\gamma=0.81$	0.95	2.28	100.19	0.11, $\gamma=0.56$	0.93	0.87	60
	90	0.11, $\gamma=1.05$	0.92	2.20	98.68	0.08, $\gamma=0.76$	0.93	0.71	51

Table 7 Confusion matrix of the logistic regression model

		Harvests 2012 & 2013			
		Predicted		Total	
ACTUA		Fail	Pass		
	-	Fail	80	12	92
		Pass	32	476	508
	Total	112	488	600	