Biological method of gaseous media formation during cold storage of fruits using track membranes

Authors: Vasilina Kostiuk, Valentina Kolodyaznaya, Olga Rumiantceva, Elena Kiprushkina, Irina Shestopalova
Affiliations: Faculty of Biotechnologies (BioTech), ITMO University
Research Objective: to investigate and substantiate the formation of the gas composition depending on the respiratory rate of fruits and the selectivity of track membranes during cold storage of apples of autumn varieties.

Objects of research: apples of autumn varieties:
- Grushovka Yudicheva
- Kordonovka
- Pepin Shafrannyi
Collaborative development:

Pavlovsk Experimental Station of Vavilov Institute of Plant Industry

Federal State Unitary Enterprise «S.V. Lebedev Institute of synthetic rubber»

Ioffe Physical-Technical Institute of the Russian Academy of Sciences
Biological method of gaseous media formation during cold storage of fruits using track membranes

Keywords:
cold storage, gas-selective track membrane (GSTM),
gas composition, controlled atmosphere, respiratory rate, apples

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Gas-selective membrane material with a track membranes substrate based on polyethylene terephthalate film

PORE DIAMETER 0.2 µm
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Container equipped with GSTM

SELECTIVITY 4,0 – 5,0; LAYER THICKNESS 10 µm
Calculation of capacity and area of gas-selective track membranes

\[
S = \frac{m}{\mu}, \quad \mu = \left(\frac{C_o^h}{C_o^k} - 1\right) \cdot \mu_0, \quad \mu_0 = \frac{pP}{J}, \quad C_{co_2} = \frac{\delta}{\sigma} \left( C_o^h - C_o^k \right),
\]

\( S \) – membrane area, \( m^2 \);
\( \mu \) - membrane capacity, \( kg/m^2 \);
\( C_o^h \) - initial oxygen concentration (21%);

\( C_o^k \) - recommended storage mode, %
\( p \) - oxygen partial pressure \((2,1 \cdot 10^4 \text{ Pa})\);
\( P \) - membrane permeability for oxygen \([3,0 \cdot 10^9 \text{ m}^3/(s\cdot N)]\);
\( J \) - respiratory rate of fruits \([2,66 \text{ m}^3/(kg\cdot s)]\);
\( C_{co_2} \) - carbon dioxide concentration in a stationary mode \((2,0 - 0,8\%)\);
\( \delta \) - respiratory quotient \((1,1)\);
\( \sigma \) - membrane selectivity \((5)\).
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### Gas composition and membrane area

<table>
<thead>
<tr>
<th>Gas composition №</th>
<th>$C_{o_2}$, %</th>
<th>$C_{co_2}$, %</th>
<th>S, cm²/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2,0</td>
<td>4,18</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
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<td>3</td>
<td>4,0</td>
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<td>10</td>
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<tr>
<td>4</td>
<td>5,0</td>
<td>3,52</td>
<td>18</td>
</tr>
<tr>
<td>5</td>
<td>5,5</td>
<td>3,41</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>6,0</td>
<td>3,30</td>
<td>22</td>
</tr>
<tr>
<td>7</td>
<td>7,0</td>
<td>3,08</td>
<td>25</td>
</tr>
</tbody>
</table>
Results:

Changes in respiratory rate in autumn varieties of apples during cold storage

- Grushovka Yudicheva
- Kordonovka
- Pepin Shafrannyi
Kinetic curves of changes in the content of the sum of mono- and disaccharides in apples during cold storage

Regression equations characterizing the change in the content of the sum of mono- and disaccharides in apples of the variety:

**Kordonovka:**

\[ C_{md} = 0,062t^3 - 0,65t^2 + 0,63t + 10,98; \quad R^2 = 0,995 \text{ (Control)}; \]
\[ C_{md} = 0,045t^3 - 0,53t^2 + 0,72t + 10,97; \quad R^2 = 0,981 \text{ (GSTM)} \]

**Grushovka Yudicheva:**

\[ C_{md} = 0,037t^3 - 0,39t^2 + 0,28t + 12,79; \quad R^2 = 0,996 \text{ (Control)}; \]
\[ C_{md} = 0,027t^3 - 0,34t^2 + 0,42t + 12,79; \quad R^2 = 0,995 \text{ (GSTM)} \]

**Pepin Shafrannyi:**

\[ C_{md} = 0,041t^3 - 0,44t^2 + 0,47t + 10,99; \quad R^2 = 0,999 \text{ (Control)}; \]
\[ C_{md} = 0,043t^3 - 0,44t^2 + 0,58t + 10,99; \quad R^2 = 0,998 \text{ (GSTM)} \]
Rate constants of oxidation reactions of the sum of mono- and disaccharides in apples of autumn varieties during cold storage

<table>
<thead>
<tr>
<th>Varieties of apples</th>
<th>Storage conditions</th>
<th>$\tau$, month</th>
<th>$K_1$, 1/month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kordonovka</td>
<td>Control</td>
<td>6</td>
<td>0.131</td>
</tr>
<tr>
<td></td>
<td>GSTM</td>
<td>6</td>
<td>0.101</td>
</tr>
<tr>
<td>Grushovka Yudicheva</td>
<td>Control</td>
<td>6</td>
<td>0.066</td>
</tr>
<tr>
<td></td>
<td>GSTM</td>
<td>6</td>
<td>0.059</td>
</tr>
<tr>
<td>Pepin Shafrannyi</td>
<td>Control</td>
<td>6</td>
<td>0.075</td>
</tr>
<tr>
<td></td>
<td>GSTM</td>
<td>6</td>
<td>0.053</td>
</tr>
</tbody>
</table>
Kinetic curves of changes in the content of organic acids in apples during cold storage

**Figure 1. Changes in the content of organic acids in “Kordonovka” apples during cold storage**

**Figure 2. Changes in the content of organic acids in “Grushovka Yudicheva” apples during cold storage**

**Figure 3. Changes in the content of organic acids in “Pepin Shafrannyi” apples during cold storage**

Regression equations characterizing the change in the content of organic acids in apples of the variety:

**Kordonovka:**
\[
C_{oa} = -0.029\tau^2 + 0.023\tau + 1.53; \quad R^2 = 0.996 \text{ (Control)}; \\
C_{oa} = 0.029\tau^2 - 0.014\tau + 1.54; \quad R^2 = 0.995 \text{ (GSTM)}
\]

**Grushovka Yudicheva:**
\[
C_{oa} = -0.016\tau^2 + 0.11\tau + 1.61; \quad R^2 = 0.97 \text{ (Control)}; \\
C_{oa} = -0.031\tau^2 + 0.046\tau + 1.45; \quad R^2 = 0.992 \text{ (GSTM)}
\]

**Pepin Shafrannyi:**
\[
C_{oa} = 0.017\tau^2 - 0.22\tau + 1.29; \quad R^2 = 0.997 \text{ (Control)}; \\
C_{oa} = 0.01\tau^2 - 0.17\tau + 1.32; \quad R^2 = 0.958 \text{ (GSTM)}
\]
Biological method of gaseous media formation during cold storage of fruits using track membranes

Keywords:
- cold storage
- gas-selective track membrane (GSTM)
- gas composition
- controlled atmosphere
- respiratory rate
- apples

Rate constants of reactions of changes of organic acids content in apples of autumn varieties during cold storage

<table>
<thead>
<tr>
<th>Varieties of apples</th>
<th>Storage conditions</th>
<th>$\tau$, month</th>
<th>$K_2$, 1/month</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Kordonovka</strong></td>
<td>Control</td>
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<td>0,252</td>
</tr>
<tr>
<td></td>
<td>GSTM</td>
<td>6</td>
<td>0,225</td>
</tr>
<tr>
<td><strong>Grushovka Yudicheva</strong></td>
<td>Control</td>
<td>6</td>
<td>0,121</td>
</tr>
<tr>
<td></td>
<td>GSTM</td>
<td>6</td>
<td>0,079</td>
</tr>
<tr>
<td><strong>Pepin Shafrannyi</strong></td>
<td>Control</td>
<td>6</td>
<td>0,129</td>
</tr>
<tr>
<td></td>
<td>GSTM</td>
<td>6</td>
<td>0,103</td>
</tr>
</tbody>
</table>
Kinetic curves of changes in the content of ascorbic acid in apples during cold storage

**Figure 1.** Changes in the content of ascorbic acid in “Kordonovka” apples during cold storage

**Figure 2.** Changes in the content of ascorbic acid in “Grushovka Yudicheva” apples during cold storage

**Figure 3.** Changes in the content of ascorbic acid in “Pepin Shafrannyi” apples during cold storage

**Regression equations characterizing the change in the content of ascorbic acid in apples of the variety:**

**Kordonovka:**

\[ C_{aa} = -0.008\tau^3 + 0.12\tau^2 - 0.85\tau + 10.3; \quad R^2 = 0.999 \text{ (Control);} \]

\[ C_{aa} = -0.001\tau^3 + 0.043\tau^2 - 0.65\tau + 10.3; \quad R^2 = 0.988 \text{ (GSTM)} \]

**Grushovka Yudicheva:**

\[ C_{aa} = 0.085\tau^2 - 1.01\tau + 12.4; \quad R^2 = 0.92 \text{ (Control);} \]

\[ C_{aa} = 0.042\tau^2 - 0.58\tau + 12.1; \quad R^2 = 0.964 \text{ (GSTM)} \]

**Pepin Shafrannyi:**

\[ C_{aa} = 0.064\tau^2 - 1.26\tau + 11.9; \quad R^2 = 0.976 \text{ (Control);} \]

\[ C_{aa} = 0.035\tau^2 - 1.06\tau + 11.7; \quad R^2 = 0.98 \text{ (GSTM)} \]
### Biological method of gaseous media formation during cold storage of fruits using track membranes

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**Rate constants of reactions of conversion of ascorbic acid content in apples of autumn varieties during cold storage**

<table>
<thead>
<tr>
<th>Varieties of apples</th>
<th>Storage conditions</th>
<th>$\tau$, month</th>
<th>$K_3$, 1/month</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Kordonovka</strong></td>
<td>Control</td>
<td>6</td>
<td>0,053</td>
</tr>
<tr>
<td></td>
<td>GSTM</td>
<td>6</td>
<td>0,045</td>
</tr>
<tr>
<td><strong>Grushovka Yudicheva</strong></td>
<td>Control</td>
<td>6</td>
<td>0,037</td>
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<tr>
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<td>GSTM</td>
<td>6</td>
<td>0,021</td>
</tr>
<tr>
<td><strong>Pepin Shafrannyi</strong></td>
<td>Control</td>
<td>6</td>
<td>0,064</td>
</tr>
<tr>
<td></td>
<td>GSTM</td>
<td>6</td>
<td>0,062</td>
</tr>
</tbody>
</table>
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#### Phytopathological indicators during cold storage, days

<table>
<thead>
<tr>
<th>Varieties of apples</th>
<th>60 days</th>
<th></th>
<th></th>
<th>120 days</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Healthy apples, %</td>
<td>Fusarium culmorum</td>
<td>Monilia fructigena</td>
<td>Healthy apples, %</td>
<td>Fusarium culmorum</td>
<td>Monilia fructigena</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kordonovka</td>
<td>94.7</td>
<td>0</td>
<td>4.8</td>
<td>90.2</td>
<td>0</td>
<td>5.3</td>
</tr>
<tr>
<td>Grushovka Yudicheva</td>
<td>92.1</td>
<td>1.9</td>
<td>6.0</td>
<td>90.0</td>
<td>3.4</td>
<td>6.6</td>
</tr>
<tr>
<td>Pepin Shafrannyi</td>
<td>91.7</td>
<td>2.6</td>
<td>4.8</td>
<td>87.5</td>
<td>4.6</td>
<td>7.9</td>
</tr>
<tr>
<td><strong>GSTM</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kordonovka</td>
<td>95.2</td>
<td>0</td>
<td>4.2</td>
<td>90.7</td>
<td>0</td>
<td>4.5</td>
</tr>
<tr>
<td>Grushovka Yudicheva</td>
<td>97.0</td>
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<td>3.0</td>
<td>94.2</td>
<td>2.7</td>
<td>5.2</td>
</tr>
<tr>
<td>Pepin Shafrannyi</td>
<td>95.4</td>
<td>2.0</td>
<td>2.6</td>
<td>92.0</td>
<td>2.0</td>
<td>2.6</td>
</tr>
</tbody>
</table>
Conclusions

It is shown that for maximum preservation of the quality, nutritional and biological value of the studied apple varieties at $t = (3 \pm 1) ^\circ C$ a controlled gas atmosphere of the following composition is recommended: oxygen concentration - $(5.2 \pm 0.1\%)$, carbon dioxide concentration - $(3.6 \pm 0.1\%)$. Controlled atmosphere was created using a gas-selective composite membrane with an area of 14-22 cm²/kg, depending on variety of apples and respiratory rate.

References

Thank you for your attention!

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