SHELF-LIFE PREDICTION OF FRESH VEGETABLES AND FRUITS USING SPECIFIC MOISTURE LOSS AND HEAT GENERATION

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Abstract
The specific moisture loss and heat generation are known for many fresh vegetables and fruits. The shelf-life of these products is also known using acceptability standards commonly used by auctions. Both data-sets were combined to develop shelf-life equations. Specific moisture loss and heat generation are factors involved for leafy (lettuce, spinach) products. For spherical products (apples, potatoes) heat generation only is the sensitive factor. A fair agreement between measured and predicted shelf-life exists for 70 % of the products. Arbitrary factors cause a deviation in the predicted shelf-life. These factors are the vapour pressure deficit and the maximum allowable moisture loss.

The concept of quality indicators

The shelf-life of fresh horticultural products is given for many products in Greidanus (1976). To specify quality, this Dutch source used the concept of quality indicators (Alvarez and Thorne, 1981), which is the application of one or more attributes of a product to indicate changes. The quality indicators for the determination of shelf-life of horticultural products ideally should be major quality indicators and they will be different for every product. The be useful as a quality indicator, this product attribute must change during time, and must be measurable with instruments or human senses. Important indicators are colour, firmness, shape, taste, sugar/acid ratio, spots, concentration of chemical substances, micro-biological spoilage. When several quality attributes are considered the calculation should allow prediction of any one factor that limits quality. The consumer might reject a product with excessive deterioration even though all other quality attributes are at acceptable levels.

Quality change models

Various models have been proposed to calculate quality changes, in most cases as a function of temperature. The *effective temperature theory* proposes that if the temperature varies with time according to some regular periodic wave then the extent of a particular reaction or change after a period of time will be the same as it would have been if the material had been held at some constant temperature for the same time. This theory was useful for frozen foods, but applications for fresh products were scarce. The *time-temperature-tolerance hypothesis* is very useful for fresh and frozen products. The rate at which an attribute changes with temperature is assumed to be exponentially (Thorne and Meffert, 1979). The basis of this hypothesis is that the rate of change against time can be constructed from the exponential (and experimental) relationship between temperature and shelf-life (quality just acceptable). *Computer-aided simulation models* incorporate laboratory experiments to predict quality changes based on properties of foodstuffs, kinetics of food deterioration reactions (Arrhenius model and Q10-method) and the properties of packaging protection and different gasses. A very considerable quantity of kinetic information is required to simulate an entire biological system. This paper shows equations which belong to this class of models, because the quality change is predicted as a function of water vapour deficit and temperature, using the product properties specific moisture loss and heat generation.

Models using specific moisture loss and heat generation
Quast (Alvarez, 1981) used as a model oxidation by atmospheric oxygen and textural changes due to water gain or loss for potato chips. Baxter (Alvarez, 1981) developed exponential equations to predict ripening of pears by selecting firmness (which depends on water loss and integrated heat generation) as a quality indicator.

Heat generation and specific moisture loss
The heat generation can be calculated with equation 1, which resembles Arrhenius'law:

$$q = A\ e^{-\frac{B}{T}} \tag{1}$$

symbol	unit	property
q	W/kg	heat generation
A	W/kg	frequency factor
B	1/K	activity
T	K	temperature

The most simple way to measure adiabatically the heat generation at a certain temperature is as follows. Spread the products for 30 minutes out over the floor of a room with constant temperature. Then put the products in an insulated box and follow the temperature rise for 2 hours. The heat generation can be calculated using the known specific heat.

Development of shelf-life equation using heat generation and specific moisture loss
The intention of this paper is to develop shelf-life equations at the optimum storage temperature. The heat generation of fresh horticultural products is accompanied by loss of carbohydrates and proteins with release of carbondioxide (CO_2). This mass loss, related to heat generation, is called carbon loss, in contrast with moisture loss. Mass loss is the sum of carbon loss, depending on the rate and type of components which are consumed, and of moisture loss, which depends on the water permeability of the skin of the product and the vapour pressure deficit. I assume that after a certain loss of these components, the mix of quality indicators indicates that the product is just acceptable, and this moment coincide with the shelf-life. The other assumption is that firmness, a major quality indicator, depends only on the specific moisture loss (a measure for the water vapour permeability) and the vapour pressure deficit.

First of all products are split in 2 groups: leafy and spherical. From experience we know that leafy product, like lettuce or spinach, react during storage very different from spherical products, like apples or cabbages. The measured shelf-life of products is given in Greidanus (1976). These shelf-lives should have changed during the last 20 years because of better cultivars or types and improved harvest, packaging and storage techniques. The specific moisture loss and the heat generation is given in table 1. The shelf-life equation is predicted with a multiple linear regression analysis.

For leafy products, stored at a temperature of 2 to 5 °C, the analysis resulted in:

symbol	unit	property

$$sl = C1 - \frac{ms*10^{+10}}{C2} \qquad (2)$$

sl	week	shelf-life
ms	kg/(kg.Pa.s)	specific moisture loss
C1 = 7	week	constant
C2 = 4	-	constant

The correlation was 79 % for this equation. The heat generation of leafy products seems to be unimportant to the prediction of the shelf-life. The shelf-life of fresh leafy products depends largely on moisture loss. At higher temperatures the vapour pressure deficit must become more important. This results an equation including the vapour pressure deficit:

$$sl = C1 - \frac{ms*10^{+10}}{C3 * dp} \qquad (3)$$

symbol	unit	property
sl	week	shelf-life
ms	kg/(kg.Pa.s)	specific moisture loss
dp	Pa	water vapour deficit
C1 = 7	week	constant
C3 = 0.06	-	constant

The multiple regression analysis (correlation 72 %) for spherical products proved to be of equal influence for heat generation and moisture loss:

$$sl = \frac{C4}{q} + \frac{C5}{ms*10^{+10}*dp} \qquad (4)$$

symbol	unit	property
sl	week	shelf-life
C4 = 160	-	constant
q	W/ton	heat generation
C5 = 500	-	constant
ms	kg/(kg.Pa.s)	specific moisture loss
dp	Pa	water vapour pressure deficit

Conclusion

1. The low correlation coefficient of the multiple regression analysis indicates the presence of large difference between actual and predicted shelf-life. For instance, mould growth could decrease the shelf-life of products, like berries (straw, black, etc.), carrots and plums. The moment of harvest for melons and pears could influence the ripeness. And perhaps higher product losses are accepted for bulk product like swede, beet, chicory roots.

2. Moisture loss is an important factor for the prediction of shelf-life of fresh horticultural products. Every predictive method should incorporate a term with specific moisture loss.

3. Measure moisture loss of new and old cultivars (types) of one leafy product to select the best cultivars.

4. An indication of the shelf-life of a new cultivated horticultural product can be obtained by measuring the heat generation (also useful information for refrigeration engineers and modified atmosphere packaging) and specific moisture loss, and using a selected shelf-life equation.

Table 1
Product properties to calculated the heat generation and the specific moisture loss of some horticultural products.

name	A	B	Specific moisture loss	
			v<1 cm/s	v>1 cm/s
	W/kg	1/K	$*10^{-10}$ kg/(kg.Pa.s)	
apple (store)	1.554E10	7682	0.73	$0.68*10^{-10}$
apple (summer)	3.745E10	7793	1.2	1.2
apricot	4.876E12	9034	1.5	-
asparagus	4.690E9	6875	-	-
banana (green)	4.543E8	6434	1.2	2.2
banana (ripe)	1.186E9	6623	1.2	2.2
beetroot	2.083E13	9496	3	8
blackberry	2.666E12	8570	4.3	4.5
black currant	2.255E15	10607	2.0	2.0
broad bean	1.185E15	10442	-	-
brussels sprouts	2.413E12	8556	-	24
calabrese	2.465E16	11004	8	-
carrot (winter) 1)	6.722E12	7023	-	-
carrot (winter)	1.543E9	6841	1.0	9.6
carrot (summer)	-	-	7.5	42
cauliflower	2.522E12	8665	3.4	6.2
celeriac	1.454E9	6689	1.0	7.4
celery	6.598E12	9158	11	38
cherry sour	3.507E13	9574	5.9	5.9
cherry s. (no stalk)	3.507E13	9574	1.6	1.6
cherry sweet	1.496E13	9359	5.9	5.9
cherry sw.(no stalk)	1.496E13	9359	1.6	1.6
chicory	1.039E11	7949	1.8	7.1
chicory root	3.135E8	6188	1.2	18
Chinese cabbage	-	-	3.9	6.6
cucumber	3.417E12	8978	2.5	8.7
currant	4.927E14	10339	2.2	2.9
eggplant	4.395E7	5551	6	-

endive	1.752E8	5751	7.5	13
french bean	9.800E11	8286	-	11
garden-cress	-	-	24	49
gherkin	2.846E12	8926	14	50
gooseberry	2.872E14	10190	2.0	2.0
grape	1.939E10	7723	1.5	2.2
grapefruit	2.283E10	7833	0.80	0.84
green pea (shelled)	1.598E12	8186	-	-
green pea (in shell)	2.571E10	7169	-	-
haricot bean	9.780E11	8286	1.2	2.2
kale	7.159E9	7164	-	22
kohl rabi (no leaves)	3.018E7	5678	2.7	4.6
leek	3.681E14	9918	5.0	6.2
lemon (yellow)	1.520E9	7067	1.5	1.9
lettuce	1.644E12	8633	13	17
mango	-	-	0.57	0.63
melon	3.635E9	7133	0.33	0.27
mushroom	2.463E10	7143	24	57
onion (dry)	1.089E6	4941	0.22	0.22
onion (green)	2.133E10	7289	-	-
orange	1.378E12	8951	1.3	1.4
oxheart cabbage	-	-	7.3	12
paprika	1.633E19	13076	2.5	2.4
parsley (normal Fe)	-	-	19	51
peach	3.909E13	9658	9.6	10.2
pear (store)	2.581E15	10911	0.69	0.88
pear (summer)	4.904E15	11041	0.80	0.80
pineapple	2.175E4	3626	1.7	2.5
plum (yellow)	1.801E12	8737	2.1	2.7
plum (red)	1.748E13	9380	3.0	3.0
purslane	-	-	18	29
radish (with leaves)	2.034E9	6645	18	67
radish (no leaves)	1.424E12	8713	12	52
raspberry	2.139E12	8498	8.7	9.0
red cabbage (store)	4.731E9	7223	0.95	1.8
red cabbage (summer)	2.807E10	7546	2.6	-
rhubarb	9.819E8	6577	6.0	7.8
salsify	-	-	-	9.2
savoy cabbage	1.770E12	8508	1.7	15
spinach	7.238E13	9410	31	52
strawberry	2.124E10	7351	8.8	11
swede	1.046E11	8075	2.5	6.6

tangerine	-	-	1.4	2.5
tomato	1.780E10	7603	0.3	-
turnip tops	-	-	14	52
white cabbage	1.958E9	6923	1.4	3.1

1) with foliage

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