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ETHYLENE AND HORTICULTURAL CROPS A CLASSIFICATION IN TERMS OF PRODUCTION AND SENSITIVITY

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INTRODUCTION

Wavin plastic film products intends to introduce in Europe a film for packaging purposes made from "ethylene absorbing material" which is produced in Japan. This film (BFG) has only briefly been tested on some horticultural products as tomatoes and broccoli; test results however, have been published in Japanese which makes interpretation difficult.
In order to evaluate the possibilities for succesful introduction of this material in the horticultural packaging field, Wavin PFP ordered the Sprenger Institute to summarize their knowledge about ethylene effects on horticultural crops. The Sprenger Institute is an institute for post-harvest technology of horticultural products. Research on ethylene effects is an important topic. This report is a compilation of all kinds of ethylene data because most of the available information is spread over various articles and reports.

WHY CONTROL ETHYLENE

Ethylene (C_2H_4) is one of a number of natural plant hormones. It discriminates itself from the other hormones because ethylene is gaseous and exchange with the surrounding air has little limitations.
Other hormones are mostly organic acids dissolved in plant cells. Even at very low concentrations ethylene has effects on growth, development and ripening of plant tissues. All plant material produces ethylene, however, mostly in minute amounts. After harvest, horticultural crops may be exposed to ethylene unintentionally as the gas is produced by the crop itself, by other crops, by micro-organisms and it is a component of air pollution from traffic or industrial exhaust gases.
Sometimes ethylene is used to promote: ripening (plums, tomatoes, bananas), flowering (iris bulbs, Bromeliaceae) or radial growth (bean sprouts). However ethylene effects are mostly detrimental.
Especially during distribution it is necessary to know what the susceptibility is of commodities to ethylene damage to assess the significance of the risks. Ethylene damage is a result of three interrelated factors (Woltering and Harkema, 1987):
a. Temperature : more damage at higher temperatures
b. Exposure time: more damage when exposed longer
c. Concentration: more damage at higher concentrations.

Ad a. An example of this is shown in figure 1. Shelf life of cucumbers decreases at higher temperatures and at higher concentrations of ethylene.

Ad b. An example of the effect of the exposure time in combination with ethylene on shelf life of cucumbers is shown in figure 2.

Ad c. Figure 3 shows the effect of the ethylene concentration on the vase life of carnations after 24 h exposure at 23^{o}C.

Especially exposure time has a pronounced effect on the response to ethylene. When the exposure time is below a certain threshold, sensitive commodities (e.g. carnations) show no response, not even to very high concentrations of ethylene (~ 10 ppm). However, when the exposure time exceeds this threshold, these flowers show a response, even at 0,03 ppm (fig. 3).

ETHYLENE PRODUCTION

The rate of ethylene production in many commodities is very low and may be negligible in normal postharvest handling.
Commodities which show a low and constant ethylene production after harvest are called non-climacteric. Mechanical damage can cause transient increases in production but the damage itself is likely to be of more importance than indirect effects via ethylene.
Fungal infection increases ethylene production as a response to disease stress but also some micro-organisms produce ethylene e.g. Fusarium oxysporum tulipae on tulip bulbs. Maximum ethylene production of this fungus may be 2 ml/kg.bulbs.h.
Table 1 shows some ethylene-producing fungi (Ilag and Curtis, 1968). Of 228 species of fungi examined 25,6% produced ethylene. They used 0,1 g dry weight in 10 ml glass syringes.

Table 1. Ethylene production of some fungi (Ilag, 1968)

species	production rate*
Aspergillus clavatus	very high
Aspergillus flavus	high
Aspergillus ustus	low
Penicillium corylophilum	high
Alternaria solani	low
Cephalosporium gramineaeum	high
Hansenula subpelticulosa	high
Thamnidium elegans	high
Sclerotinia laxa	low
Schizophyllum commune	high

* very high = > 100 ppm; high = > 1 ppm; low = 0,2-1 ppm

Ethylene production is also related to temperature. At higher temperatures ethylene production increases (fig. 4).
Most products which are botanically classified as fruits show a climacteric pattern of respiration and may show greatly differing rates of ethylene production at different stages in their post-harvest life. When the fruits develop from unripe to ripe, ethylene production increases by at least 10 fold.

Typical rates of production for immature (preclimacteric) and mature (climacteric) fruits are shown in table 2.

Table 2. Ethylene production rates of some climacteric fruits at 20°C

fruit*	rate of production (μl C_2H_4/kg.h) immature	mature
Apple	0,1	200
Apricot	0,03	0,4
Kiwi fruit	< 0,01	50
Melon	0,1	50
Peach	0,1	100
Pear	0,6	30
Tomato	0,2	120
Banana	0,005	10
Avocado	10	100
Orange	0,003	4
Passion fruit	10	345
Cherimoya	0,02	660
Plums	3	225
Blue berry	0,15	0,40
Grapes	0,004	0,043
Pineapple	0,49	0,15

* These rates are different for each variety and depend also on growth circumstances, season, climate and other factors

In the column "mature" maximum rates are given which were found in literature or from own measurements.
Table 3 shows some ethylene production rates from different apple varieties.

Table 3. Ethylene production rates from some apple varieties (at 20°C, climacteric stage)

apple cultivar	ethylene production (μl C_2H_4/kg.h)
Schone van Boskoop	245
Cox Orange Pippin	100
Bramleys Seedling	36
Elstar	50
Golden Delicious	30
Spartan	13

Table 4 shows what happens during a storage season for apple cv. Schone van Boskoop. Analyses are carried out at 20°C. Apples were stored before analyses at 1% O_2; 0,5 CO_2 at 4,5°C.

Table 4. Ethylene production from "Schone van Boskoop" in relation to storage time

date	ethylene production (μl C_2H_4/kg.h)
18- 9-1986	< 0,01
23- 9-1986	0,15
3-10-1986	7,8
16-10-1986	150
18- 3-1987	245

It is the high production rate of climacteric fruits that makes them potentially dangerous to other (ethylene-sensitive) commodities, but such ripe fruit itself is usually not responsive to additional ethylene.

Table 5 gives an ethylene production classification for some fruits and vegetables.

Table 5. Ethylene production at optimum storage temperatures (Kader and Kashmire, 1984)

C_2H_4 µl/kg.h	non chill sensitive	chill sensitive
Very low (less than 0,1)	Asparagus Cabbage Carrot Grape Lettuce Onion Radish Chicory Brussels sprouts	Ginger Citrus Potato Sweet potato
Low (0,1-1,0)	Broccoli Kiwi (unripe) Mushroom Beans Berries	Cucumber Egg plant Pineapple Sweet peppers
Moderate (1,0-10)	Kiwi (ripe) Figs Lychee	Tomato Banana Melon Mango
High (10-100)	Apple Peach Pear Plum	Avocado Papaya
Very high (> 100)	-	Cherimoya Passion fruit

Most ornamentals are non-climacteric products. However, during flower senescence ethylene production may show a climacteric-like pattern (fig. 5). Several factors are known to affect ethylene production:

a. Position of the flower (horizontal vs. vertical) (fig. 6)
b. Dark-stress; lack of light increases C_2H_4 production
c. External CO_2 concentration (fig. 7)
d. Pretreatment with inhibitors of ethylene production or action such as STS (Silverthiosulphate) and AOA (amino-oxyacetic acid) (fig. 8)
e. Pollination of the flowers (fig. 9)
f. Availability of water
g. External ethylene concentration.

Under natural conditions ethylene production is under the control of the flower. This homeostasis may become uncontrolled caused by one of the factors mentioned above and then autocatalyses may occur. Due to this process carnation flowers may produce 1000 times more ethylene during wilting than is normal.

Table 6 gives some ethylene production rates for flowers during dry storage at 20°C placed in the dark.

Table 6. Ethylene production from some cut flowers

species-cultivars	C_2H_4 production µl/kg fresh weight.h
Carnation 'Lena'	0,05
Chrysanthemum	0,44
Cymbidium	0,005
Euphorbia fulgens	0,92
Fresia	0,15
Iris 'Ideal'	0,05
Lilium 'Connecticut King'	0,10
Rose 'Sonia'	0,39
Tulip 'Apeldoorn'	0,29

Another group of flowers called "summer flowers" show also the same low ethylene production range.
Some flowers as Trachelium and Nigella damascena have a "moderate" production level.

Tabel 7. Ethylene production of cut "summer flowers" placed horizontally in dark (Woltering, 1985) in µl C_2H_4/kg fresh weight.h

species	production	species	production
Achillea filipendulina	0,66	Gypsophila paniculata	0,64
Aconitum napellus	0,31	Helianthus	0,32
Allium sphaerocephalon	0,46	Hypericum	0,66
Amaranthus	0,09	Kniphofia	0,64
Antirrhinum major	1,26	Liatris	0,63
Asclepias tuberosa	0,44	Limonium sinuatum	0,13
Aster novi-belgii	1,10	Lysimachia clethroides	0,55
Astilbe	0,12	Matthiola incana	0,26
Bouvardia	0,29	Nigella damascena	4,60
Campanula pyramidalis	0,42	Ornithogalum thyrsoides	0,18
Centaurea cyanus	1,33	Phlox paniculata	0,44
Chelone	0,19	Physostegia virginiana	0,30
Chrysanthemum parthenicum	0,16	Rudbeckia	0,58
Crocosmia x Crocosmiiflora	0,15	Saponaria	1,76
Delphinium ajacis	0,62	Scabiosa caucasica	1,32
Eremurus	0,28	Solidago	0,28
Erigeron	0,93	Trachelium	3,75
Eryngium	0,22	Triteleia brodiaea	0,05
Gladiolus colvillei	0,15		

Other ornamentals such as potted plants, nursery stocks and flower bulbs all show a very low ethylene production rate (< 0,1 μl C_2H_4/kg.h) except Fusarium infected tulip bulbs which may produce up to 2000 μl/kg.h.

ETHYLENE FROM OTHER SOURCES

Potential sources of ethylene other than plant material are commonly well known air polluters as:
a. Exhaust gases from combustion engines such as forklifts, cars and trucks.
b. Industrial waste gases.
c. Cigarette smoke,
d. Combustion of coal, oil, gas and wood.
e. Ethylene generating chemicals as ethephon and ethrel.

In many of the above mentioned situations (e.g. Dutch auctions with traffic in the building) ethylene concentrations have been investigated and at present we have a fairly good indication about the actual ethylene levels in practice (fig. 10-14).
Precautions can be taken against high levels of ethylene. Avoidance is the simplest approach and could entail use of electric forklifts, excluding sources of pollution and proper ventilation. Use of ethylene-absorbing equipment as a precaution is in our view only desirable when ventilation possibilities are limited.
This may happen when cooling capacity is too low or when products are stored under CA or MA conditions. In these cases ethylene may accumulate.
Storage of climacteric fruits with a high ethylene production level together with ethylene sensitive products should be avoided.
Such a situation however, is exceptional in normal postharvest storage.
Most ethylene problems occur in mixed loads in transit or, at the end of the distribution chain at wholesalers or supermarkets that have too few storage rooms to separate sensitive and non-sensitive products.

ETHYLENE SENSITIVITY FRUITS AND VEGETABLES

As mentioned above most products which show a high ethylene production are not sensitive to high external ethylene levels once they are in the climacteric stage of their ripening process. Immature products such as apples, bananas and tomatoes are very sensitive to external ethylene till the time they produce much ethylene by themselves.
Table 8 shows some beneficial effect of ethylene removal during CA or MA storage of various climacteric fruits.

Table 8. Low ethylene storage effects at various fruits (Knee, 1985)

fruit	storage period (days)	C_2H_4-conc. (ppm)	process retarded
Apple 'McIntosh'	190	< 10	softening
Apple 'Bramleys'	250	< 2	scald and softening
Avocado	60	< 0,04	softening and rotting
Banana	70	< 0,05	softening
Kiwi fruit	180	?	softening
Lemon	190	< 2	rotting
Mango	21	< 0,01	softening
Pear	130	< 2	flesh browning

In spite of the long storage periods the effects of ethylene removal are small (but significant).

Non-climacteric crops show a great variability in response to external ethylene. In some cases this leads to very clear visual damage, in other cases such as carrots the taste may be influenced (sweet to bitter).
A description of ethylene effects is given in table 9.

Table 9. Effects of ethylene on quality of vegetables (Knee, 1985)

Asparagus	Increased toughness
Beans	Yellowing
Broccoli	Yellowing, abscission of florets
Cabbage	Yellowing, leaf abscission
Carrots	Bitter flavour
Cucumber	Yellowing and softening
Aubergine	Calyx abscission, browning pulp and seed
Lettuce	Russet spotting
Potato	Sprouting
Tomato	Colouration

The responses of fruits and vegetables to ethylene have not been studied in sufficient detail to make reliable prediction about the effect of the gas under each possible climate condition. However bananas, aubergines, cucumbers, kiwi fruit, cabbage and lettuce all give a half maximum response at about 0,1 ppm when exposure time is long enough at that specific storage temperature (fig. 15).
Table 10 shows a sensitivity classification from fruits and vegetables and their optimum storage temperatures.

Table 10. Response of vegetables and fruits to ethylene (in commercial picking stage)

storage temp. (oC)	sensitivity to ethylene: high	moderate		low	
0-5 vegetables	Broccoli	Spinach	Asparagus	Artichoke	onion
	Brussels sprouts	Red cabbage	Celery	Olives	Shalot
		White cabbage	Celery leaf	Mushrooms	Scorzonera
		Savoy cabbage	Pea	Garlic	Carrot
	Cauliflower	Iceberg lettuce	Leek	Celeriac	Sweet corn
	Endive	Chinese cabbage	Beetroot	Fennel	Bean sprouts
		Kale	Broad bean	Kohlrabi	
	Lettuce	Witloof chicory	Potatoes	Rhubarb	
	Turnip green	Purslane		Radish	
	Cress				
fruits	Kiwi fruit	Mandarines		Strawberry	
	Apricots	Oranges		Raspberry	
				Ripe apples	
	Nectarine	Lychee		Blackberry	
	Peach				
	Unripe pears			Cherry	
	Plums			Sour cherry	
				Nuts and Figs	
6-10 vegetables	Zucchini	Sweet Pepper (green)		Sweet pepper (red)	
		- beans			
fruits	Avocado	Olive	Melon	Water melon	
	Passion fruit	Pineapple	Honey melon		
11-15 vegetables	Egg plant	-		Tomato (breaker)	
	Gherkin				
	Cucumber				
	Tomato (green)				
fruits	Banana	Lemon		-	
	Mango	Grapes			
	Papaya	Ginger			

In some experiments when the only ethylene source is the product itself ethylene removal gives a slightly positive effect on product quality.
These experiments are mostly carried out to achieve a longer storage time without accompanying loss of quality. But when products are genetically suitable for long term storage (more than 6 weeks) and the need to prolong distribution time is felt, then mostly CA storage is applied.
Benefits from CA storage to product longevity are evident for especially apples but many vegetables also show a very positive reaction e.g. cabbage and Brussels sprouts.

When products are packed in plastic film the air composition in the package will change because of respiration and ethylene production.
Products produce CO_2, C_2H_4, H_2O and consume O_2. The final climate dependings on many factors as:

a. Time
b. Temperature
c. Film properties as thickness, area, diffusion coefficients etc.
d. Respiration versus volume ratio.

This way of packaging is called modified air packaging (MA) and is often effective for product keepability.
The most important problem in MA packaging is to find a film with a high diffusion rate for oxygen entering the package when product has a high respiration level.
Lack of oxygen leads to anaerobic respiration which causes immediate severe quality loss.
As respiration levels are strongly related to temperature, care must be taken that in the distribution chain temperatures of the packed product are as close as possible to optimum storage temperatures.

ETHYLENE SENSITIVITY OF ORNAMENTAL PRODUCTS

While studying senescence, it became obvious that many flowers and ornamental potted plants are very sensitive to ethylene.
In table 11 an ethylene sensitivity classification for cut flowers is given.

Table 11. Classification of cut flowers according to their sensitivity to exogenous ethylene (Woltering and Harkema, 1980-1981)

species	cultivar	ethylene sensitivity	symptoms
Alstroemeria	Carmen	oo	discoloration of
	Maria	oo	petals (orchid) and
	Orchid	ooo	rapid wilting
	Rosario	•	
Carnation	Scania	oooo	wilting of petals
	White Sim	oooo	
	William Sim	oooo	
	Le reve	oooo	
	Orange triumph	oooo	
Carnation (spray)	Silvery Pink	oooo	wilting and
	Red Baron	oooo	bud blasting
	Sunshine	oooo	
Anthurium andreanum	Avo Anneke	o	wilting
	Avo Claudia	•	
	Avo Tineke	•	
Asparagus	-	o	abscission of leaves
Cattleya	-	oooo	wilting
Chrysanthemum	Horim	•	increased fungal
	Spider	o	invasion of flowers
	Westland	•	
Cymbidium	several cv.	oooo	coloration of labellum
Cymbidium (mini)	several cv.	oooo	coloration and wilting
Dendrobium phalaenopsis	Lady Hamilton	oooo	epinasty of peduncles and wilting
Euphorbia fulgens	Albatros	oooo	yellowing and
	Orange	oooo	abscission of leaves
	Creme	oooo	
Forsythia(x)intermedia	Spectabilis	o	advanced rate of flower development

species	cultivar	ethylene sensitivity	symptoms
Fresia	Aurora	oo	vase life reduction bud blasting
	Ballerina	oo	flower malformation
	Royal Blue	oo	
Gerbera jamesonii	Agnes	o	wilting outer
	Beatrix	o	anthers
	Veronica	o	
Gloriosa rothschildiana	-	o	wilting
Iris	Ideal	ooo	
	Prof. Blaauw	ooo	
	Symphony	oo	
	Witte van Vliet	ooo	bud outgrowth inhibited
Lilium	Arai	oo	
	Connecticut King	ooo	flower bud
	Enchantment	oooo	blasting
	Lady killer	oooo	and malformation
Daffodil	Carlton	ooo	wilting
	Dutch Master	ooo	
	Golden Harvest	ooo	
Nerine bowdenii	-	o	blueing flower malformation
Nerine sarniensis	Corusca Major	•	
Nerine mancelli	-	•	
Paphiopedilum	-	oooo	wilting
Phalaenopsis	-	oooo	wilting
Prunus triloba	Multiplex	ooo	bud blasting
Rose	Belinda	ooo	
	Diana	•	
	Ilona	oo	
	Motrea	o	flower malformation
	Sonia	ooo	shorter vase life
Syringa vulgaris	Mad. Florent	•	wilting
	Stepman	o	and flower malformation
	Lavalliensis	oo	

species	cultivar	ethylene sensitivity	symptoms
Tulip	Apeldoorn	ooo	flower malformation
	Gander	o	and blueing
	Lustige Witwe	o	in Gander and L.W.

● = not sensitive
o = low sensitivity
oo = moderate sensitivity
ooo = high sensitivity
oooo = extreme sensitivity

In table 12 a sensitivity classification is given for "summer flowers".

Table 12. Ethylene sensitivity in cut "summer" flowers (Woltering, 1984)

species	C_2H_4 sensitivity	species	C_2H_4 sensitivity
Aconitum napellus	oooo	Dianthus barbatus	oooo
Agapenthus africanus	oooo	Eremurus	o
Allium azureum	oo	Gladiolus colvillei	oo
Antirrhinum major	ooo	Gomphrena globosa	o
Asclepias tuberos	ooo	Gypsophila paniculata	oooo
Bouvardia	oooo	Kniphofia	oooo
Campanula pyramidalis	oooo	Matthiola incana	oooo
Centaurea cyanus	o	Phlox paniculata	oooo
Chelone	ooo	Physostegia virginiana	oooo
Clarkia elegans	oo	Saponaria	oooo
Crocosmia x crocosmiiflora	oo	Scabiosa caucasica	oooo
Dahlia	o	Silene armeria	o
Delphinium ajaces	oooo	Trachelium	oooo
Triteleia brodiaea	o		

Table 13. Cut "summer" flowers that are not sensitive to ethylene (24 hours, 3 ppm C_2H_4 at 20^oC) (Woltering, 1984)

species	Dutch name
Achillea filipendulina	duizendblad
Alchemilla mollis	vrouwenmantel
Allium sphaerocephalon	sierui
Amaranthus	kattestaart
Anethum graveolens	dille
Aster novi-belgii	herfstaster
Astilbe	-
Callistephus chinensis	zaaiaster
Celosia argentea 'Christata'	hanekam
Chrysanthemum maximum	-
Chrysanthemum parthenicum	matricaria
Chrysanthemum segetum	gele ganzebloem
Erigeron	fijnstraal
Eryngium	kruisdistel
Godetia	zomerazalea
Heliantus	zonnebloem
Helipterum manglesii	Rhodante
Helipterum roseum	-
Hypericum	hertshooi
Liatris	-
Limonium sinuatum	Statice
Limonium suworowii	staart-Statice
Lysimachia clethroides	wederik
Nigella damascena	juffertje in 't groen
Ornithogalum thyrsoides	zuidenwindlelie
Rudbeckia	zonnehoed
Solidago	guldenroede
Zantedeschia elliottiana	Gele Galla
Zinnia elegans	-

The sensitivity of ornamental pot plants to exogenous ethylene was investigated at the Sprenger Institute by exposing them in the range from 0-15 ppm C_2H_4 for 24 or 72 h in darkness in 20^oC. In general flowering plants appeared more sensitive to C_2H_4 treatment than foliage plants, exhibiting abscission of flowers, flower buds or of total inflorescences after 24 h. Foliage plants showed abscission and yellowing of leaves.
The sensitivity of potted plants is classified according to 8 classes. Species that did not respond to 24 h treatment but did respond to 72 h treatment were classified as 1, 2, 3 or 4. Species that responded to 24 h treatment were classified as 5, 6, 7 or 8. See figure 16.
Table 14 and 15 give an ethylene sensitivity classification for ornamental potted plants.

Table 14. Foliage plants: C_2H_4 toxicity symptoms and sensitivity after treatment with 0-15 µl/l C_2H_4 for 24 or 72 h in darkness at 20°C (Woltering, 1987)

plant species	C_2H_4 toxicity symptoms					sensitivity classification[2]
	Abscission[1]		leaf yellowing	fruit ripening	epinasty	
	leaves	fruits				
Anthurium scherzerianum						0
Aralia (Fatsia japonica)	C				x	2
Asparagus densiflorus 'Sprengeri'	D					1
Asplenium nidus						0
Capsicum annuum	C	C				2
Chamaedorea elegans						0
Codiaeum variegatum						0
Cordyline fructicoSA						0
Dieffenbachia 'Marianne'			x			1
Dizygotheca elegantissima	CD					3
Dracaena marginata			x			1
Dracaena sanderiana			x			1
Eucharis grandiflora			x			1
Euphorbia keysii	D		x			3
Euphorbia pseudocactus	D		x			6
Ficus benjamina	C					1
Ficus deltoïdea	C	C		X		3
Ficus pumila	C					2
Hedera canariensis 'Variegata'	C					1
Nephrolepis exaltata						0
Philodendron scandens oxycardium	C					3
Rhaphidophora aurea			x			3
Schefflera compacta	CD				x	4
Scindapsus pictus						0
Solanum pseudocapsicum	C	C		x		7
Yucca elephantipis			x			1

[1] Letters refer to the position of the abscission zones: C, at base of petiole; D, at base of the leaf blade

[2] See figure 16

Table 15. Flowering plants: C2H4 toxicity symptoms and sensitivity after treatment with 0-15 µl/1 C2H4 for 24 or 72 h in darkness at 20oC

plant species	C_2H_4 toxicity symptoms								sensitivity classification
	Abscission[1]			flower wilting	bud blasting	leaf yellowing	microbial attack	epinasty	
	flowers and flower buds[2]	inflorescences	leaves						
Achimenes hybrids	A								7
Azalea indica			C						3
Begonia Rieger hybrids	AC								6
Begonia semperflorens	AC								6
Beloperone guttata		C	C						8
Browallia speciosa	A		C						8
Calceolaria x herbeohybrida	A								5
Campanula isophylla				x	x	x	x		7
Chrysanthemum morifolium							x		4
Clerodendron thomsoniae	C		C						8
Cyclamen persicum	A			x					3
Euphorbia pulcherrima	C		C	x				x	2
Exacum affine 'Atrocoeruleum'				x					1
Fuchsia hybrids	BC		C					x	9
Hibiscus rosa-sinensis	B		C			x			9
Kalanchoë blossfeldiana				x	x				7
Kohleria hybrids	A								7
Pachystachus lutea		C	C						6
Pelargonium zonale				x	x	x	x		3
Primula acaulis									0
Rechsteineria cardinalis	A								7
Saintpaulia ionantha hybrids				x			x		3
Senecio cruentus hybrids									0
Sinningia hybrids	A								2
Steptocarpus hybrids	A								7
Vinca minor	A								7

[1]Letters refer to the position of the abscission zones: A, at base of corolla/petals; B, at base of receptacle; C, at base of petiole/peduncle/inflorescence.

[2]Refers to individual flowers or flowers from within an inflorescence.

A number of environmental factors such as high temperature, dark storage and water stress are known to evoke C_2H_4-like toxicity symptoms in some species. This could be the result of stimulation of endogenous C_2H_4 production and/or C_2H_4-sensitivity. Ethylene sensitive plants are less suitable for handling and transportation. It is remarkable that most of the currently economically important species are relatively insensitive to ethylene.

DISCUSSION

When a non-climacteric product is placed in a closed bag, depending on the ethylene production and the diffusion characteristics, the ethylene concentration in the bag will increase.
An increased ethylene concentration during storage will no doubt have detrimental effects on quality.
However, diffusion of ethylene and carbon dioxide is generally of the same order of magnitude thus also accumulation of carbon dioxide will appear. The latter will inhibit the potentially detrimental effects of ethylene or may even increase the quality as was shown to be the case in gerbera plantlets grown in vitro (Woltering, 1988).
It is therefore doubtful if removal of ethylene from the internal atmosphere will give rise to a prolonged keepability.
In climacteric products the situation may be different. The most important goal is to delay the appearance of the autocatalytic ethylene production. The latter is known to be hastened by exposure of the product to exogenous ethylene and removal of exogenous ethylene may therefore delay the process.
However, during aging the tissue generally becomes more sensitive to ethylene and this will initiate the autocatalytic process irrespective of the concentration of ethylene in the surrounding air.
Once initiated the process cannot be stopped by removal of ethylene.
Generally spoken, an increased carbondioxide concentration will be much more effective than just removal of ethylene from the surrounding air.

Knee (1985) says that most of the known succesful applications of ethylene removal are as a supplementary technique to MA or CA storage of climacteric fruits. He suggests that there might be other fruits or vegetables which post-harvest life could be extended by ethylene removal.
A number of observations disagree with this view:

a. Storage experiments with non-climacteric products as Brussels sprouts, Chinese cabbage and cauliflower did not show any benefit to product keepability when ethylene was removed to an extremely low level by means of "permanganate on alumina" pallets (ethysorb) (Mertens, unpublished results).
b. In senescence studies with emasculated cymbidium flowers which were placed in extremely fresh air (< 1 ppb ethylene), it appeared that the normal autocatalytic processes were not delayed in comparison to storage in ambient air 5-10 ppb (fig. 17).
c. Aharoni (1985) was succesful in retarding decay of broccoli when packed in sealed PE-film. Although ethylene played the primary role in the regulation of senescence, respiratory CO_2 was the important factor for maintaining keepability.

CONCLUSION

In spite of the fact that ethylene removal might be useful in some cases one can expect more benefit when the tissue sensitivity or the ethylene production is inhibited.

This can be achieved by:
- Increased carbon dioxide concentration.
- Decreased oxygen concentration.
- Use of silver salts (especially silverthiosulphate (STS)).
- Use of amino oxyacetic acid (AOA) or aminoetoxyvinyl glycine (AVG).

Increased carbon dioxide and decreased oxygen concentrations will suppress ethylene sensitivity (especially CO_2) and ethylene production (especially O_2) (Smith, 1966; Uota, 1969; Sisler, 1979; Aharoni, 1985; Burg and Burg, 1967). In the cut flower industry STS is widely used as a pretreatment for ethylene-sensitive flowers (Veen, 1983) and also AOA is of interest (Harkema et al., 1987).

In our point of view, ethylene removal in a package does not contribute much to the handling and storage possibilities of the products and an ethylene absorbing property of a plastic film is therefore less important then other properties such as the diffusion coefficient and the possible release of toxic substances (Woltering, 1988).
Calculations about the desired absorption capacity of the film, in order to keep the ethylene concentration beneath a certain threshold are given in appendix I.

MA packaging or CA storage for ornamentals is hardly applied in practice. Cut flowers and potted plants show very little beneficial response to CA atmosphere. High CO_2 levels can cause injury. An extreme exception is daffodils which can be stored in about 100% N_2 atmosphere. Also flower bulbs and nursery stocks are as well commonly not packed in "closed" films or stored under CA conditions.

Appendix 1

HOW TO CALCULATE ETHYLENE ABSORPTION RATES

To calculate the amount of ethylene that has to be removed out of a package by means of the BFG-film it is necessary to know the diffusion coefficient for ethylene. Therefore we carried out an experiment which showed that in a 8,5 l container closed with 0,04 m² BFG-film an outside ethylene concentration of 16,5 ppm led to an inside concentration in the container from 0,04 ppm up to 5 ppm in 24 hours. This method is chosen to avoid interactions with absorption. Tests were carried out at: 20°C; 50% R.H.

By means of formula 1 it is possible to find the diffusion coefficient: $D^{c}_{C_2H_4}$

$$D^{c}_{C_2H_4} = \frac{V}{A} * \frac{d}{\Delta t} * \ln \frac{C_S - C_A}{C_E - C_A} \quad (1)$$

$D^{c}_{C_2H_4}$ = diffusion coëfficënt for a particular gas [m²/s]
V = volume of container [m³]
A = area of diffusion [m²]
d = thickness of the film [m]
Δt = time interval [s]
C_S = concentration of the gas inside at start [ppm]
C_A = concentration of the ambient gas [ppm]
C_E = concentration inside at time = Δt [ppm]

$$D^{c}_{C_2H_4} = \frac{8,5 \; . \; 10^{-3}}{0,04} * \frac{0,026 \; . \; 10^{-3}}{24 \; . \; 3600} * \ln \frac{0,036 - 16,5}{5,0 - 16,5} = 2,3 \; . \; 10^{-11} \; m^2/s$$

Example: 500 g Brussels sprouts are packed in BFG-film and stored during 10 days at 10°C and then sold.

Product data of Brussels sprouts:
Bulk density = 250 kg/m³
C_2H_4 production = 0,10 μl/kg.h (10°C)
C_2H_4 threshold = 0,1 ppm (> 0,1 ppm = yellowing)

When 0,5 kg product is packed in BFG-film and distribution time takes 10 days on an average temperature at 10°C then the amount of produced ethylene is:

0,5 (kg) * 0,10 (μl/kg.h) * 240 (h) = 12 μl C_2H_4

In 10 days diffusion removes the following amount:

With a small free air volume the steady state will be reached soon:

$$D = \frac{D^c_{C_2H_4}}{d} * A * \Delta C * 10^{-6} \quad (2)$$

D = diffusion rate [m^3/s]
$D^c_{C_2H_4}$ = diffusion coefficient [m^2/s] = $2{,}3 \cdot 10^{-11}$
d = thickness of film [m] = $0{,}026 \cdot 10^{-3}$
A = area [m^2] = $0{,}15 \cdot 10^{-6}$
ΔC = concentration in-out [m^3 C_2H_4/m^3 air] = 0,096

$$\text{So: } D = \frac{2{,}3 \cdot 10^{-11}}{0{,}026 \cdot 10^{-3}} \cdot 0{,}15 \cdot 0{,}096 \cdot 10^{-6} = 1{,}27 \cdot 10^{-14} \ m^3/s$$

In 10 days this is:

$1{,}27 \cdot 10^{-14} * 3600 * 24 * 10 * 10^{9} = 11\ \mu l\ C_2H_4$

As:

Ethylene removal = C_2H_4 absorption + C_2H_4 diffusion
or:

C_2H_4-absorption = 12 - 11 = 1 μl C_2H_4.

When this amount of ethylene is not absorbed it will lead to a concentration inside the package that will be higher than the threshold value.

As discussed before the threshold value is determined by the CO_2-concentration in the package but the absorption of the film has to be when expressed in standard terms minimal:

$1\ (\mu l\ C_2H_4)/10 \cdot 24\ (h) * 1/4{,}02 \cdot 10^{-3}\ (1/kg) = 1{,}037\ \mu l\ C_2H_4/kg \cdot \text{film} \cdot h$

to avoid any ethylene damage risk.

4,02 g is used for one package and thickness is 0,026 mm.
This is a calculation method that can be used for all products when product data as C_2H_4-sensitivity and production are known and also diffusion and absorption properties of a film.

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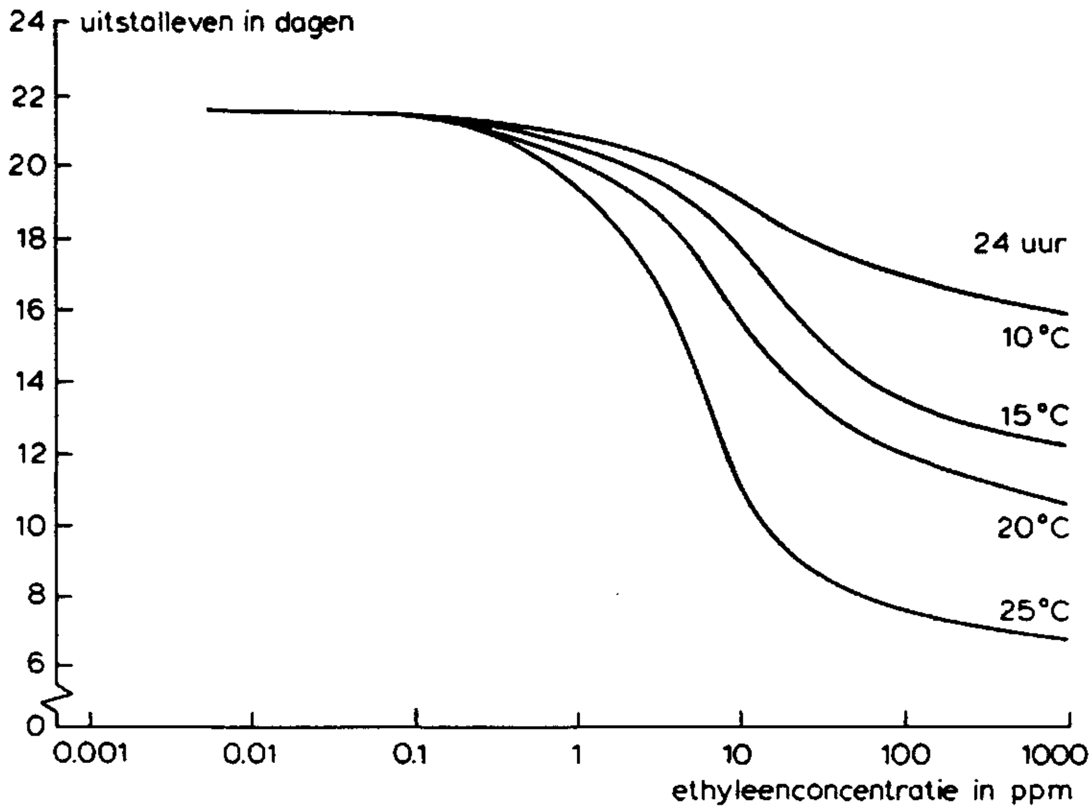


Figure 1. Ethylene effects on cucumbers influenced by concentration and temperature (Sterling 1985)

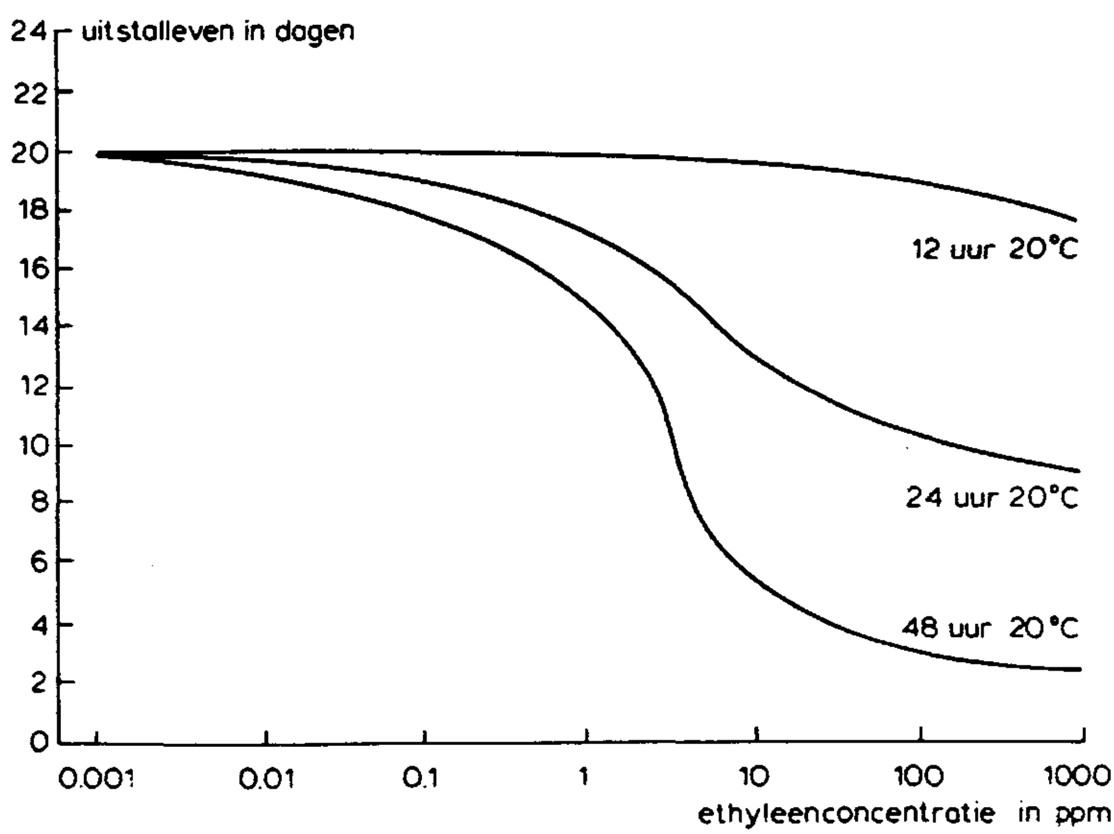


Figure 2. Ethylene effects on cucumbers influenced by exposure time and concentration (Sterling e.a., 1985)

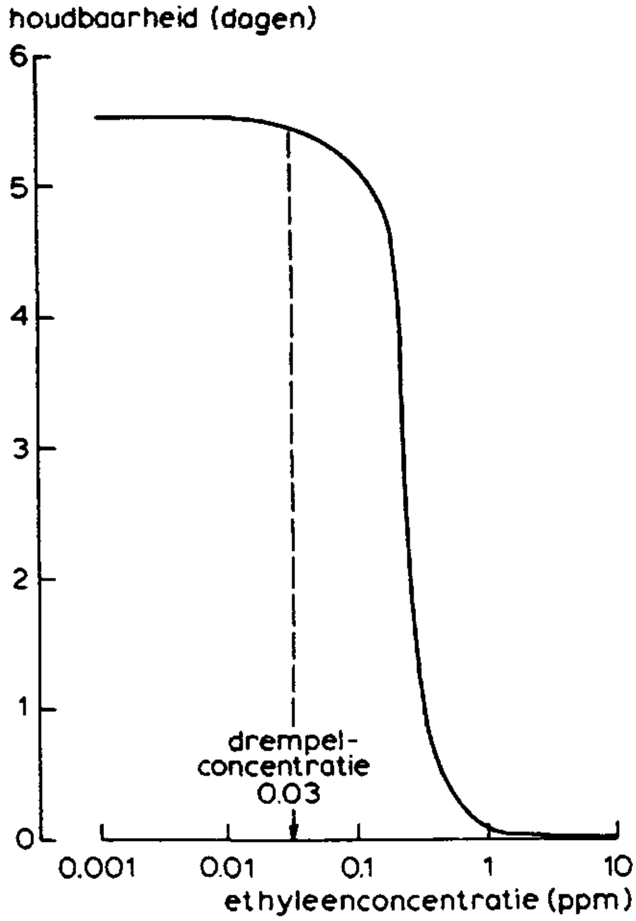


Figure 3.
Keepability of carnations
(Woltering, 1985)

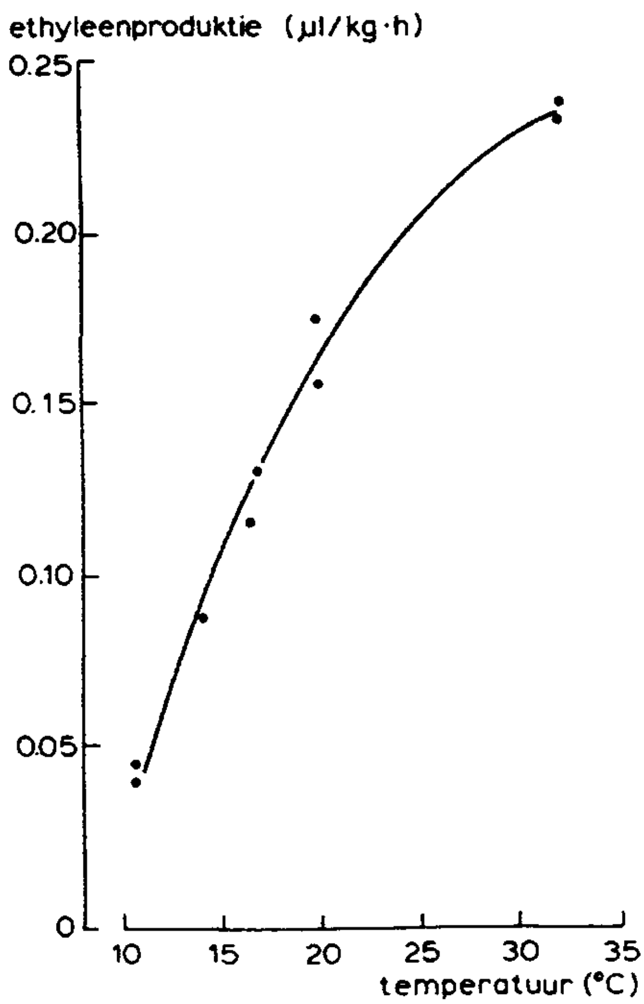


Figure 4.
Ethylene production of rose
'Ilona' at different temperatures (Woltering, 1982)

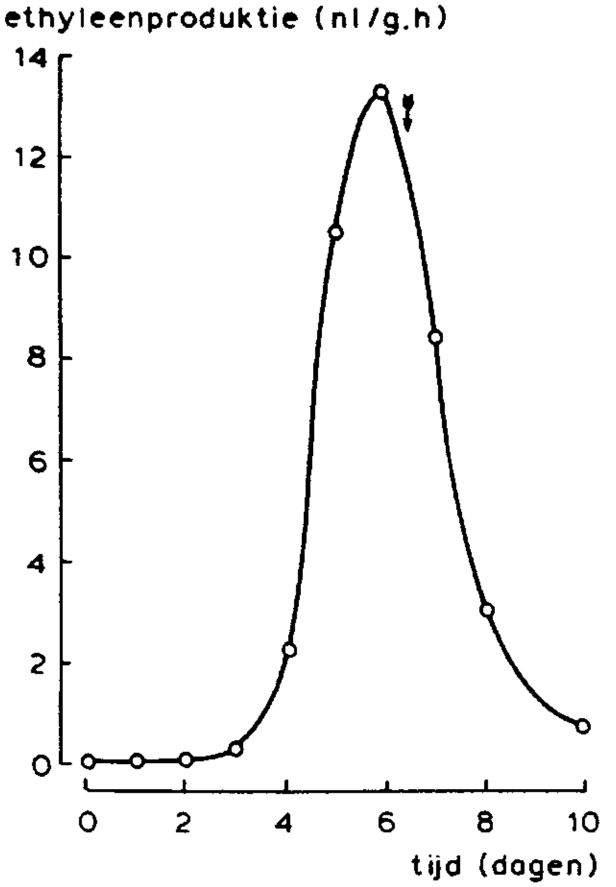


Figure 5.
Ethylene production from carnation during the wilting process (Woltering, 1982)

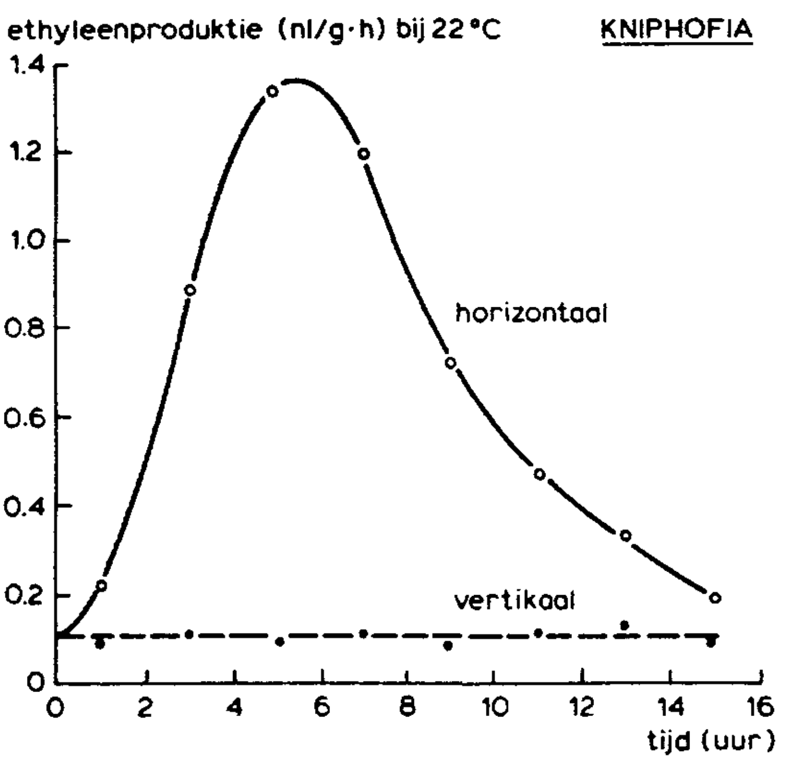


Figure 6. Ethylene production from kniphofia flowers as a result of position (Woltering, 1985)

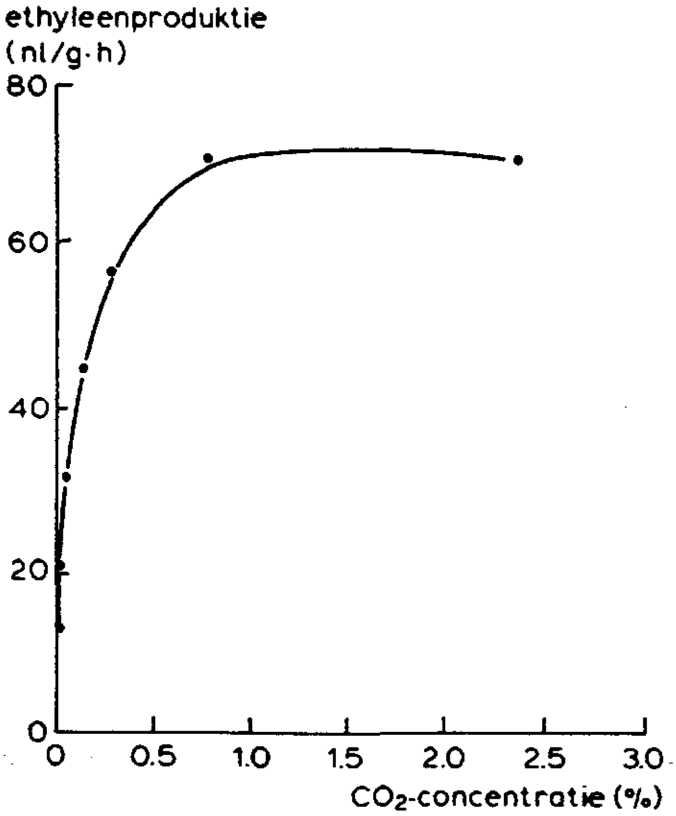


Figure 7.
Ethylene production influenced by CO_2-concentration from rice-plants (Kao en Yang, 1982)

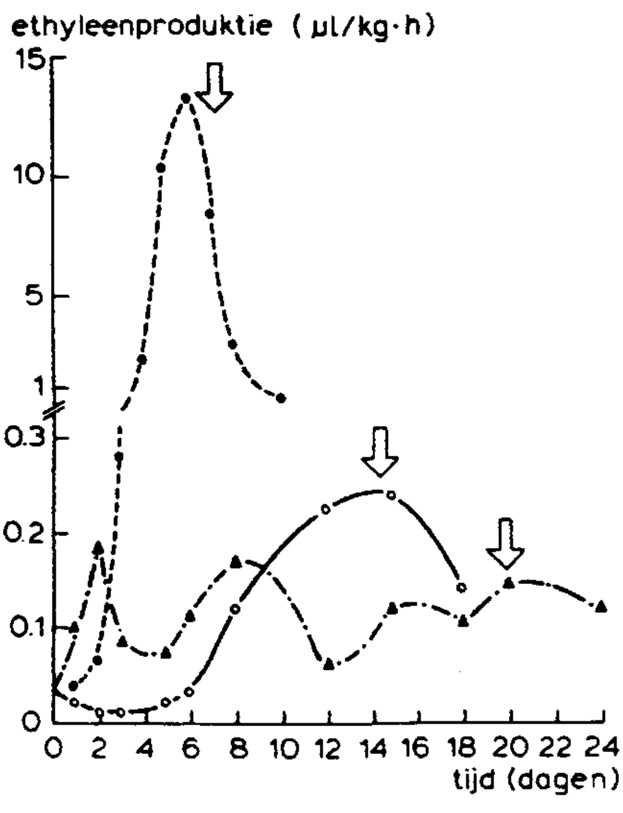


Figure 8.
Ethylene production (at 20°C) of carnation 'Scania', on water (o), pretreated with AOA (o) or STS (Δ). The arrow is time of wilting (Woltering en Sterling, 1986)

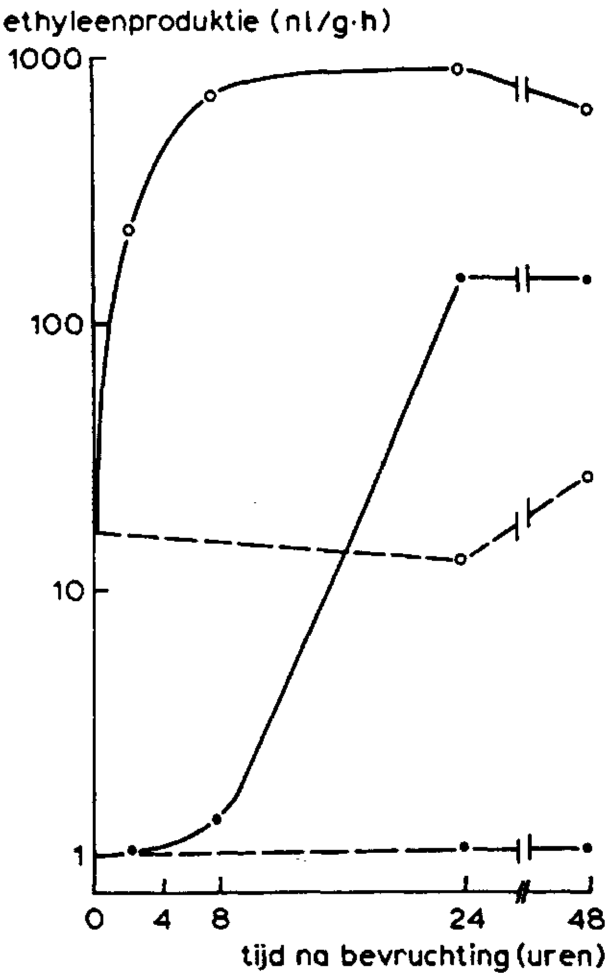


Figure 9.
Ethylene production of petals (•) and (o) of pollinated (——) and non-pollinated (---) carnations (Nichols e.a., 1983)

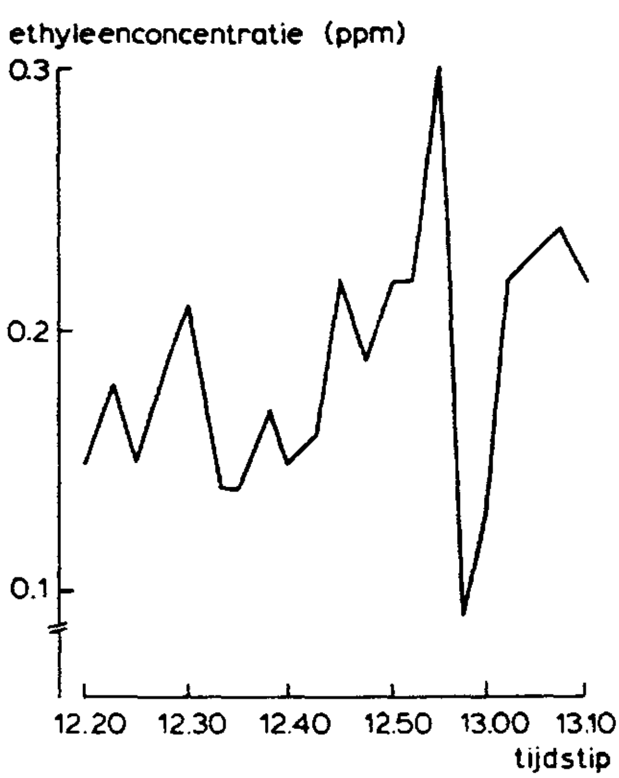


Figure 10.
C_2H_4 concentration in a Dutch flower auction (Boerrigter, 1981)

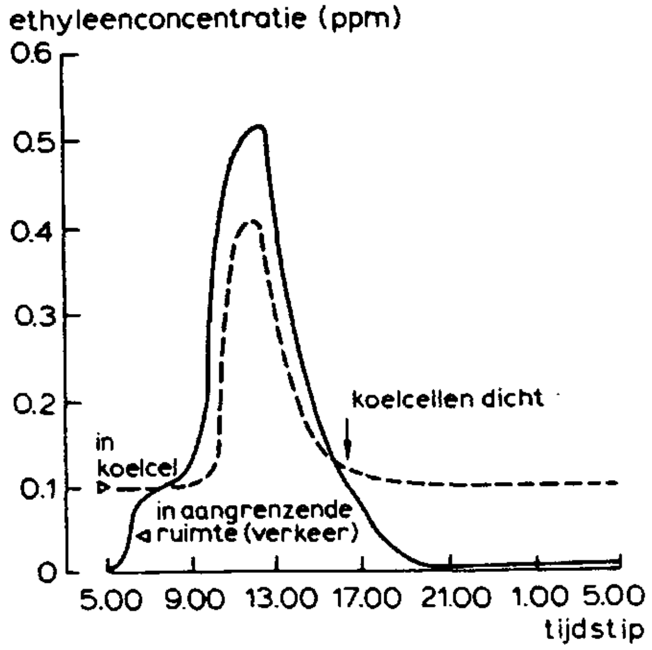


Figure 11.
C_2H_4 concentration at a wholesalers' flower market (Boerrigter, 1982)

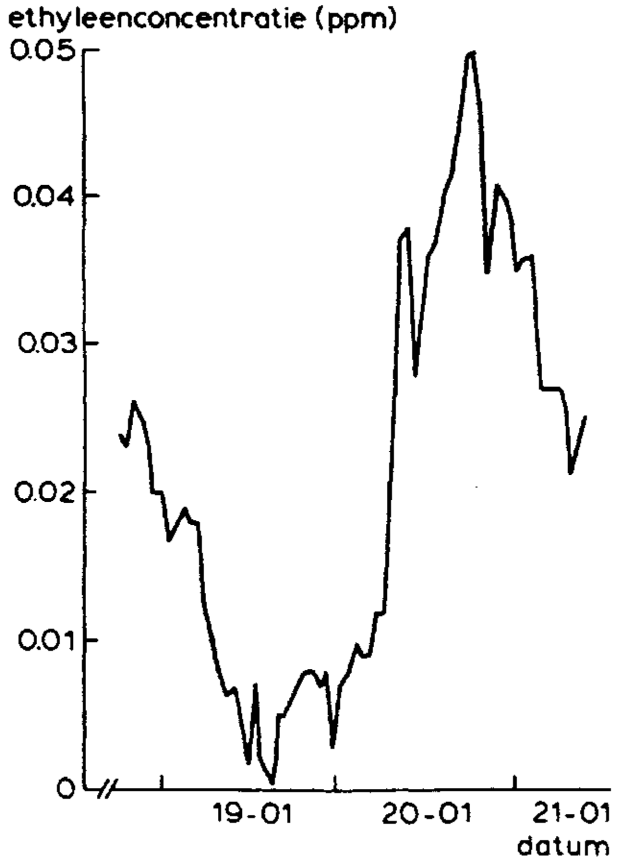


Figure 12.
C_2H_4 concentration in outside air (Wageningen) with smog conditions (Woltering, 1983)

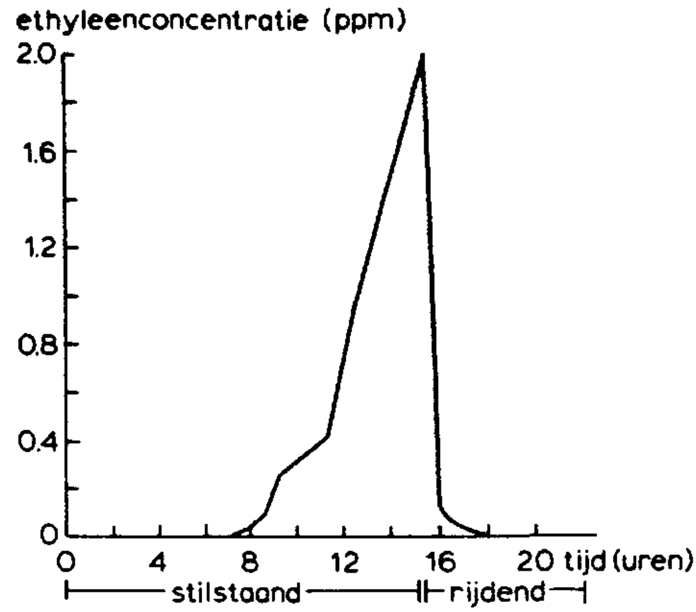


Figure 13. C_2H_4 concentration in a canvas closed truck loaded with fruits, vegetables and flowers (Damen e.a. 1981)

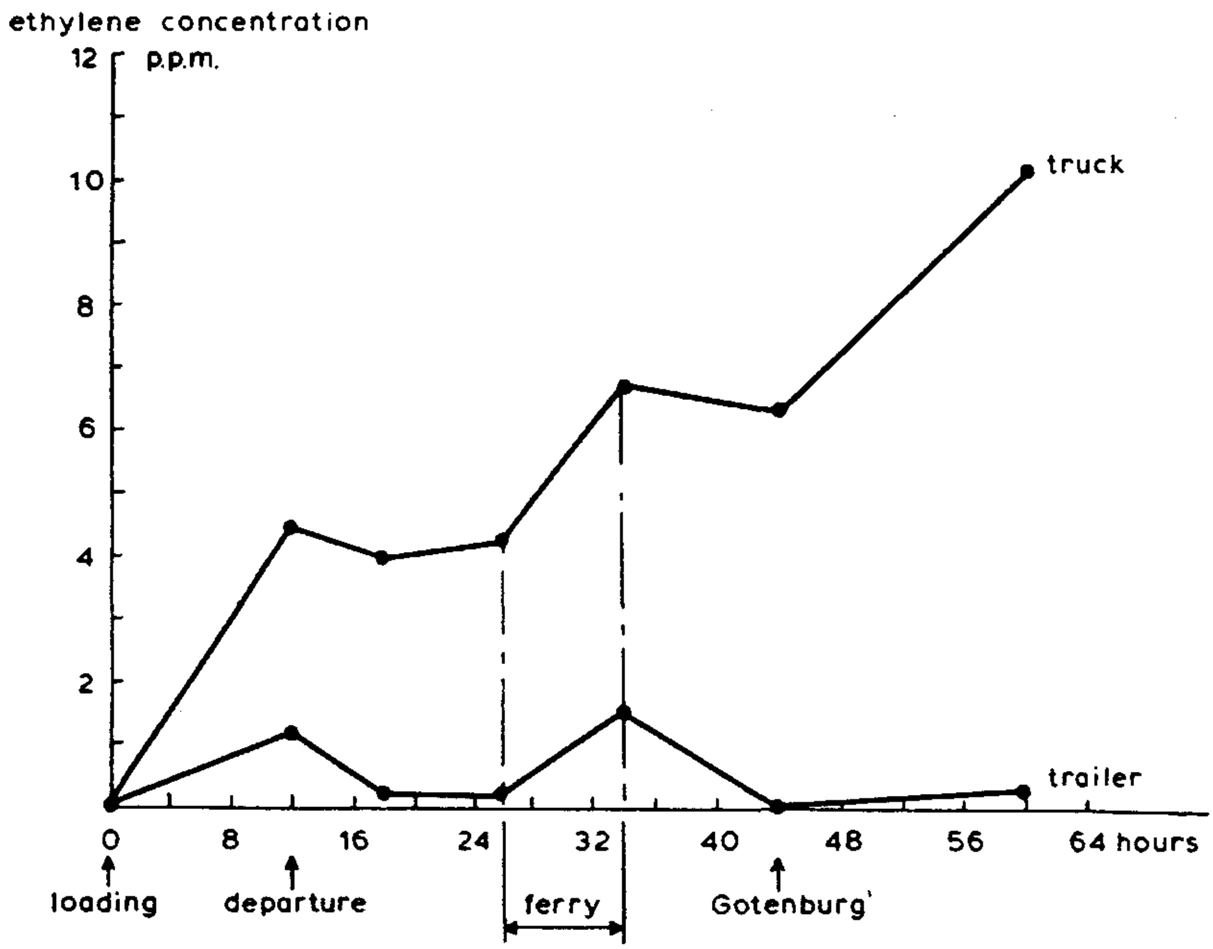


Figure 14. Time course of ethylene accumulation during long-term transport of commodities from Holland to Sweden.
A. Closed truck; B. Ventilated trailer (Boerrigter, 1982)

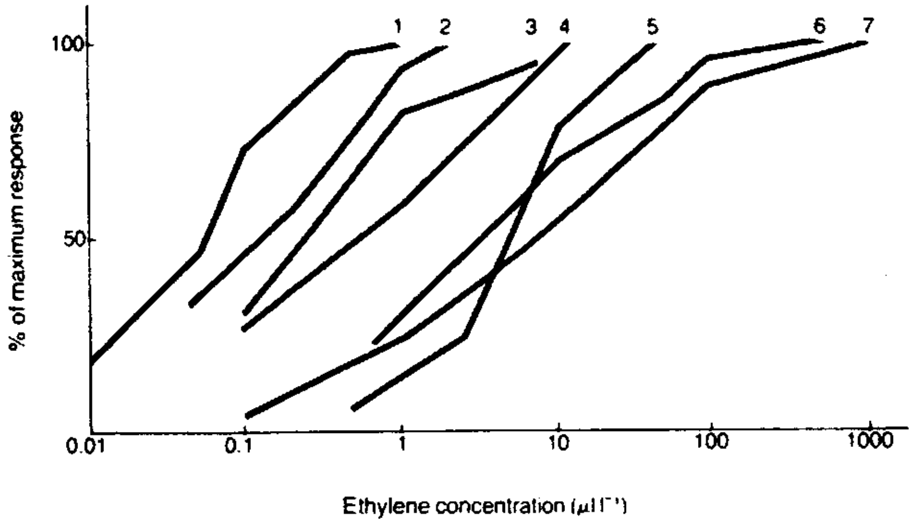
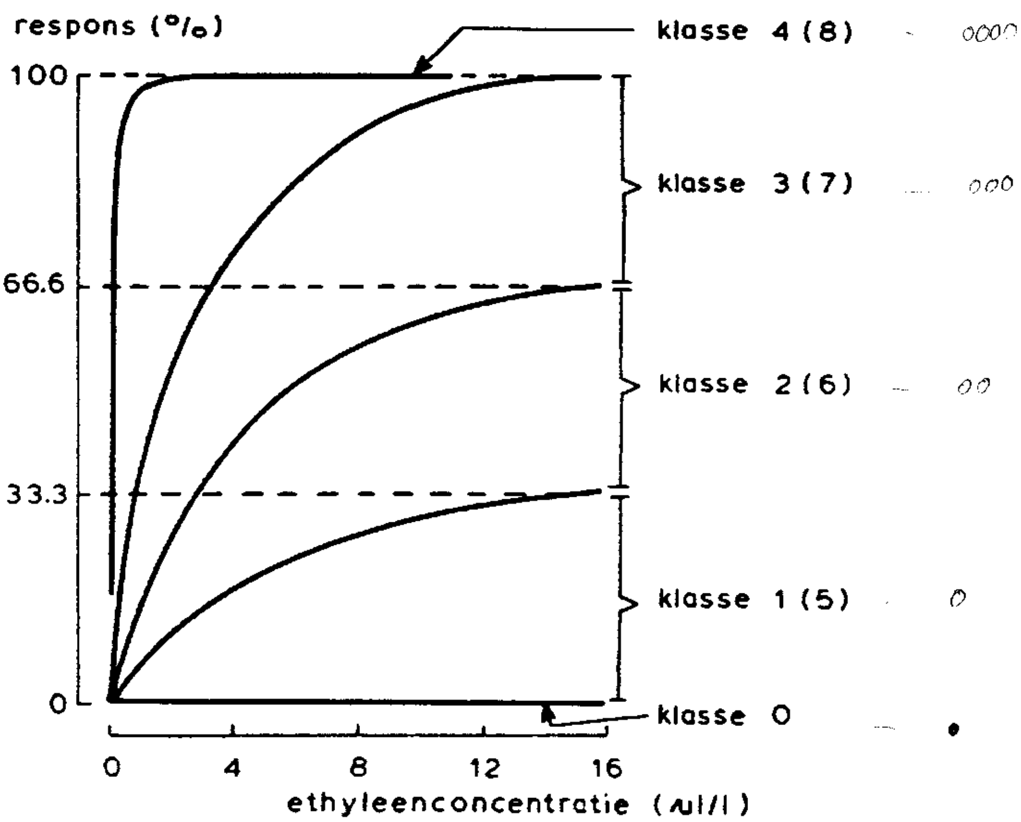


Figure 15. Concentration dependency of responses to ethylene in various fruit
(1) Induction of ripening in Dwarf Cavendish banana (Liu, 1976)
(2) Induction of ethylene synthesis in Anjou pear (Wang, Mellenthin and Hansen, 1972); induction of the climacteric in Canteloupe melon (McGlasson and Pratt, 1964) is very similar
(3) Induction of climacteric in Gros Michel banana (Biale and Young, 1981)
(4) Induction of climacteric in avocado pear (Biale, 1960b)
(5) Stimulation of respiration in immature Honeydew melon (Pratt and Goeschl, 1968)
(6) Stimulation of respiration in Navel Orange (Biale, 1960a)
(7) Stimulation of respiration in lemons (Biale and Young, 1981)



Figuur 16. Ethylene sensitivity classification for potted plants (Woltering, 1984)

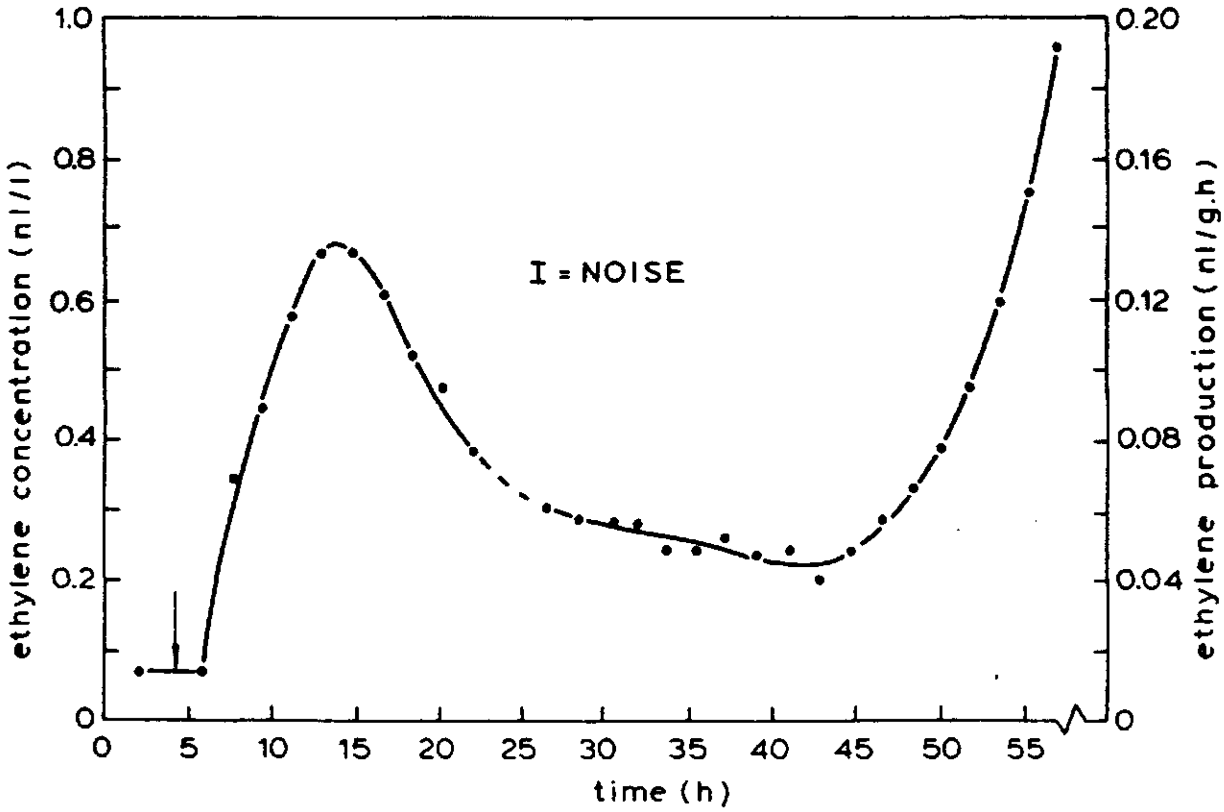


Figure 17. Calculated ethylene production (right ordinate) and difference between ethylene concentration in the outlet air from an empty cuvette and from a cuvette with a single Cymbidium flower (cv. Mary Princhess 'Del Rey') (left ordinate) as a function of time. Arrow indicates time of emasculation.
Flow rate - 0.9 L/h; temperature - 22°C

Aan : Boerrigter

Van : Hans van der Schild

d.d. : 911008

Gegevens produktbewaring

Ter kennisname hierbij een overzicht met bewaargegevens voor een aantal land- en tuinbouwprodukten, opgesteld door Ad Scheer van het Informatie- en Kenniscentrum Akker- en Tuinbouw, Afd. Milieu, Kwaliteit en Techniek te Ede (tel.: 08380-71565).

IKC
Informatie en Kennis Centrum Akker- en Tuinbouw
Afdeling Milieu, Kwaliteit en Techniek

product	code	temp	RV	voorkoel	bewaar	duur_wk	ethyprod	geurprod	ethygev	geur	uitdr	smet	LTB	kleur	oud
aardap-chi	2	7-8	90-95		droog	28-36			00		X	X	X		
aardap-con	2	4-5	90-95		droog	28-36			00		X	X	X		
aardap-fri	2	6-7	90-95		droog	28-36			00		X	X	X		
aardap-poo	2	3-4	90-95		dro/nat	25-28			00		X	X	X		
aardbei	1,2	0-1	90	nat	nat	.5-1			0		X	X	X		
abrikoos	5	0-1	90						000						
ananas	5	11-13	85-90			3-4			00			X	X	X	
andijvie	1,2	0-1	90-95	nat	nat	2			00		X	X			
anone	5	13-14	85-90				X								
artisjok	1	1-2	95	nat		1-3			0		X	X			
asperge	2	0-1	95-98	nat		1-2			00	X	X		X	X	
aubergine	1	10-13	90-95	nat		1-2			000				X		
augurk	1,2	13	90-95	nat		0-1			000		X	X	X	X	
avocado	5	12-13	90			2-3			000						
banaan	5	12-14	85-95			1-3			000						
bes blauw	4	1-3	90-95			1-2			0	X		X			
bes-kruis	4	0-1	90			2-3			0			X			
bes-rood	4	0-1	90			2-3			0						
bes-veen	4	1-3	85-90			4-5			0						
bes-zwart	4	0-1	90			1-2			0						
beurre ale	3	-.5-0	90-95			16-17					X	X			
beurre har	3	0-2	90-95			12-13					X		X		
bladselder	1,2	-1-0	90-95			1-2			00		X	X	X	X	
bleekselde	2	0-2	90-95	nat/vac	nat	2-4			00		X	X		X	
bonne loui	3	-.5-0	90-95			4-8							X		
boon-pronk	2	5-6	90-95	nat		1-2			00		X		X	X	
boon-spek	2	5-6	90-95	nat		1-2			00		X		X	X	
boon-sperc	2	5-6	90-95	nat		0.5-1			00		X		X	X	
boon-tuin	2	1-3	90-95	nat		1-2				X	X		X	X	
boskoop	3	4-5	90-92			20-25	X				X	X			
braam	4	0-2	90			0-1			0				X		
broccoli	1,2	0-1	90-95			1-2			000		X			X	
cactusvijg	5	5-7	90			3-4					X				
champignon	1	0-1	90-95	nat		0-1			0		X			X	
cherimoya	5	13-14	85-90			1-2	X								
courgette	1,2	8-10				0-1			000		X		X	X	
cox's-o-pi	3	4-5	85-90			12-17	X				X		X		X
cranberry	4	0-1	90			4-6			0		X				
dadel	5	1-3	80-90			.5-1									
doperwt	2	0-1	95-98	nat		0-1				X			X		
doyenne	3	-.5-0	90-95			16-21					X	X			
druif	4	1-3	90-95	nat		4-8					X	X			X
elstar	3	2-2.5	90-95			12-13	X					X	X		X
framboos	4	1-3	85-90	nat		.2-.7			0	X	X	X			
gemberwort	5	2-4	80			12-16									
gieser-wil	3	-.5-0	90-95			16-21					X	X			
gloster	3	1-2	90-95			16-21	X				X	X	X		X
golden-del	3	1-2	90-95			12-21	X					X	X		X
granaatapp	5	1-3	80-85			4-5									
guave	5	8-10	85-90			1-2									

product	code	temp	RV	voorkoel	bewaar	duur_wk	ethyprod	geurprod	ethygev	geur	uitdr	smet	LTB	kleur	oud
jona gold	3	1-2	90-95			12-17	X				X	X	X		X
kaki	5	1-3	85-90			1-2									
kapucijner	2	1-3	95-98	nat		.5-1				X	X		X		X
karmijn-de	3	4-4.5	90-95			8-10	X				X	X	X		
kastanje	4	1-3	70-75			16-25									
kiwi	5	0-2	90-95	nat	nat	20-22			000		X				
knoflook	2	1-3	80-85			16-25		X				X			
knolselder	2	0-1	90-95	droog		16-21					X				
knolvenkel	1,2	0-1	90-95	nat		1-2					X				
komkommer	1	12-13	90-95	nat	nat	.5-1			000		X	X	X	X	
kool-bloem	1,2	0-1	95-98	nat		3-6		X	000		X	X		X	
kool-boere	2	0-1	90-95			3-4			00						
kool-chine	1,2	0-1	95-98	nat		4-6		X	000		X	X			
kool-geel-	2	0-1	90-95			24-27			000		X	X			X
kool-groen	2	0-1	90-95			3-4			000		X	X			X
kool-rood	2	1-3	90-95			24-25			000		X	X			X
kool-spits	2	0-1	90-95			1-2			000		X	X			X
kool-sprui	2	-1-0	90-95			1-2			000		X	X	X	X	
kool-witte	2	1-3	90-95			32-36			000		X	X			X
koolraap	2	0-1	90-95			24-26			0				X		
koolrabi	1	0-1	90-95	nat		.1-1			0		X	X		X	
kroot	2	3-4	90-95			16-25			0						
kweepeer	5	1-3	85-90			8-13					X				
lime	5	8-10	85-90			6		X			X	X	X		
lombarts	3	3-3.5	90-95			16-22	X				X	X	X		
meloen	2	5-6	85-90	nat		1-2	X		0		X	X	X		
meloen-wat	2	12-17	85-90	nat		2-3			00		X	X	X	X	
mierikswor	5	1-3	90-95			36-44		X			X				
morel	4	1-3	85-90	nat		1-2			0	X	X	X		X	
noot-okker	4	0-1	80-90			32-35									
okra	5	8-10	90-95	nat		.5-1.5					X	X			
paprika-ge	1	7-8	90-95	nat		1-2			0		X	X	X	X	
paprika-gr	1	9-10	90-95	nat		1-2			00		X		X	X	
paprika-ro	1	7-8	90-95	nat		1-2			0		X	X	X	X	
pastinaak	5	1-3	90-95			8-25					X				
peen-bos	2	0-1	90-95	nat		1-2			0		X	X		X	
peen-bos	2	0-1	90-95	nat	nat	1-2			00		X	X		X	
peen-was	2	0-1	95-98	nat	nat	20-22			0		X	X		X	
peen-was	2	0-1	95-98	nat		0-4			0		X		X	X	X
peper	5	0-1	90-95			8-10					X				
perzik	4	1-3	85-90	nat		.5-1	X		000	X	X	X		X	X
peterseli	1,2	1-3	90-95	nat		2-4			0		X	X			
peul	2	0-1	90-95	nat	nat	1				X	X	X	X		
postelein	1,2	0-5	90-95	nat/vac	nat	.2-.8			0		X	X	X		
prei	2	-1-0	90-95	droog	nat/droo	4-6		X	00		X	X		X	
pruim	4	0-1	85-90	nat		1-3	X		000				X	X	
raapsteel	1,2	0-2	90-95	nat/vac	nat	.5-1			00		X	X		X	
rabarber	1,2	0-1	95-98	nat		2-3					X	X		X	
radijs	1,2	0-1	95-98	nat		1			0		X	X		X	
rammenas	1	0-1	95-98	nat		12-18			0		X	X		X	
schorsener	2	0-1	95-98	nat		16-18			X		X	X			X
sjalot	2	0-1	80-85			32-45		X				X	X	X	
sla-ijs	1,2	0-1	90-95	vac/nat		1-2			000		X	X		X	
sla-krop	1,2	0-1	90-95	vac/nat		1-2			000		X	X		X	
sla-rode	1,2	0-1	90-95	vac/nat		1-2			000		X	X		X	

product	code	temp	RV	voorkoel	bewaar	duur_wk	ethyprod	geurprod	ethygev	geur	uitdr	smet	LTB	kleur	oud
sla-veld	1,2	0-1	90-95	vac/nat		.5-1			000		X			X	
spinazie	1,2	0-1	90-95	nat		.5-1			000		X	X		X	
suikermais	2	0-1	90-95	nat		.5-1			0						
tauge	5	0-1	90-95	nat		0-1			0		X				
tomaat	1	10-13	80-90	nat		.5-2	X						X	X	
tuinkers	1	0-1	90-95	nat		1-2			0		X	X			
ui-parel	2	0-1	80-90					X				X	X	X	
ui-plant	2	0-1	80-90					X				X	X	X	
ui-zaai	2	-1-3	80-90		droog	20-32		X				X	X	X	
ui-zilver	2	0-1	80-90					X				X	X	X	
venkel	1,2	0-1	90-95	nat	nat	1-2			00		X		X	X	X
witlofkrop	1	0-1	90-95	nat		2-3			000		X		X	X	
witlofwort	2	-1-0	90-95			30-45					X	X			
wortel-win	2	0-1	90-95			18-26			0	X	X	X			
zoete kers	4	1-3	85-90	nat		.5-1				X	X			X	

GLASGROENT	1
VOLLEGROND	2
HARDFRUIT	3
ZACHTFRUIT	4
TROPISCH	5

0 – weinig

000 – veel.

oud(erdomsbederf)

kleur → verkleuring

LTB → Lage Temp. Bederf

uitdr(oging)

geur(gevoelig)

ethyleen gevoelig

A. Scheer
08300-71565