RESEARCH NEWSLETTER NO. 43
May 2019
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Ethylene sensitivity of tulip cultivars: Some are resistant to ethylene!

Fusarium is a devastating disease of tulips and can cause significant economic loss. It is well known that aside from direct damage to individual infected bulbs, the ethylene that is produced during infection can cause significant economic loss during storage and shipping. Ventilation of the ethylene from the storage room has a significant economic cost, to say nothing of the concern for greenhouse gas emissions.

Since the time of Wim de Munk in the early 1970s at the LBO, we have understood that Fusarium-infected bulbs produce ethylene. While we say "bulbs produce ethylene" it is nearly certain it is actually the fungus itself that is producing all the ethylene. When Fusarium was inoculated onto killed bulb tissue, ethylene is released (Miller) and pure Fusarium cultures release ethylene when growing on agar plates (Swart).

Ethylene can cause flower abortion and malformation when the bulbs are forced. The production and presence of ethylene during summer bulb storage and ocean shipment requires high ventilation rates to maintain ethylene levels below acceptable thresholds and adds significant costs to the summer bulb storage phase.

Over the last 15+ years we have investigated the susceptibility of tulip cultivars to ethylene. An earlier report on this work can be found in Newsletter 28 from April 2012. In this newsletter, we'll present an updated list of tulip cultivars based on their sensitivity to ethylene administered on October/November 2018 at Cornell University. The major conclusion is that ca. 20% of tulip cultivars appear to be resistant to ethylene.

What we did

Each year, all available cultivars in our ongoing research program were evaluated. Given this list goes back >10 years and that most of the cultivars we have used are "newer" ones to the market so as to develop forcing information for North America, the list notably contains many cultivars that are not widely grown and in some cases, may even be extinct. However, starting with the current season, we began a specific effort to evaluate the most important cultivars in the overall assortment. As a result, most of the "top 25" cultivars were tested in 2018-2019, and we anticipate continuing and expanding the evaluation of the most important cultivars during the foreseeable future.

Bulbs were supplied from the Netherlands and arrived in Ithaca in Late September after normal commercial shipment at 17°C. Bulbs were stored ventilated at 17°C after arrival and prior to use.
We treated bulbs with 10 ppm ethylene flowing at 10 liters per minute at 20°C into 0.4 m3 plexiglass chambers containing the bulbs. In all experiments, bulbs were treated for two weeks.

After ethylene treatment, bulbs were held at 17°C for 4 weeks, then planted (three, 30-cm pots per treatment with 15 bulbs in each pot) and cooled for 16 weeks (initially at 9°C, dropping to 1°C as rooting and shoot growth progressed). Pots were forced in a glass greenhouse at 17°C under standard conditions. At flowering, the number of stems with blind or aborted flowers or with severe petal malformation were

determined. Thus, our definition of "resistance" is essentially the ability of a cultivar to produce saleable stems. Subtle effects, such as height change (ethylene treated bulbs are usually shorter when flowering) or the production of side shoots (which are usually increased by ethylene) do not factor into our ratings.

In each year, the entire experiment is conducted two times, with the ethylene treatment of the first set generally being given near Oct 1-15 with the second set being treated in late October-early November.

What we found

To this point in time, we have evaluated 162 cultivars for sensitivity to ethylene in the October-November time period. We have found that tulips vary greatly in response to ethylene. We rated cultivars as ethylene "resistant", "susceptible" or "susceptible but inconsistent".

Resistant cultivars (Table 1) have never shown flower abortion or blasting due to ethylene exposure given under the conditions described above (autumn treatment in Ithaca) NY. In total about 20% of 162 cultivars tested so far have been substantially resistant to exogenous ethylene as we administer it in the experiments (Table 2 and Fig. 1). Also included in the table is a column "years of data per cultivar". The larger this number the more robust and reliable the resistance is. For example, Leen vd Mark, has never suffered injury in 9 years of trials (18 separate experiments) can be considered to be very highly reliable resistant to ethylene. Conversely, Ad Rem has only been used in 1 year of trials (2 separate experiments), but in that year, no damage was seen from ethylene. While this is positive, additional experiments with Ad Rem could reveal susceptibility which would lead to us reclassifying it as an "inconsistent" cultivar. In other words, more data is needed especially for the resistant cultivars with lower numbers of years of trials.

"Inconsistent" cultivars (Table 2, about 36% of those tested so far) have proven to vary a great deal between the two experiments in a single year or between years. It is common for "inconsistent" cultivars to show significantly more injury in the second experiment each year, that is, is seems that sensitivity to ethylene increases as 17°C storage progresses into November. In essence, the "inconsistent" cultivars, seem to have some degree of ethylene "resistance" but it is unpredictable and not reliable. As such, for practical purposes, these cultivars really can be thought of as "sensitive". An example is shown in Fig. 2.

Cultivars listed as susceptible are always significantly injured from these ethylene treatments (Table 2, about 44% of all cultivars). An example is Purple Flag (Fig. 3).

Among all three groups, it is notable that sport or mutant relationships are consistent. For example, Prinses Irene and Orange Princess which derive from Couleur Cardinal are all resistant, as are Prominence and Libretto and Kees Nelis and Bright Parrot. When combining inconsistent and susceptible cultivars, van Eijk and Lady van Eijk are both susceptible as are Purple Flag and White Flag and finally the Strong cultivars: Strong Gold, Strong Fire and Strong Love are all susceptible.

Significance and limitations

We believe the identification of ethylene resistant cultivars to be a highly important finding. For decades, the wisdom has been that tulip bulbs are susceptible to ethylene in the summer storage period before planting, and this has been understood to mean all cultivars. However, our results suggest as many as 20% of tulip varieties could show significant resistance to ethylene treatments in the October to November time frame. This could be very important for breeding efforts (long term) but could also be useful for staging cultivars in storage rooms as some cultivars can obviously tolerate greater levels of

ethylene. Perhaps the combined knowledge of the fully resistant cultivars and the fully sensitive cultivars could be especially useful in molecular investigations of ethylene sensitivity in tulip.

A potential limitation to this work is that it is conducted on exported bulbs, in October/November. We do not know whether these results apply to bulbs in storage in July, August or September. In other words, are resistant cultivars like Leen vd Mark, Kees Nelis and Couleur Cardinal also resistant to ethylene in those earlier months? This is a significant question because the concentrations of ethylene needed for injury in July and August are much lower than the 10 ppm we use, and it is known the ethylene sensitivity of tulip bulbs changes throughout development. It is an open question if cultivars resistant in October are also resistant earlier in the season at whatever target level of ethylene is chosen.
We have looked to see whether any obvious correlations exist between our results and the cultivar groups or with the ratings of disease susceptibility from the 1993 LBO list but there are no obvious relationships. On the other hand, the 1993 list might not be reflective of the present situation, as Fusarium strain continue to evolve. Also, we continue to do experiments on the level of ethylene that is produced by cultivars upon intentional infection with Fusarium (a topic for a future newsletter). While there is a very large variation in ethylene formed upon inoculating various cultivars, there appears to be no relationship between ethylene sensitivity of tulip bulbs and the quantity of ethylene produced upon Fusarium infection.

Table 1. Listing of 32 tulip cultivars that to this date, show resistance to ethylene. The "years of data" is essentially a measure of the reliability of the rating. Cultivars with 1 or 2 years of data could, in future experiments, show ethylene susceptibility. Cultivars with 3 or 4 or more years of data are likely to be reliable ethylene resistant.

Cultivar	Years of data per cultivar
Ad Rem	1
Blue Ribbon	4
Bright Parrot	6
Caractere	3
Columbus	2
Corvette	1
Couleur Cardinal	3
Davenport	2
Delta Storm	1
Friso	3
Full House	2
In Love	1
Kees Nelis	6
King's Cloak	3
Leen vd Mark	9
Libretto	3
Mondial	3
Nashville	4
Orange Princess	3
Pink Floyd	3
Playgirl	1
Prinses Irene	3
Prominence	4
Salvo	1
Sevilla	3
Siberia	1
Versaci	1
White Liberstar	1
White Marvel	1
Wirosa	3
Yellow Sun	2
Yellow Valery	1

Table 2. Listing of 162 tulip cultivars based on ethylene sensitivity after 1-12 years of trials as of May 2019. Bulbs were exposed to 10 ppm ethylene (20C, in air) for 2-week periods, typically in the late October to late December time frame, with two experiments per year. Cultivars listed as non-sensitive (20% of all cultivars) have never shown significant damage from ethylene (defined by flower abortion). Those listed as susceptible (44% of cultivars) were consistently highly damaged by ethylene (flower abortion). Those listed as "inconsistent" (36% of cultivars) were resistant in most experiments, but were injured in some replicates within a year or were inconsistent between years, so from a practical standpoint, they should be considered susceptible. The "years of trials" indicates how robust each rating is: the greater the number, the more reliable the rating should be. For example, the ethylene resistance rating of Leen vd Mark, with 9 years (16 experiments) of no injury is very solid, whereas the rating of Ad Rem, with only 1 year (2 experiments) is less reliable and more experiments should be conducted. Data are from Cornell University Research through the 2019 forcing season.

Cultivar		Ethylene susceptible? (conservative rating)	Years of data per cultivar
1.	**Ad Rem**	No	1
2.	**Blue Ribbon**	No	4
3.	**Bright Parrot**	No	6
4.	**Caractere**	No	3
5.	**Columbus**	No	2
6.	**Corvette**	No	1
7.	**Couleur Cardinal**	No	3
8.	**Davenport**	No	2
9.	**Delta Storm**	No	1
10.	**Friso**	No	3
11.	**Full House**	No	2
12.	**In Love**	No	1
13.	**Kees Nelis**	No	6
14.	**King's Cloak**	No	3
15.	**Leen vd Mark**	No	9
16.	**Libretto**	No	3
17.	**Mondial**	No	3
18.	**Nashville**	No	4
19.	**Orange Princess**	No	3
20.	**Pink Floyd**	No	3
21.	**Playgirl**	No	1
22.	**Prinses Irene**	No	3
23.	**Prominence**	No	4
24.	**Salvo**	No	1
25.	**Sevilla**	No	3
26.	**Siberia**	No	1
27.	**Versaci**	No	1
28.	**White Liberstar**	No	1

29.	**White Marvel**	No	1
30.	**Wirosa**	No	3
31.	**Yellow Sun**	No	2
32.	**Yellow Valery**	No	1
33.	**Aafke**	YES, inconsistent	1
34.	**Ace Pink (Aruba)**	YES, inconsistent	1
35.	**Adamo**	YES, inconsistent	3
36.	**Agrass White**	YES, inconsistent	6
37.	**Alibi**	YES, inconsistent	3
38.	**All Season**	YES	3
39.	**Andorra**	YES, inconsistent	1
40.	**Angelique**	YES	3
41.	**Annie Schilder**	YES	3
42.	**Antarctica**	YES, inconsistent	1
43.	**Apeldoorn**	YES	3
44.	**Baby Blue**	YES	2
45.	**Banja Luka**	YES	4
46.	**Bearing Point**	YES	4
47.	**Ben van Zanten**	YES	1
48.	**Black Jack**	YES	4
49.	**Bolroyal Pink**	YES	4
50.	**Bolroyal Silver**	YES, inconsistent	3
51.	**Calgary**	YES	6
52.	**Canasta**	YES	8
53.	**Cantata**	YES	1
54.	**Capri**	YES	1
55.	**Capri Rose**	YES, inconsistent	1
56.	**Carola**	YES	9
57.	**Charade**	YES	5
58.	**Chato**	YES	1
59.	**Cherry Delight**	YES, inconsistent	3
60.	**Cilesta**	YES	3
61.	**Crème Upstar**	YES	2
62.	**Curly Sue**	YES, inconsistent	4
63.	**Darwin Snow**	YES	1
64.	**Denmark**	YES, inconsistent	5
65.	**Diamond Parrot**	YES	1
66.	**Dominiek**	YES, inconsistent	3
67.	**Donau**	YES, inconsistent	3
68.	**Double Focus**	YES	1
69.	**Dow Jones**	YES, inconsistent	1
70.	**Dynasty**	YES, inconsistent	8
71.	**Endurance**	YES, inconsistent	1

72.	**Escape**	YES, inconsistent	5
73.	**Fabio**	YES, inconsistent	4
74.	**Finola**	YES	1
75.	**Flashback**	YES	1
76.	**Foxtrot**	YES	5
77.	**Freeman**	YES	1
78.	**Furand**	YES	1
79.	**Fusarino**	YES	4
80.	**Fusor**	YES	3
81.	**Gabriella**	YES, inconsistent	4
82.	**Gavota**	YES, inconsistent	1
83.	**Gironde**	YES	1
84.	**Golden Parade**	YES, inconsistent	1
85.	**Gwen**	YES	4
86.	**Hakkun**	YES, inconsistent	2
87.	**Havran**	YES, inconsistent	1
88.	**Honeymoon**	YES	2
89.	**Ile de France**	YES	2
90.	**Innuendo**	YES	7
91.	**Jan van Nes**	YES	6
92.	**Jumbo pink**	YES, inconsistent	4
93.	**Kikomachi**	YES, inconsistent	8
94.	**Kung Fu**	YES, inconsistent	4
95.	**Lady van Eijk**	YES	1
96.	**Lalibela**	YES, inconsistent	3
97.	**Laptop**	YES	3
98.	**Laura Figi**	YES, inconsistent	3
99.	**Leo Visser**	YES, inconsistent	1
100.	**Lilac Cup**	YES	2
101.	**Louvre**	YES, inconsistent	3
102.	**Lundy**	YES	1
103.	**Madelon**	YES, inconsistent	3
104.	**Marie Jo**	YES	2
105.	**Marit**	YES, inconsistent	1
106.	**Mary Belle**	YES	3
107.	**Mascara**	YES	1
108.	**Mascottee**	YES	3
109.	**Maserati**	YES	1
110.	**Match**	YES	2
111.	**Miss Elegance**	YES	4
112.	**Mistress**	YES	5
113.	**Monte Carlo**	YES, inconsistent	4
114.	**Montezuma ®**	YES	1

115.	**Negrita**	YES	4
116.	**Oscar**	YES, inconsistent	6
117.	**Pallada**	YES	5
118.	**Parade**	YES	3
119.	**Parade Design**	YES, inconsistent	1
120.	**Parrot Prince**	YES	1
121.	**Passionale**	YES	5
122.	**Pieter de Leur**	YES, inconsistent	4
123.	**Pim Fortuyn**	YES	2
124.	**Pinocchio**	YES, inconsistent	2
125.	**Plaisir**	YES, inconsistent	4
126.	**Pleasure**	YES, inconsistent	3
127.	**Popcorn**	YES	4
128.	**Pretty Woman**	YES, inconsistent	5
129.	**Princeps**	YES	1
130.	**Purple Flag**	YES	12
131.	**Purple Lady**	YES	4
132.	**Purple Prince**	YES	1
133.	**Quidam**	YES	1
134.	**Remise**	YES, inconsistent	3
135.	**Renegade**	YES, inconsistent	1
136.	**Ronaldo**	YES, inconsistent	3
137.	**Royal Ten**	YES	4
138.	**Saigon**	YES, inconsistent	6
139.	**Santander**	YES	3
140.	**Sapporo**	YES, inconsistent	4
141.	**Seadov**	YES	2
142.	**Sensual Touch**	YES	1
143.	**Singapore**	YES, inconsistent	5
144.	**Snowboard**	YES, inconsistent	4
145.	**Spryng**	YES	3
146.	**Strawberry Ice**	YES	1
147.	**Strong Fire**	YES	1
148.	**Strong Gold**	YES, inconsistent	8
149.	**Strong Love**	YES	3
150.	**Surrender**	YES	3
151.	**The Mounties**	YES, inconsistent	4
152.	**Toplips**	YES, inconsistent	1
153.	**Toproy**	YES	2
154.	**Update**	YES	1
155.	**van Eijk**	YES, inconsistent	5
156.	**Varinas**	YES, inconsistent	5
157.	**Verandi**	YES, inconsistent	6

158.	**White Flag**	YES	2
159.	**White Heaven**	YES, inconsistent	3
160.	**World's Favourite**	YES, inconsistent	4
161.	**Yellow Flight**	YES, inconsistent	8
162.	**Yellow Present**	YES, inconsistent	3

Image 3695

Image 3765

Fig. 1. Kees Nelis, a cultivar that has proven to be resistant to ethylene over many years of experiments. In each panel, pot on the left is the control, pot on the right is ethylene treatment to the bulbs the previous fall. The top photo is from the early experiment, bottom photo the later experiment. While the top photo shows a subtle effect of ethylene on plant height, plants in both sets (early and late) are showing full flowering of all stems.

Image 3693

Image 3746

Fig. 2. Antartica, an example of an "inconsistent" cultivar. In each panel, pot on the left is the control, pot on the right is ethylene treatment to the bulbs the previous fall. The top photo is from the early experiment, bottom photo the later experiment. Note much greater injury from the ethylene in the second set.

Image 3631

Image 3756

Fig. 3. Purple Flag, an example of a consistently ethylene sensitive cultivar. In each panel, pot on the left is the control, pot on the right is ethylene treatment to the bulbs the previous fall. The top photo is from the early experiment, bottom photo the later experiment. In our experiments, ethylene treatment of Purple Flag bulbs results in essentially 100% flower abortion when forced.