Factsheet 10/13
(HDC projects BOF 61, 63, 70, 71, 74 and project extensions)

Bulbs & Outdoor Flowers

Hot-water treatment of daffodil bulbs

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Hot-water treatment (HWT) is used to manage stem nematode and basal rot in daffodil bulbs. Bulbs are usually immersed in water containing disinfectant and fungicide and maintained at 44.4°C for three hours. This factsheet reviews the HWT process and discusses how bulb growers can use HWT to continue safeguarding the health of bulb stocks.

Action points

- Hot-water treatment (HWT) should continue to be used in concert with physical (optimal bulb drying and storage) and cultural (general hygiene and debris removal) control measures. Bulb handling before and after HWT should be of the highest standard.
- The duration of routine HWT should be extended to three hours and 15 minutes (to allow bulb-core temperatures to reach dip temperatures) but the temperature should remain at 44.4°C ±0.1°C; both time and temperature should be accurately controlled and ideally temperature should be measured in the centre of a bulb during HWT.
- If predominantly small (<10 cm) or predominantly large (>16 cm) bulbs are being treated, HWT duration could be shortened or lengthened by five minutes, respectively.
- The general disinfectant, FAM 30, should be added to HWT tanks to maintain the health status of the bulb stocks being treated.
- Storite Clear Liquid or Tezate 220 SL (thiabendazole) or Bravo 500, Life Scientific Chlorothalonil or LS Chlorothalonil (chlorothalonil) should be added to HWT tanks if basal rot is a problem. Where the thiabendazole fungicides are being used the addition of an acidifier, sodium bisulphate, is recommended to keep the water pH at 2.5 to 3.0.
- All tank additives should be topped up at the original rate as necessary, and growers should be aware that a proportion of some active ingredients may be lost or dissipated during the HWT process.
- Thiabendazole- and chlorothalonil-based products can be alternated as post-lifting and HWT applications or alternated each time a stock is lifted and treated.
- Shorter cold dip treatments (post-lifting and pre-soaking) should be used with care as FAM 30 and thiabendazole may not completely control stem nematodes and basal rot spores under these conditions.

1. HWT facility with 2 x 4 tonne tanks and overhead holding tank

Background

Hot-water treatment (HWT, often called 'sterilising') is a key operation in bulb handling; all daffodils intended for field production need HWT to control the potentially devastating stem nematode ('eelworm', *Ditylenchus dipsaci*). Daffodil bulbs intended for forcing or retail sale are not normally treated. In the 1930s it was shown that adding the disinfectant formalin (formaldehyde) to the tank water improved control of stem nematode and also helped to control basal rot (base or Fusarium rot, *Fusarium oxysporum f.sp. narcissi*). Subsequently a fungicide was often added to the tank water for improved effect.

In 2008 the horticultural use of formalin was banned by EU directive, forcing bulb growers to seek a replacement disinfectant or biocide urgently. About the same time increasing restrictions were imposed on the fungicide thiabendazole used in bulb dipping, so alternative fungicides were also needed.

The HDC therefore commissioned several projects to address these issues and the results are summarised in this factsheet.

Having reviewed the potential alternatives to HWT it was considered that none were suitable, all requiring a long development period and (or) substantial funding (Table 1). Despite some disadvantages, HWT is a tried and tested technique. On the other hand, when alternative disinfectants/biocides and fungicides were screened against stem nematodes and basal rot spores in the laboratory, an iodophore disinfectant (FAM 30) and a chlorothalonil fungicide (Bravo 500) were identified as potential replacements for formalin and thiabendazole. The results also reminded us of the effectiveness of the high temperature treatment against stem nematodes in its own right, even in plain water with no disinfectant added.

Table 1. Alternatives to HWT

Treatment	Reason for dismissal
'Vapour heat treatment' (steam treatment)	Killing stem nematodes required treatment for eight hours at 47.7°C, which damaged the bulbs.
Vacuum infiltration (of pesticides)	Tested, but not followed through; probably impractical on a large scale.
Microwave treatment	Small-scale tests promising, but high cost of development likely.
Nematicide application (via HWT, cold dips, soil incorporation or crop spraying)	Effective nematicides not available in the UK, though there has been some success with crop spraying in the USA.
Plant breeding for resistance or tolerance	No known natural resistance to stem nematode; would be a long-term project.

Effects of HWT

Control of stem nematode

The lack of evidence or history of stem nematode in a stock does not mean HWT is unnecessary, and the industry's appreciation of this has resulted in broadly successful management of stem nematode. Despite this, the nematode remains the greatest threat to the daffodil crop, and occasional outbreaks do happen. Low levels of stem nematode can be destructive; it was reported that just four nematodes can seriously damage a bulb in a year, while 50 can destroy it. An infested stock can be wiped out in three years. The lethal temperature for stem nematodes is close to that which causes significant damage to bulb tissues, so temperatures during HWT must be accurately and precisely controlled. Knowing a little of the stem nematode life-cycle can help us understand how HWT works.

Life of the stem nematode

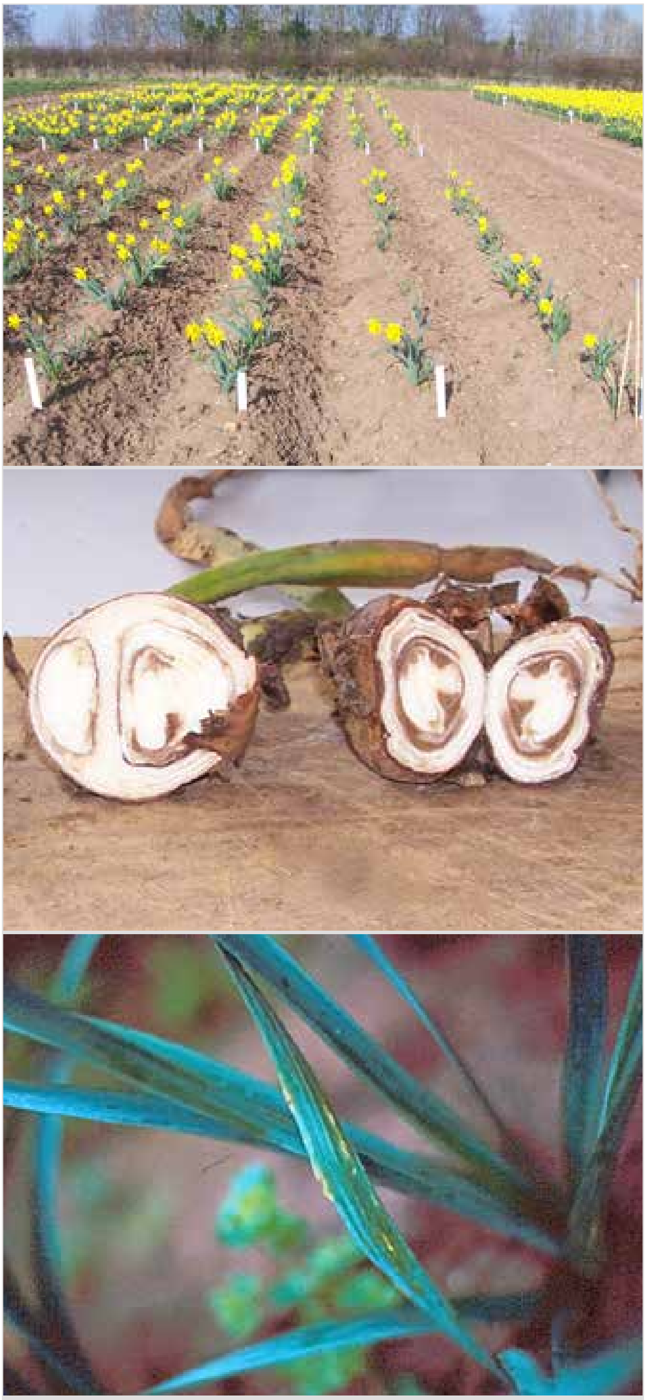
Stem nematodes multiply rapidly in warm bulbs whether planted or in storage. The transparent nematode, up to 1.2 mm long, completes its life-cycle within the bulb in about 20 days. It lays up to 500 eggs at a time. The hatchling progresses rapidly through four immature stages; the fourth stage pre-adult either migrates to the leaves or stem or stays in the bulb scales before moulting to an adult which can leave the bulb and infect others.

In decaying bulbs, however, the pre-adult moves to the outside of the bulb and forms 'wool', a mass of dehydrated nematodes, a survival mechanism should the bulb become desiccated. Wool exudes around the base plate (and sometimes around the bulb neck) and appears as pin-heads of off-white, fluffy material. This is easily dispersed, resistant to desiccation and heat, can survive for ten years in its dry state, and can rapidly re-hydrate on contact with water. When bulbs with wool receive HWT, the nematodes can re-hydrate and escape into the tank water. The wool stage and the free-swimming nematodes are more heat-resistant than those remaining in the bulbs, and formalin helped to control them.

In moist soil, stem nematodes can survive in the absence of host plants (including many common crops and weeds) for about a year. They can move up to one metre per year through the soil in moisture films, more in sandy or waterlogged soil or in furrows with standing water. Entering the bulb neck from the soil and eating their way through one bulb-scale at a time, they leave brown ring symptoms quite unlike those of basal or neck rot.

Control of other pests and diseases

Compared with stem nematode, other pests have similar or lower tolerance to high temperature, so are incidentally controlled by HWT. Pests reportedly controlled include the nematodes *Aphelenchoides subtenuis* (narcissus bulb and leaf nematode, associated with root and base plate rots) and *Pratylenchus penetrans* (root-lesion nematode, associated with 'soil sickness'), bulb-scale mites (*Steneotarsonemus laticeps*) and bulb mites (*Rhizoglyphus* species), and larvae of the large narcissus fly (*Merodon equestris*) and small narcissus flies



2. **Stem nematode symptoms: (1) gaps in the field rows, (2) brown rings in bulbs and (3) foliar symptoms ('spikkels')**

3. **Bulb symptoms of (1) bulb-scale mite, (2) large narcissus fly larva (right) and (3) basal rot spreading upwards**

(*Eumerus* species). There is no persistent effect of this treatment, but if a chlorpyrifos insecticide is added to the tank water the bulbs should be protected from invasion by large narcissus fly for a year. Basal rot, smoulder (*Botrytis narcissicola*) and leaf scorch (*Stagonospora curtisii*) may be controlled if an appropriate disinfectant or fungicide is added to the tank water.

Collateral damage

Temperatures lethal to stem nematode are close to those damaging daffodil tissues, but some crop vigour and quality must be sacrificed for a high level of nematode control. Even properly done, HWT will result in some leaf-tip and flower damage and minor yield loss. If appropriate, warm-storage treatment will mitigate this damage. By the second year of the crop no such damage will be evident and plant growth will have increased to compensate for the reduced growth in the year following HWT.

Cultivars vary in their sensitivity to HWT damage. 'Carlton' is a mainstream cultivar regarded as relatively sensitive and dwarf cultivars (like 'Tête-à-Tête') are also affected.

HWT-related damage will increase if HWT is carried out too early, too late, for too long a time, at too high a temperature, or after storing bulbs at too low a temperature.

- Early HWT (before adequate flower bud development) leads to dead flower buds.
- Late HWT (when the flower bud is well developed or when the root initials are well advanced in the base plate) leads to dead flower buds, severe leaf damage and root loss.
- Excessively hot or long HWT leads to severe leaf distortion or stunting, grey rings or spots in the scales, and the death of the stem apex with the abnormal production of extra bulb units.

4. HWT damage of daffodils: (1) leaf mottling and roughening and dead flower buds and (2) small 'starry' flowers

HWT facilities

An HWT facility consists of treatment tanks, a holding ('slave') tank or tanks (where the dip is held while treatment tanks are loaded and unloaded) and the associated heaters, heat exchangers, circulation pumps and control gear, together with adjacent bulb drying, holding and storage areas. The holding tanks are often sited above the treatment tanks, with one holding tank per treatment tank or a common holding tank. In the UK the usual modern design is the front-loading, drive-in tank, in which bulk bins are loaded and unloaded by fork-lift truck through a door in the front of the tank. There may be a suite of two to four tanks with a capacity between one and ten tonnes each, each tank holding several half to one tonne bulk bins. Top-loading tanks are also found, with a hinged lid through which the bins are loaded and unloaded using an overhead hoist or a fork-lift truck with specially designed tines that hold the bins underneath for loading and unloading the tank.

Key requirements for the HWT facility

Capacity: adequate to carry out HWT in a window of three to four weeks, taking account of the tonnage of bulbs treated annually and the size and number of tank loads achievable in that time.

Construction: tanks usually of mild steel painted with anti-corrosion paint, all components resilient to chemicals used; well insulated.

Health and safety: includes adequate ventilation, appropriate PPE, ease of using tank doors, safe access for cleaning and maintenance.

Heating: capable of providing rapid initial heating and fine temperature control during HWT, range 40 to 50°C with accuracy of ±0.1°C, easy-to-read built-in temperature monitoring and recording, temperatures calibrated annually.

Location: outside or well ventilated, away from (and not downwind of) sources of infection, good vehicular access, easy to wash down floor and surfaces and segregation of clean and dirty bulb areas.

Pumps: even flow of water through the heat exchanger and treatment tank, usually directed through the back wall of the tank into the pallet bases of the bins and requiring eight to ten pumped tank volumes per hour (24,000 to 30,000 litres/hour for each tonne of bulbs); capable of handling some solids, sufficient head of pressure to cope with blockages, designed to achieve circulation without cavitation (which can lead to foaming).

Size: tanks suitable for a water to bulb ratio of 3:1 (e.g. 3,000 litres water per tonne of bulbs) with top of bins covered by at least 2.5 cm of water.

The HWT process

Bulb handling

HWT should not be seen as a technique used in isolation: it should go hand-in-hand with good bulb handling and storage and maintaining hygiene around bulbs and equipment. Bulbs should be cleaned and graded before HWT, as excess soil, debris and small bulbs will hinder the flow of water. Before and after HWT, ideal storage conditions are 17°C, a relative humidity below 75% and good air movement with some exchange of fresh air. Cooler storage can increase HWT-damage and slow shoot development, while storage above 20°C can encourage basal rot and stem nematode.

Many types of bulk bin are used for bulb storage and dipping, but their pallet bases should line up with the hot-water inlets in the tank (to ensure good water flow into the bins). Bins should have corner posts projecting upwards by about 2.5 cm, leaving gaps between stacked bins to allow the required water movement through the bulbs. The outward ends of the pallet bases should be blocked with foam-rubber 'closers', again to improve water flow through the bulbs. Bins should be fitted with some kind of wire-mesh lid to prevent the loss of bulbs.

In practice bulbs are often stored at ambient temperatures in a variety of buildings or outside: if this is unavoidable, bins should at least be protected from sun, rain and contamination, even when left temporarily.

Tank maintenance

Tanks should be serviced each year a few weeks in advance of the HWT season, remembering they may be needed before the main season for treating contaminated stocks, early-lifted or reclaimed bulbs, or for sterilising bulb boxes or trays. It is important to have temperature control and monitoring devices checked and calibrated (for example, against a certified thermometer) before use, although the final settings should be checked in working tanks under a normal load of bulbs. The HWT buildings and environs should be clean, where practical using an industrial vacuum cleaner rather than brushes, with debris being buried or burnt off-site in a down-wind direction. At the end of the season the tanks should be washed down and flushed with clean water. Routine maintenance should be carried out and the tanks painted with a suitable anti-corrosion paint.

Timeliness

To minimise damage, daffodil bulbs should be treated once all the floral parts have been formed (called 'Stage Pc') but before the root initials are obvious in the base plate. 'Stage Pc' was formerly determined by dissecting out the buds to ensure the paracorolla (trumpet or cup) initials were present, but it is now carried out by date, starting HWT in the second half of July in west Cornwall and late-July/early-August in eastern England. Growers should aim to complete HWT within a three to four week window.

In terms of treatment running order, poeticus varieties produce fine, early roots and should be treated first, followed by small-cup, large-cup, and then trumpet varieties; however varieties susceptible to basal rot will also benefit from early treatment.

Water quality

Little is known of the effect of water quality on HWT, though water pH may affect the solubility of some dip additives and standing water from pipe-work may be atypical and should be drawn-off before filling the tanks. A larger effect of water quality may come from debris left in the tanks and pipe-work which are often difficult to clean properly. A biocide should be added from the outset. As HWT progresses, the dip will become more contaminated; in practice, it is normal to re-use HWT dips for as long as possible.

Temperature and duration

The temperature and duration of HWT needed to kill stem nematodes are close to those that can seriously damage bulbs, so the regime used has to be a compromise between effective control and avoiding unacceptable damage. For example, the temperature can be safely raised from 44.4°C to 46.1°C for three hours but increasing it to 47.2°C for the same time impairs crop vigour. Temperatures above 44.4°C should be used only in combination with pre-warming and pre-soaking. At 54.4°C even a 45 minute treatment is lethal. (In this factsheet many temperatures are conversions from Fahrenheit to Centigrade so they may appear rather over-specified).

Over time it has become possible to measure and control temperature with greater precision, so it is unsurprising that the recommended temperature and duration have increased over the years in a bid to improve control, becoming even more critical in the process.

- In the early 20th Century pioneers used treatments of one to six hours at 48.9°C, but the equipment was quite crude and the treatments mostly lethal.
- From the 1910s to the 1930s the recommendation was three hours at 43.5°C.
- In the 1930s and 1940s the recommendation was increased to three hours at 44.4°C or four hours at 43.5°C, and from the 1970s three hours at 44.4°C has been the consistent advice in the UK.

The temperature of the pre-heated water naturally falls when it is pumped back to the loaded tank, so it is usual to time the HWT period from when the dip regains its target temperature (44.4°C). With experience growers can 'surcharge' the set temperature to counteract this cooling effect, so the target temperature is re-gained more quickly. The surcharge temperature should be determined for each tank, but should probably never exceed about 49°C.

Increasing precision in HWT regimes

Treatments have been derived from measuring temperatures in the centre of the bulb and the treatment duration needed to kill stem nematodes. During recent HDC funded research on bulb-scale mite it appeared that standard HWT was inconsistent in controlling bulb-scale mites, so whether the target temperature was really being achieved was investigated further.

Using typical HWT facilities, temperatures of the water and in the middle of bulbs were logged. An example result is shown in Figure 1 along with an explanation of the results and the main findings and conclusions of the research are listed in Table 2, both overleaf.

The term 'accumulated hot-water minutes' was suggested as a simple way to express the high temperature treatment received at the bulb core, accumulating each minute at 44.3°C or above, on the assumption that the minimum effective HWT temperature is 44.4°C ±0.1°C. The project indicated that 'accumulated minutes' varied greatly between different facilities ostensibly applying the same treatment, and also varied sometimes between different runs in the same facility. Not all examples reached the target of 180 'accumulated minutes' and others were slightly over-treated.

As a rule-of-thumb it is suggested that the standard HWT treatment could be increased to three hours and 15 minutes from the time the circulating dip reaches (or re-gains) 44.4°C, to allow the bulb-core to reach the same temperature. If only small bulbs are being treated (smaller than 12-14 cm) then the time could be reduced to three hours and ten minutes, or, if larger, increased to three hours and 20 minutes.

Figure 1. An example of water and bulb-core temperatures during a three hour HWT at 44.4°C

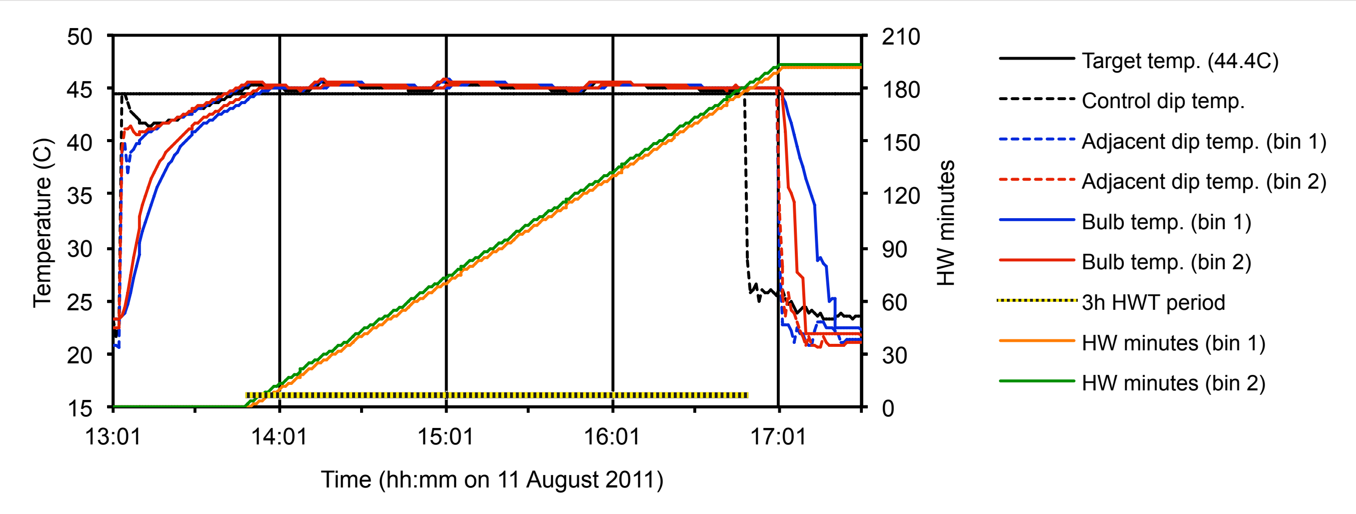


Figure 1 is an example of dip and bulb-core temperatures in two bins during a three hour HWT at 44.4°C, shown from when the pre-heated dip was pumped into the loaded tank, until the bins were removed from the tank and placed on a drying wall.

The dotted lines show the dip temperatures near the control sensor ('control', black) and in the bins by the tagged bulbs ('adjacent', blue and red). The solid blue and red coloured lines show bulb-core temperatures. The orange and green solid lines lines show the accumulated number of minutes the bulb-cores have been at, or above, the threshold temperature of 44.3°C. The horizontal black and yellow patterned line shows the duration of the three hour HWT period. The 44.4°C target temperature is shown by the horizontal black line.

Following initial immersion, bulb dip temperatures climbed back to the set temperature, with bulb-core temperatures lagging behind. Subsequently, the bulb-core temperatures fluctuated a little, but remained on the high side of 44.4°C. The downwards, black-dotted line indicates when the dip was pumped out of the tank, and the downwards, blue and red-dotted lines indicate when the two bins were removed from the tank. In this case both bulbs accumulated the required 180 'hot-water minutes' by the end of the three hour period, but continued to accumulate 'hot-water minutes' until the bins were unloaded from the tank.

Table 2. Main findings from monitoring water and bulb-core temperatures during HWT

Finding	Conclusion
Once at the set temperature the dip temperature remained steady, but the temperature achieved was not always the temperature required.	HWT controllers should be regularly calibrated for accuracy and should not begin to time the HWT period until the required temperature is reached in the dip around the bulbs.
In different facilities the temperature of the dip circulating around the bulbs took from 20 to 100 minutes from the start of dipping to reach the set temperature.	In some facilities the heating-up time was slow and the heaters should be improved. This could also be affected by the prior temperature at which the bulbs had been held.
Bulb-core temperature then took a further ten to 25 minutes to reach the set temperature (in a 12-14 cm grade bulb) but thereafter dip and bulb-core temperatures remained close.	A short allowance should be added to the usual three hour treatment to allow bulb-core temperatures to reach the dip temperature.
When the dip was pumped out at the end of HWT, if the bins were left in situ for another 15 minutes bulb-core temperature fell only slowly from the set temperature.	For repeatable results the removal of the bins at the end of HWT should be consistent; it is probably best to move bins to the drying/cooling facility promptly after a drain-down period, making use of an effective alarm or other warning system.
Bulb-core and dip temperatures were consistent between bulbs in different positions within a bin, and in different bin positions within a tank; but sometimes variations were recorded between runs.	For repeatable results the routines used should be consistent from dip-to-dip and day-to-day.
Testing bulbs of grades <10, 10-12, 12-14, 14-16 and >16 cm, compared with the smallest grade each additional grade needed approximately six extra minutes to reach the target temperature.	There would be some advantage in treating different grades of bulbs separately, though this could add considerably to the bulb handling required and may not be practical. Where predominantly small, medium or large grades are being treated in whole loads, the usual three hour period might be adjusted appropriately.
Bulbs of different cultivars, including long-necked bulbs like 'Actaea' and others with different densities, showed no difference in the warm-up time required.	There are no issues over treating mixed cultivars together.

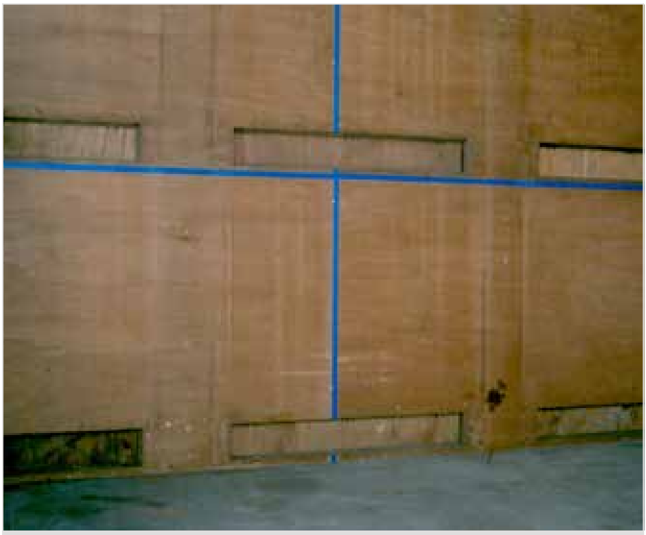
Bulb treatment after HWT

At the end of HWT, if foam or scum is visible on the surface of the dip, it should, if possible, be skimmed-off before pumping-out the tank (or lifting out the bulbs in top-loaders) to prevent potentially infective material being deposited on treated bulbs.

While the tank door is open and the bins are being extracted, check that the dregs of the dip do not run across the yard or spread around on the wheels of fork-lift trucks. Once the tank has drained down, any loose bulbs found on the floor of the tank or lodged elsewhere should be collected and discarded.

After HWT bulbs should be allowed to drain-down and should then be promptly moved to a drying wall or fixed or mobile fans fitted over bins and using positive or negative pressure to cool, ventilate and surface-dry the bulbs. Whatever ventilation and storage is used, it should be in a clean area away from unsterilised bulbs. There is no evidence from trials that extra-rapid cooling is beneficial, but delayed or slow cooling can result in 'over-cooking' because daffodil bulbs hold heat well.

Traditionally, bulbs were fully surface-dried after HWT and stored until replanting in September when soil temperatures had cooled and were less favourable to basal rot. In modern practice bulbs are planted as soon as practical after HWT, with the practical advantage of reducing storage/handling costs. However, it does means that bulbs are planted into relatively warm soil in August, which may encourage basal rot.



5. **Drying wall for surface drying bulbs**

Biocides and pesticides

Disinfectants/biocides

Before formalin was banned, there had been concerns about its future availability, and from time to time researchers had tested alternatives. Peroxyacetic acid (as Jet 5) and glutaraldehyde are examples of biocides that can be effective against stem nematode and basal rot, but they lack the cheapness of formalin and, for various reasons, cannot be recommended. Of the biocides tested in recent HDC funded projects, only an iodophore biocide was effective and crop-safe. The iodophore used was FAM 30, a well-known farm disinfectant used against foot and mouth disease. Other biocides tested and found to be ineffective were ascorbinic acid, chlorine dioxide, citric acid, Silwet L-77 and Spore-kill; hydrogen cyanamide (Cultamide) was effective but phytotoxic.

FAM 30 was tested in farm-scale HWT at 4.0 or 8.0 L of product per 1,000 L of water. Bulb and flower yields were slightly reduced when the higher rate was used, though the higher rate resulted in more saleable bulbs and fewer rotted ones. A compromise rate of 6.0 L per 1,000 L has been suggested, or the rate could be varied between 4.0 and 8.0 L per 1,000 L depending on the health of the stock treated. There are other iodophore biocides on the market besides FAM 30 and it is probable some of these have been used and would be effective, though they have not been formally tested.

The 2011 lift of two-year-down daffodils was the first to be harvested that had not received formalin regularly before planting, and fortunately no crop disasters have been seen as a result. Formalin had probably incidentally controlled bioload (microbial contamination) in HWT systems, and, not surprisingly, unpleasant aromas have been reported from HWT tanks subsequently. FAM 30 was shown to be effective in dealing with bioload in the water and equipment.

Despite recent results in the UK, chlorine dioxide was shown to be highly effective against fungal pathogens in extensive research in the USA. In the UK it was shown to be effective against bioload, though its freedom from phytotoxicity has not been convincingly proven at the present time. One advantage of chlorine dioxide is that its concentration can be automatically monitored and topped-up through a dosing unit in situ, so it is definitely an alternative for possible use in the future.

The HDC understands that biocides remain outside the remit of pesticide approvals, provided they are not claimed to have specific action against plant pathogens. Biocides are currently being reviewed by the EU and it is possible their availability might change in the process.

Fungicides

Although many fungicides are approved for use on ornamental crops as foliar sprays, thiabendazole (as Storite Clear Liquid and Tezate 220 SL) and chlorothalonil (as Bravo 500, Life Scientific Chlorothalonil and LS Chlorothalonil) are the only ones now approved via Extensions of Authorisation for Minor Use (EAMUs) in the UK as bulb dips (Table 3).

In trials over many years, thiabendazole fungicides have been more consistently effective than others with the added benefit of having nematicidal activity. It has been shown to control stem nematode both in trials and in practical HWT. As of 2008, thiabendazole was limited to one application per year, with a maximum rate of use (1.25 L of product per 1,000 L of water), but similar constraints apply to the chlorothalonil products. However, thiabendazole products are also no longer available to growers in the Isles of Scilly, thiabendazole-resistant strains of the basal rot pathogen are not uncommon, and the cost of these fungicide products is relatively high.

The bulb dip approval for chlorothalonil resulted from HDC trials that showed it was effective against basal rot spores and was crop-safe. In trials, Bravo 500 was used at 0.5 or 1.0 L of product per 1,000 L of water. There were only small and variable differences between effects of the two rates, so a middle rate (0.75 L per 1,000 L) has been suggested.

Table 3. Pesticides for use in HWT and cold-dipping

Disease or pest treated	Active ingredient and concentration in product	Product	EAMU number	Marketing company	Approved crop, maximum rate of use, number of applications and latest date
Basal rot / neck rot (*Fusarium oxysporum f.*sp. *narcissi*)	Chlorothalonil 500g/L	Bravo 500	2011/0943	Syngenta Crop Protection UK Limited	Narcissus bulb (dip) 1L product/1,000L water, once per year, before planting
		Life Scientific Chlorothalonil	2012/0379	Life Scientific Limited	
		LS Chlorothalonil	2011/1881	Kilcullen Kapital Partners	
	Thiabendazole 220g/L	Storite Clear Liquid	2007/0924	Syngenta Crop Protection UK Limited	Narcissus bulb (dip) 1.25L product/1,000L water, once per batch (between lifting and re-planting), before planting
		Tezate 220 SL	2009/1180	Agrichem BV	
Large narcissus fly	Chlorpyrifos 480g/L	Alpha Chlorpyrifos 48 EC	2009/1085	Makhteshim-Agan (UK) Limited	Non-edible ornamental bulbs (dip) 10L product/1,000L water (one 15 minute cold dip) or 5L product/1,000L water (one three hour HWT)
		Cyren	2005/0236	Headland Agrochemical Limited	
		Pyrinex 48 EC	2010/0043	Makhteshim-Agan (UK) Limited	

In recent HDC funded work other fungicides were evaluated against basal rot spores in a search for alternatives. Products containing prochloraz and (or) tebuconazole were more effective against a range of basal rot isolates than either thiabendazole or chlorothalonil, and were intermediate in price. A product containing copper oxychloride was also effective, at higher concentrations. This work is continuing, including the testing of other conazole fungicide products. EAMUs are being sought for these materials (prochloraz has previously held an off-label approval for bulb dipping).

Insecticides

Where large narcissus fly is an issue a chlorpyrifos insecticide (Alpha Chlorpyrifos 48 EC, Cyren or Pyrinex 48 EC) may be added via EAMU permission to the HWT tank (Table 3). Used at a rate of 5.0 L of product per 1,000 L water it will protect the bulbs from subsequent invasion by larvae for one year only. It is non-phytotoxic when used with pre-soaking.

Wetters, anti-foam materials and acidifiers

It has long been recommended to add a non-ionic wetter to HWT tanks, to enhance wetting and hence uptake of additives by the bulbs. But wetters have activities of their own, so the recommended concentration should not be exceeded. Anionic or cationic wetters are not recommended as they are more chemically reactive.

While tank and pump design should obviate against foam production in the system, this does sometimes happen, most obviously on the surface of the dip. Where foaming occurs an appropriate amount of an anti-foam product should be added.

Where Storite Clear Liquid or Tezate 220 SL is being used, the addition of an acidifier (sodium bisulphate) is recommended. Thiabendazole is more soluble in water at a low pH, and, despite these products being acidic formulations, much of the active ingredient settles out on the tank floor and other surfaces. At start up, sodium bisulphate should be added at a rate of 1.38 kg per 1,000 L of dip, and it should be added to the tank first and allowed to dissolve before adding the other ingredients. When topping-up more sodium bisulphate should be added, at the same rate as before. The aim should be to maintain a pH level between 2.5 and 3.0 (a lower pH may be harmful), and to achieve this it may be necessary to add a further 0.25 kg per 1,000 L of dip at the start of each day. FAM 30 is an acidic formulation, so if used in a tank mix with Storite Clear Liquid or Tezate 220 SL, a separate acidifier may not be needed. It is not known whether acidifiers or acidic formulations contribute significantly to the corrosion of tanks and pipe-work.

Tank mixes

In recent HDC funded trials half-rates of FAM 30 and of Bravo 500 were combined in one treatment, and no adverse effect of using both materials together was found. Many other combinations of biocide, fungicide and other pesticides have been used in commerce such as FAM 30 + thiabendazole. These mixtures have not been tested under trial conditions, so should be used with caution. In earlier HDC funded work a tank mix used in the Netherlands consisting of prochloraz, formalin and reduced rate captan and thiabendazole was tested in HWT (three hours at 44.4°C), and severely reduced crop vigour. In a follow-up trial the same mixture was free of adverse effects when used with the typical Dutch HWT regime of two hours at 43.5°C.

Chemical stability

It has long been suspected that active ingredients are 'lost' from the circulating dip during HWT, most obviously because white deposits are seen on the tank floor and other surfaces when the bins are unloaded. An active ingredient may exist both in solution and in suspension within the dip; suspended material will settle out and eventually reach an equilibrium at which point the concentration of suspended material will remain stable. With both thiabendazole and chlorothalonil this occurs after about two days in HWT conditions, at which point there remains about 25% of the target concentration of active ingredient circulating in the dip. This might be improved by effective stirring of the deposits, though in a trial extra pumping failed to raise the circulating concentration of chlorothalonil. For thiabendazole it has been shown that this residual concentration was adequate to treat bulbs with basal rot, and it is likely that this applies also to chlorothalonil.

6. Evidence of deposits left behind on the floor of a HWT tank

Active ingredients are also 'lost' by chemical reactions. In addition to biocide 'lost' by absorption to organic material, the iodine in FAM 30 appears to react with metal surfaces so its concentration falls. Other examples of chemical degradation are the acid or alkaline hydrolysis that occurs with some pesticides.

Concentrations and topping-up

The volume of water depleted by absorption to the bulbs, leakage, etc. should be topped-up to the original mark, ideally after every dip. Appropriate amounts of the biocides, fungicides, etc. should be added to the top-up water at the original concentration. Where chemicals are actively being 'lost', as in the case of the iodine in FAM 30, appropriate topping-up regimes may be more difficult to define. As an interim measure, until more is known, they could simply be topped up at the standard rate.

It is sensible to check on the concentrations of active ingredients at intervals. Occasional samples could be taken for the analysis of pesticide concentration at an analytical laboratory. Dip-stick tests, if not always easy to interpret, are available for some biocides, such as FAM 30. When adding acidifier to thiabendazole dips, acidity is one property that can be checked easily, using a portable pH meter or digital probe.

Spent dip disposal

To reduce the amount of spent dip for disposal at the end of HWT, topping-up can be progressively restricted towards the end of the HWT season. It may be possible to combine the remaining dip from two or more tanks, or to operate on a reduced load, in order to minimise the amount of dip for disposal.

Variations in HWT procedures

Early HWT for improved pest and disease control

Early HWT causes more damage to flowers, but is nevertheless used when the need to control pest or disease overrides the need to minimise crop damage.

- Bulbs re-claimed from forcing can be removed from the glasshouse, left to die-down and then recovered from their growing medium for HWT before the main HWT season.
- Bulbs with a particular basal rot problem can be treated early, which is more effective than delaying until the regular HWT date.
- Bulb stocks having (or suspected of having) a stem nematode infestation can also be lifted early (taking precautions not to spread the infestation) and treated as early as practical. The bulbs should not be stored in warm conditions or allowed to dry-out, which would increase nematode numbers and wool formation.

Pre-warming and pre-soaking regimes to reduce HWT damage

Where the first year flower crop is important, treatments have been developed to reduce HWT-induced damage in the year after treatment. This involves the additional steps of 'pre-warming' and 'pre-soaking' and is followed by HWT at a higher than usual temperature. Only stocks known to be free of stem nematode should be treated in this way.

The bulbs are pre-warmed (stored warm), say for one week at 30°C, though this is not critical and regimes of three to eight days at 30 to 35°C can be used. The elevated temperature appears to slow down development of the shoot initials, making them less sensitive to disruption by high temperature, and also extends the window in which HWT can be carried out safely. Pre-warming does decrease the subsequent vigour of bulbs, but this is more than balanced by the beneficial effects on flower quality. Bulbs should be dry at the start of pre-warming, since moisture plus heat will encourage the development of soft rot (*Rhizopus* species).

Pre-warming partially desiccates the bulb, leading to nematode wool formation, so it should be followed by pre-soaking. This means immersing the bulbs in a HWT or dip tank at ambient temperatures for three to four hours, or overnight, to allow the wool to re-hydrate. It should be followed immediately by HWT for three hours at the elevated temperature of 46°C, which counteracts the enhanced heat-resistance of the nematodes. A biocide and (or) fungicide should be added to the pre-soak tank to control the spread of pests and diseases. Where a cold pre-soak of at least three hours is used, FAM 30 should be effective against stem nematode.

Storage at 18°C to lessen HWT damage

The lower limit of the warm storage effect is about 18°C. If bulbs are stored for two weeks at 18°C before HWT, HWT-induced damage can be prevented. Sometimes this is called 'partial pre-warming', and, unlike pre-warming, requires neither pre-soaking nor a higher HWT temperature. Assuming that the temperature of HWT alone will control stem nematodes, an 18°C treatment offers a way around the loss of formalin in the pre-soak tank.

If late HWT is necessary simply because of the volume of bulbs to be treated, then its adverse effects can be mitigated to an extent by using this 18°C treatment.

Bulb-scale mite control for bulbs being forced

Milder HWT regimes and 'dry heat' treatments have been tested to see if they might be used to control bulb-scale mite in bulbs intended for forcing, without damaging the flowers. A short HWT of one hour at 44.4°C, originally with formalin but with neither pre-warming nor pre-soaking, was enough to kill adults and eggs, and this treatment is used by some bulb forcers. There is still some doubt about the quality of flowers obtained. It is doubtful whether using FAM 30 for a one hour treatment would be effective.

A dry heat treatment of three hours at 42°C was sufficient to kill adults and eggs without significant effects on bulb vigour or flower quality. Only stocks infested (or suspected of being infested) with bulb-scale mite need be treated.

Cold dip and bulb spray treatments

Post-lifting cold dips

Cold dips with formalin and a fungicide, usually applied for 15 minutes shortly after bulb lifting, were a useful and effective way of managing basal rot because it is done some weeks before HWT. But should cold dips be used without formalin? FAM 30 was shown to be effective against wool-stage nematodes as a three hour cold dip. Earlier, FAM 30 had been tested against stem nematodes for disinfecting equipment at ambient temperatures, and had been shown to kill free-swimming nematodes in three to four minutes in clean, cold water, or in 20 minutes if soil was present; however, it was inactive against wool-stage nematodes unless these had first been wetted for 24 hours. Recent work has shown that FAM 30 is generally effective against basal rot resting spores in cold dips of 15 to 25 minutes duration, and that the same treatment will, to an extent, control basal rot in infected bulbs. Hence, while short post-lifting cold dips in Storite Clear Liquid, Bravo 500 or FAM 30 to control basal rot are possible, this may not work in dirty water, would not control wool-stage nematode, and a 15 minute treatment might be too short.

Post-lifting bulb sprays

As an alternative to bulb dips, fungicides have been applied to bulbs shortly after lifting by directly spraying onto bulbs between pre-cleaning in the yard and the drying-wall or drying-floor. The major advantage is that this does not add to the drying burden. Thiabendazole fungicides can be effective applied in this way with a variety of spray equipment, though problems are perceived in achieving good bulb coverage with a variable-sized product that does not turn well on a roller table. As Storite Clear Liquid or Tezate 220 SL may now be applied only once per year to a bulb crop, there is no longer the option of a double-treatment post-lifting and in HWT, but a post-lifting spray could be used if another fungicide were used later in HWT. Other fungicides were also tested as bulb sprays and captan and chlorothalonil fungicides were found to be effective, although no approvals are available for either fungicide. Although less likely, the possibility of pest or disease spread during bulb spraying could not be ruled out.

Other fungicide applications

A range of other biocide or fungicide applications has been tested by growers as possible alternatives or adjuncts to HWT. These include spray-application as the bulbs are elevated from the soil or when being re-planted, and as pre-planting dips. Such methods have either been shown to be less effective than either post-lifting treatments or HWT, or have not been formally evaluated, so none of these methods can be recommended. No evidence has been produced that foliar spray programmes applied in the field have any incidental benefit in controlling basal rot.

Integrated crop management

HWT and non-chemical control

The control of pests and diseases of daffodils has always involved an integrated approach, using pesticides along with physical and cultural control measures. Physical controls include careful bulb-handling and appropriate storage, while cultural controls encompass adequately long rotations, restricted nitrogen manuring, crop inspections, removal and destruction of infected material, good general hygiene (cleaning and disinfecting buildings and equipment and debris removal) and soil management.

Anti-resistance strategies

Where fungicides are used, care should be taken to reduce the likelihood of pathogens developing resistance to fungicides. Strains of the basal rot fungus resistant to thiabendazole have been known for some years, so, despite being the most effective fungicide against the disease, its use should be restricted; this has already been partly forced by restrictions imposed on the use of thiabendazole in 2008.

Currently, the available bulb dip fungicides cover only two active ingredients from two mode of action groups, so the options are limited to post-lifting thiabendazole dip or spray treatment followed by chlorothalonil in HWT, or chlorothalonil in a post-lifting dip followed by thiabendazole in HWT, or a single (HWT) or double (post-lifting dip plus HWT) application of chlorothalonil, or simply alternating thiabendazole and chlorothalonil in the HWT tank each time a stock is lifted and treated.

Recent work however, has shown that prochloraz, tebuconazole and copper oxychloride have potential for basal rot control, possibly (if EAMUs can be obtained) providing three more mode of action groups that could be integrated into any future anti-resistance strategy.

Conclusions

At the present time the HWT technique should be pursued as the best option for stem nematode and basal rot control, indeed recent projects have endorsed the general effectiveness of modern HWT facilities. For stem nematode control, strict checks of the duration and temperature of HWT are needed, to ensure that close to 180 'accumulated hot-water minutes' are received in the middle of the bulb. While the temperature should be maintained at 44.4°C, it is suggested that the duration of HWT should be increased to three hours and 15 minutes. If predominantly small (<10 cm) or predominantly large (>16 cm) bulbs are being treated, this duration could be shortened or lengthened by five minutes, respectively.

The fungicide options (and hence the options for developing an anti-resistance strategy) for basal rot control in HWT are currently limited. Thiabendazole-based fungicides are most generally effective, but are expensive, and resistance of the basal rot fungus to them has been known for some years. EAMUs for the potentially alternative fungicides prochloraz, tebuconazole and copper oxychloride are being investigated. Post-lifting cold dip and spray treatments, and HWT regimes involving a cold pre-soak, should be treated with caution, since, compared with formalin, the effectiveness of FAM 30 under these conditions is marginal.

Further information

HDC Factsheets

HDC Factsheet 05/08. 'Management of large narcissus fly'.

HDC Factsheet 13/04. 'Acidification of 'Storite' in HWT for narcissus basal rot control'.

HDC Grower summaries and reports

BOF 74. 'In vitro screening of fungicides with potential to control basal rot of *Narcissus* caused by *Fusarium oxysporum* f.sp *narcissi*'.

BOF 71a. '*Narcissus*: The use of FAM 30 disinfectant as a cold dip treatment for Fusarium basal rot'.

BOF 71. '*Narcissus*: The use of FAM 30 disinfectant as a cold dip treatment for Fusarium basal rot – whole bulb tests'.

BOF 70a. '*Narcissus*: Chlorine dioxide – assessing crop safety in daffodils treated in hot-water treatment'.

BOF 70. '*Narcissus*: Chlorine dioxide – a potential disinfectant for use in hot-water treatment and other bulb dips'.

BOF 69. '*Narcissus*: Suppression of Fusarium basal rot using composts amended with specific biocontrol agents'.

BOF 63b. 'Integrated control of bulb-scale mite in *Narcissus*: Validation of bulb temperatures during hot-water treatment'.

BOF 63a/63. 'Integrated control of bulb-scale mite in *Narcissus*'.

BOF 61c. 'Daffodils: Developing alternatives to formalin. The concentration of chlorothalonil fungicide and iodophor disinfectant in HWT and cold dips'.

BOF 61b. 'Daffodils: Alternatives to use of formaldehyde in HWT tanks for the control of stem nematode and Fusarium basal rot'.

BOF 61a. '*Narcissus*: Alternatives to the use of formaldehyde in hot-water treatment tanks for the control of stem nematode and Fusarium basal rot' - experimental work.

BOF 61. '*Narcissus*: Alternatives to the use of formaldehyde in hot-water treatment tanks for the control of stem nematode and Fusarium basal rot' - review.

BOF 49. '*Narcissus*: Disinfectants for the control of stem nematode on bulb handling hardware and the fabric of buildings'.

BOF 43a/43. '*Narcissus*: The use of acidifiers in bulb dip and spray treatments'.

BOF 42. '*Narcissus*: The handling of bulb stocks with basal rot'.

BOF 39. '*Narcissus*: Examination of the links between soil nitrogen and basal rot'.

BOF 31a. '*Narcissus*: Fungicides for the control of basal rot and fungi associated with neck rot'.

BOF 31. 'A review of the control of basal rot and other diseases in *Narcissus* '.

BOF 25a. '*Narcissus*: Bulb-scale mite control using hot water treatments'.

BOF 24. 'Large narcissus fly control: The use of chlorpyrifos'.

BOF 15. '*Narcissus*: Latest safe date for hot-water treatment'.

BOF 12. '*Narcissus*: Pre-warming prior to hot-water treatment'.

BOF 6. '*Narcissus*: Biological and integrated control of narcissus basal rot'.

HDC publications can be accessed on the HDC website (www.hdc.org.uk).

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