Project NA20000

Cost effective thinning for Nashi (desktop evaluation and grower workshops)

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Preamble: This review is the major output for the Hort Innovation levy funded project NA20000 - Cost effective thinning for Nashi (desktop evaluation and grower workshops). The objectives of the project are to identify opportunities for the reduction in thinning/budding costs for the Nashi industry, to engage with industry perspectives and experience and to provide recommendations for the prioritisation of any potential future R&D. The review covers the available scientific, industry and grey literature relating to crop load management of Nashi plus further issues identified in the workshops held in August 2021 and January 2022 with growers from Victoria, South Australia and Western Australia.

Contents

1. Introduction

Pears belong to the genus *Pyrus* within the Rosaceae family, subfamily Pomoideae and are closely related to apples (*Malus*) and quince (*Cydonia*). The *Pyrus* genus can be subdivided into two major groups: Occidental (European) and Oriental (Asian) pears (Ferradini *et al.* 2017; Quinet & Wesel 2019). According to Saito (2016) there are at least 29 widely recognised primary species within the *Pyrus* genus. European cultivars all belong to the species *P. communis*. The most cultivated species of Asian pear include the Ussurian pear *(P. ussuriensis* Maxim), Chinese white pear (*P.* x *bretschneideri* Rehder), Chinese sand pear and Japanese pear (*P. pyrifolia* Nakai), and Xinjiang pear (*P. sinkiangensis* Yu) (Bao *et al.* 2007; Katayama *et al.* 2016). Bao *et al.* (2007) suggests that the progenitor of Japanese pears originated from China. Interspecific hybridisation occurs readily between the different pear genera (Wrolstad *et al.* 1991; Jun & Hongsheng 2002).

Unlike European pears which exhibit a pyriform shape, the fruit shape of Asian pears is global or spheroidal (Benitez & Pensel 2004). The other major botanical difference is in the calyx – Asian pears do not have the characteristic sepals of European cultivars. Skin may be either bronzed (russeted), or yellow or greenish in colour. Fruit is crisp in texture, juicy with high sugar content, weak acidity and low aroma (Benitez & Pensel 2004, Colavita *et al.* 2020). A major physiological difference between the Occidental and Oriental groups is that Asian pears, unlike European pears, reach optimum quality when allowed to ripen on the tree (Quinet & Wesel 2019).

According to Wrolstad *et al.* (1991), the principal Asian pear cultivars in China are 'Ya Li', 'Tzik', 'Chioubaili', 'Shiyue Huali', 'Pinguola', 'Tsu Li' and 'Jinjbaili', and in Japan include 'Nijisseiki' (20th Century), 'Chojuro', 'Kosui', 'Hosui' (Abundance), 'Kikisui', 'Shinseiki' (New Century) and 'Shinsui'.

Various terms are used for Asian pear, Nashi is used in Japan, NZ, France, Argentina, Brazil and Australia; salad pear, pear-apple and Oriental pear are common names in the US; Asian pear is the preferred trade name (Wrolstad *et al.* 1991). The term Nashi will be used for the remainder of this review.

2. Phenological stages in Nashi

Phenology is the study of periodic plant (and animal) life cycle events and how these are influenced by seasonal variations in climate. The change from one phenological stage to another is triggered by environmental changes, and hence phenological events are ideal indicators of the impact of local and global changes in weather and climate (Meier *et al.* 2009). Hack *et al.* (1992) developed a system for uniform coding of phenologically similar growth stages of all mono- and dicotyledonous plant species – the BBCH scale. The general BBCH scale considers 10 principal growth stages, numbered from 0 to 9 with secondary growth stages defining short developmental steps characteristic of the respective plant species, which are passed successively during the respective principal growth stage. These secondary stages are also coded using the figures 0 to 9, hence the combination of figures for the principal and the secondary stages results in a two-digit code. Not all primary stages are applicable to all species, for example Nashi phenology shows eight of the 10 principal stages: bud (0), leaf development (1), shoot development (3), inflorescence emergence (5), flowering (6), fruit development (7), fruit maturity (8) and senescence (9) (Martinez *et al.* 2016). Further details of the BBCH scale as it relates to Nashi are provided in Appendix 1.

An understanding of the different growth or developmental stages is important for the correct timing of many orchard management practices. Plant growth is highly responsive to day length and climate, and deciduous fruit trees are particularly influenced by winter chill and temperature, hence application of the BBCH scale is a useful tool to ensure that management practices are undertaken at the appropriate time, and it is particularly useful for correct timing of plant bioregulator application.

3. Flowering and fruit set

Pears flower on spurs, short shoots and one-year-old wood, with flower initiation occurring in the spring-summer of the preceding season. Initiation of spur and terminal shoot buds begins 3-6 weeks after bloom, while axillary buds on first-year-wood (extension shoots) are formed later in the season (Bound 2020). Anything that interrupts or reduces the amount of photosynthates produced through photosynthesis will reduce the quality of the developing buds. Bound (2020) lists the following factors that can lead to a reduction in available assimilates, and thus reduced bud quality:

- excessive vegetative growth
- lack of light or shaded buds
- poor leaf quality through inadequate nutrition, irrigation or disease/insect attack
- heavy crop load
- high temperatures during the bud development phase causing trees to shut down.

Nashi pears have an indeterminate inflorescence with racemes of 8-10 flowers (Esumi *et al.* 2007), unlike the determinate inflorescence found in apple and quince. Flowers open in progression acropetally from the side-lateral to the terminal.

Time of flowering varies with cultivar but is dependent on local climatic conditions and the degree of chill received over winter. Figure 1 illustrates the average flowering times for many Nashi cultivars in Orange, NSW.

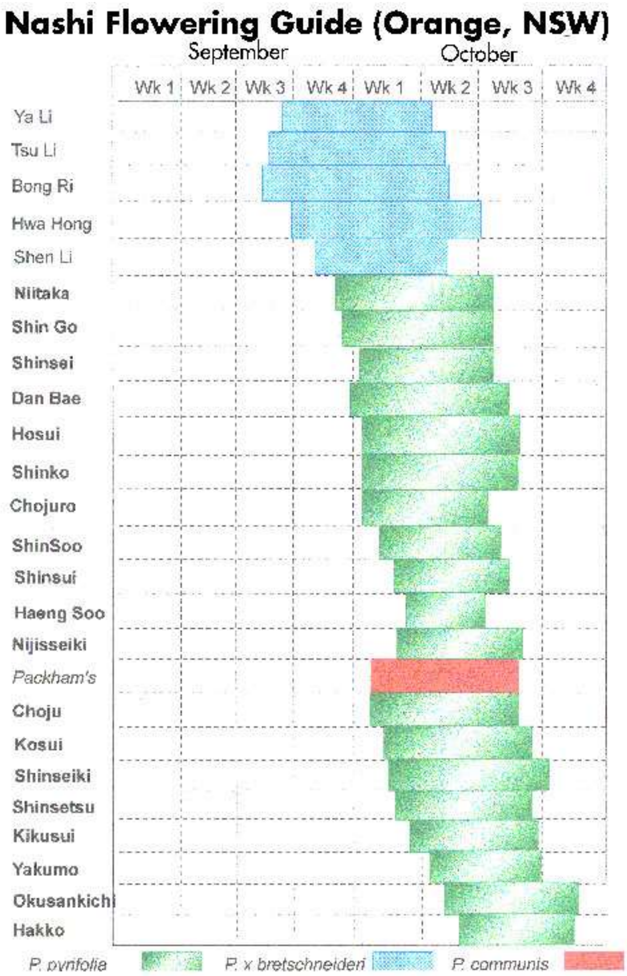

Figure 1*: Flowering times for Nashi in Orange, NSW in relation to the European pear cultivar Packhams' Triumph. (Source: NSW DPI https://www.dpi.nsw.gov.au/agriculture/horticulture/pomes/other/nashi)*

3.1. Role of dormancy (rest) breakers

Deciduous fruit trees require accumulation of chill hours over the dormant winter period for synchronous bud break to occur. The climate across the temperate regions of southern Australia, where Nashi is grown, is characterised by gradual transitions from one season to another and occasionally warm winters, unlike the marked seasonal transitions observed in most northern hemisphere temperate growing regions. This often results in insufficient chill accumulation and can cause physiological damage to trees leading to non-synchronous bud burst and extended flowering (Thomas *et al.* 2012). With a warming climate, many production regions in Australia may become marginal in terms of achieving sufficient chill exposure for high-chill cultivars (Luedeling *et al.* 2011; Measham *et al.* 2014).

Application of chemical dormancy-breaking agents has become a routine practice in many regions with insufficient winter chill in order to manipulate bud break, thus synchronising floral bud break and ensuring a commercially viable flowering and fruit set (Bound & Jones 2004a; Bound & Miller 2006). The most commonly used dormancy-breaker in apples is hydrogen cyanamide (HC), and although it is not registered for pears it is often still applied in regions that lack sufficient winter chill for synchronous bud break. HC can also be used with mineral oil (MO) to reduce the dose rate (Sagredo *et al.* 2005). Other bud break agents include vegetable oils (VO), methyl esters of fatty acids such as Waiken™, and the fertiliser adjuvant Erger® (Table 1).

Studying the use of HC to improve flowering and fruit set in several Nashi cultivars ('Hosui', 'Kosui', 'Shinsui' 'Nijisseiki' and 'Shinseiki)', Klinac *et al.* (1991) reported an advancement in the onset of flowering and a reduction in the length of the flowering period in all cultivars, but a greater response was observed in the later flowering cultivars 'Nijisseiki' and 'Shinseiki'. They also reported that an application of 3% HC at 30-50 days before natural flowering substantially improved overlap of the pollinator 'Shinseiki' with the flowering periods of other cultivars.

In Brazil, Faoro & Nakasu (2002) note that application of HC and MO is required to ensure adequate bud break in 'Hosui, 'Kosui' and 'Nijisseiki'. Abreu *et al.* (2021) reported that HC and HC+MO were more effective than Erger® in promoting bud break of 'Hosui'. In studies evaluating the effect of vegetable (sunflower) and mineral oils on bud break, yield and enzymatic activity in the cultivar 'Hosui', Botelho *et al.* (2021) found that treatment with 4% MO plus 2% VO was as effective as the standard HC treatment in releasing bud dormancy; they reported a reduction in the activity of the catalase enzymes in the buds of the trees treated with MO and VO, indicating the mode of action is through oxidative stress, similar to the action of HC. They concluded that the application of 4% MO plus 2% VO may be a more sustainable alternative for inducing bud break in 'Hosui' pear trees due to the reduction in cost and environmental impact. In Brazil, MO+HC, branch bending and girdling have been used to promote bud break, and flowering of Nashi may occur 10 to 15 days earlier than normal depending on the timing of MO and HC treatments (Petri & Herter 2002).

According to Honjo *et al.* (2002), 'Kosui' requires around 800 chill hours to break endodormancy, while other cultivars require more than 1600 hours. Faoro & Nakasu (2002) note that 'Kosui' is well adapted to warmer areas in Brazil where chill accumulation is over 400 hours, but 'Nijisseiki' has poor bloom and reduced shoot growth in areas with chill accumulation between 500-700 hours. Petri & Herter (2002) reported that for the high-chill cultivar 'Nijisseiki', increasing chilling up to 1,440 hours resulted in higher percentage of bud break and flower number per bud. Once sufficient chill hours have accumulated, application of dormancy breakers has no effect (Abreu *et al.* 2021).

A list of registered dormancy breaking agents available in Australia is provided in Table 1, however none of these chemicals have label recommendations for pear and growers need to be aware that off-label use of chemicals can lead to crop damage, compliance issues or damage to reputation.

Table 1: *Dormancy breaking products registered in Australia*

Trade name/s	Active constituent	Purpose	Crops registered for
Dormex®, Cyan™, Duomax®	Hydrogen cyanamide	Regulation of bud burst	Apples, grapes, kiwifruit plums, almonds, walnuts
Erger®	Decanol alkoxylate	Dormancy breaker	Fertiliser adjuvant with label recommendations for apples, cherries
Waiken™	Methyl esters of fatty acids	Initiation of dormancy break	Apples, cherries, grapes

3.2. Fruit set

Fruit set is the developmental stage that marks the transition of a flower (ovary) into a young fruit (BBCH scale 71, Martínez-Nicolás *et al.* 2016). The degree of fruit set can be calculated using the following formulae:

- *Number of fruit per 100 blossom clusters* = Number of fruit set / number of blossom clusters x 100
- *Fruit set (%)* = Number of fruit set / total number of blossoms x 100

Fruit set is dependent on pollen being transported from the anthers to the stigma (pollination), followed by pollen germination and growth of the pollen tubes through the pistil and finally, fertilisation of the ovules. Inability to complete any of these processes will prevent fruit set from occurring. The germination and growth rate of pollen are dictated by temperature (Colavita *et al.* 2020) and pollen does not germinate when temperatures are below 10°C (Yoneyama 1989). The stigma is only receptive to pollen for a short time period, and Williams (1965) reported that the stronger the flowers the longer they remain receptive, also noting that the ovules of strong flowers remained capable of fertilisation for almost twice as long as those of normal flowers. Thus, the effective pollination period (EPP) is limited by the period of stigma receptivity, the rate of pollen tube growth, and ovule longevity (Williams 1965; Sanzol & Herrero 2001). A good description on parameters determining the EPP, ie. stigmatic receptivity, pollen tube kinetics and ovule longevity, is provided by Sanzol & Herrero (2001). The EPP can be modified by temperature, flower quality and chemical application (Sanzol & Herrero 2001). Frequent rain and/or high humidity during the flowering period are not conducive to good fruit set (Jun & Hongsheng 2002).

Rohitha & Klinac (1994) list several factors that can influence pollination, fruit set and yield in apple and pear cultivars, including distance from the polliniser and pollen availability, plant nitrogen status, the presence of water on the stigmas, and the effective flowering period between compatible cultivars. Yoneyama (1989) also notes that pollen attachment is reduced when sigmas are dry, and advises that strong dry winds can prevent full expansion of Nashi flowers, leading to loss of viability.

3.3. Pollen compatibility

Most Nashi cultivars are self-incompatible, exhibiting typical gametophytic self-incompatibility (Saito 2016), so cross-pollination with another compatible cultivar is required for good fruit set. Gametophytic self-incompatibility is controlled by a single multi-allelic locus, the *S*-locus, so cross-compatible pollinisers are required that bear different S-haplotypes. Stable fruit set is given by cross-pollination with pollen bearing an S-haplotype different from either of the S-haplotypes of the pistil (Okada *et al.* 2008) however two cultivars with one overlapping S-loci (Figure 2) are semi-compatible (Zhang & Gu 2019).

According to Rohitha & Klinac (1990), 'Nijisseiki' and to a lesser extent 'Kosui' are partially self-compatible. Beutel (1998) has indicated that 'Nijisseiki' and 'Shinseiki' will set good crops when planted alone or in large single-cultivar blocks.

S-genotypes have been determined for a number of Nashi cultivars; the only self-compatible cultivar described so far is 'Osa-Nijisseiki', a mutant derived from 'Nijisseiki' (Halász & Hegedűs 2006). Table 2 shows the S-genotypes of the cultivars grown in Australia, and the Japanese recommendations for pollinators are shown in Table 3. In California the flowering period of the European cultivar 'Bartlett' ('Williams') also overlaps that of 'Chojuro', Nijisseiki' and 'Shinseiki' and is an effective pollinator for these cultivars (Johnson 1983). Johnson also notes that 'Packham's Triumph' could be a more effective pollinator of Nashi under Australian conditions, suggesting that the cross compatibility of both 'Packham's Triumph' and 'Beurre Bosc' be examined relative to the Nashi cultivars for which there are reasonable blossom overlaps.

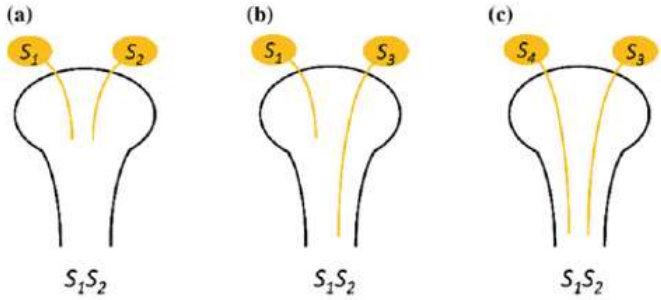

***Figure 2**: Self-incompatibility reactions: (a) cross-incompatible, (b) semi-compatible, and (c) cross-compatible (Source: Zhang & Gu 2019).*

***Table 2**: Incompatibility groups and S-genotypes of Nashi cultivars grown in Australia (adapted from Halász & Hegedűs 2006)*

Cultivar	Group	S-Genotype
Osa-Nijisseiki	Self-compatible	$S_2S_4^{sm}$
Nijisseiki	Group IV	S_2S_4
Shinseiki	Group V	S_3S_4
Hosui	Group VI	S_3S_5
Kosui / Shinsui	Group VII	S_4S_5
Chojuro	Unique genotype	S_2S_3

***Table 3**: Pollinator combinations recommended by MAFF Japan (Johnson 1983)*

Cultivar	Pollinators
Chojuro	Hosui, Shinko
Hakko	Chojuro, Shinko (not Shinsui)
Hosui	Chojuro, Shinko (not Niitaka)
Kikusui	Chojuro, Hosui, Kosui (not Nijisseiki)
Kosui	Hosui, Chojuro (not Shinsui)
Nijisseiki	Chojuro, Hosui and others
Niitaka	Shinko, Ya Li, Chojuro if blossom advanced
Osa-Nijisseiki	Not required
Shinko	Hosui, Chojuro if blossom advanced or pollen stored
Shinseiki	Chojuro, Hosui, Kosui
Shinsui	Chojuro, Shinko
Ya Li	Tsu Li, Chojuro if pollen stored

3.4. Seed number and fruit quality

There is a strong relationship between seed set and fruit shape and weight. Most pome fruit contain five carpels, but Nashi fruit can have between four and eight carpels, each carpel having the capacity to carry two seeds (Rohitha & Klinac 1990; Goodwin 2012). Several authors have reported a significant correlation in Nashi between the number of fully developed seeds per fruit and fruit weight at harvest (Yoneyama 1989; Rohitha & Klinac 1990; Beutel 1998). Rohitha & Klinac (1990) found that even seed distribution around the fruit core was related to fruit symmetry and, based on the levels of seed set observed in four cultivars, they concluded that considerable potential exists for raising the quality of Nashi fruit by optimising pollination and seed set. Perfect fruit shape is enhanced by fully pollinated flowers (Johnson 1983). Seed number also impacts on fruit sugar content; according to Yoneyama (1989), when more than six seeds are present, an extra seed can increase sugar content by 0.1-0.2 percent.

Development of fruits without fertilisation, or parthenocarpy, is common in pears (Colavita *et al.* 2020) but cross-pollinated fruit with seeds tend to be larger and more uniform in shape than parthenocarpic fruit or fruit with few seeds (Beutel 1998).

Pyrus species are pollinated by insects, but in Japan, cross-pollination is routinely carried out by hand, (Yoneyama 1989; Rohitha & Klinac 1992), while in many countries including Australia, cross-pollination is reliant on honey bees and other pollinating insects. The flowers produce nectar to attract pollinators, however the sugar content of pear nectar is low (10-15°Brix) compared to that in many other fruit tree species (Faoro & Orth 2011; 2015). In studies on bee flower visits in São Joaquim, Faoro & Orth (2015) reported that pollinating insects were only attracted to pear flowers by their pollen as nectar secretion was insignificant. Ruderal plants in the inter-row with high nectar sugar content, such as white clover and dandelion, attract more honey bees than pear tree flowers (Faoro & Orth 2015). Goodwin (2012) recommended that hives should have a high brood/bee ratio as pollen foragers are likely to be better pollinators than nectar foragers due to the low volume and low sugar content of the nectar.

Ambient temperatures have a strong impact on bee activity, with temperatures between 15° and 26°C being optimal for bee foraging activity (Silva 2001, cited in Faoro & Orth 2015), and a lack of activity below 10°C (Jackson 2005). Studies by Gallo *et al.* (2002, cited in Faoro & Orth 2015) demonstrated the positive relationship between honey bee activity and temperature, recording 14.5 flowers visited/minute at 23°C while at 14°C visits were reduced to 3.1 flowers/minute.

Faoro & Orth (2015) noted the necessity of installing large numbers of honey bee hives to ensure adequate pollination. In Australia, two to five hives per hectare are recommended for pollination, with eight hives per hectare common in New Zealand (Goodwin 2012).

In commercial pear orchards it has been suggested that the percentage of pollinisers in the orchard could be as high as 20% (Faoro & Orth 2011). According to Goodwin (2012), European pears will also successfully pollinate Nashi flowers if they are flowering at the same time.

3.5. Bud abortion

Floral bud disorders resulting in abortion and/or disintegration of buds when touched have been described by Kingston *et al.* (1990) and Trevisan *et al.* (2005). According to Kingston *et al.* (1990) the collective term for these disorders is *budjump* and the problem is widespread in New Zealand, with higher incidences reported in the growing regions of the North Island than in the South Island. Budjump has also been reported in Brazil in areas with insufficient chilling hours (Nakasu *et al.* 1995; Trevisan *et al.* 2005). Although there were no reports of this disorder in Japan or California prior to the 1990's (Kingston *et al.* 1990), erratic flowering and bud loss has been observed in Japan's warmer regions since 2009 (Ito *et al*. 2018).

The incidence of budjump has been reported to be more severe in cv. 'Hosui' than in 'Kosui', 'Shinsui', 'Nijisseiki', or 'Shinseiki' (Klinac & Geddes 1995). Higher levels of bud abortion were found when high temperatures were followed by a sudden temperature decrease (Nakasu *et al*. 1995), however these authors state that the physiological stage of the flower bud at which abortion occurs is unknown. Klinac & Geddes (1995) reported that bud loss was more prevalent on young trees and on young wood in older trees, with least bud loss at branch tips and on spur buds on older wood. Following studies examining

‘Kosui’ and ‘Niitaka’ at five locations over a six-year period, Ito *et al.* (2018) concluded that warmer autumn-winter temperatures may prevent the acquisition of freezing tolerance, disturb endodormancy progression and disrupt floral organ development, thereby causing flowering disorder. They found that risk of occurrence of flowering disorder and bud abortion was likely to be higher in high-chill cultivars than in low- or mid-chill cultivars and at lower latitudes compared with higher latitudes.

4. Commercial production of Nashi

In Japan, Nashi accounts for over 87% of the total planted area allocated to pears (Saito 2016), and the leading cultivars are ‘Kosui’, ‘Hosui’, ‘Nijisseiki’, ‘Niitaka’, ‘Akizuki’, ‘Nansui’, ‘Shinko’, and ‘Gold Nijisseiki’, a black spot resistant cultivar. Production in Argentina is centred in the Patagonia region and, while multiple cultivars were introduced, plantings have reduced to three cultivars – ‘Shinseiki’, ‘Nijisseiki’ and ‘Hosui’ (Benitez & Pensel 2004). In Brazil, the main cultivars are ‘Hosui’, ‘Kosui’ and ‘Nijisseiki’ (Faoro & Nakasu 2002). Commercially important cultivars in New Zealand include 'Shinsui', 'Kosui', 'Hosui' and 'Nijisseiki' (Buwalda *et al.* 1989). Klinac *et al.* (1995) also list ‘Shinseiki’ as one of the main cultivars for New Zealand. It is difficult to obtain production figures and area planted to Nashi, as most countries include European pears when reporting total pear production.

Nashi has been produced commercially in Australia for the fresh market for around 35 years, but the industry has remained small, with 877 tonnes produced in 2019/20 (production value of $3.1 million), down from 1,384 tonnes in 2018/19 and 2,370 tonnes in 2017/18 with production values of $4.2 and $7.0 million respectively (Australian Horticulture Statistics Handbook 2019-20). While there is some production in other states, depending on year, Victoria produces 80-90% of Australia’s Nashi crop.

There are several cultivars grown in Australia, but the main cultivar is the green smooth skin ‘Nijisseiki’, accounting for 80% of Nashi plantings. 'Nijisseiki' is extremely precocious, flowering profusely and setting heavily in all seasons; it also has a sensitive skin and is prone to russet. After finding that during the early stages of fruit development the number of leaves per unit branch length for 'Nijisseiki' was nearly twice that for other cultivars tested (average of 151 vs 84 per m respectively), Buwalda *et al.* (1989) suggested that the ability of 'Nijisseiki' to sustain very high fruit loads is probably related to high leaf density.

Following a study of Nashi production in Japan, Johnson (1983) recommended that, for successful production in Australia, research into effective thinning would be needed in order to ensure acceptable fruit size, noting that the large fruit size obtained in Japan was substantially a response to heavy crop thinning practices performed by hand. Australian growers report that while many Nashi cultivars grown in Australia have between 5-6 flowers per cluster, ‘Nijisseiki’ commonly sets 10-12, and at times up to 15, flowers per cluster, with only 2-3 producing good fruit shape.

5. Crop load management

Crop load management is one of the most important cultural practices in many perennial fruit tree crops that produce an excess of fruit. Optimal crop loads are normally achieved through removal of excess flowers and/or fruitlets from the tree (termed crop regulation or thinning), or by preventing flower initiation from occurring. Bound (2001) and Webster (2002) describe several methods by which this reduction in flowers/fruitlets can be accomplished:

1. hand thinning
2. application of plant bioregulators (PBRs) that either prevent fertilisation at flowering or result in abscission of flowers/fruitlets
3. shading (photosynthetic inhibition) of the tree

4. physical removal by use of mechanical devices
5. cultural practices such as pruning

The inverse relationship between vegetative growth and flowering is well recognised along with the importance of maintaining a balance between canopy volume and fruiting (Jones *et al.* 1998; Close & Bound 2017). A high level of photosynthate supply is required for developing fruit (Faust 1989, cited in Colavita *et al.* 2020). Thinning excess flowers/fruit helps to balance the fruit:shoot ratio, leading to an increase in assimilates for both reproductive and vegetative sinks (Costa *et al.* 2019), resulting in an increase in fruit size and improved fruit appearance and intrinsic quality, all of which lead to a higher crop value (Jones *et al.* 1998; Costa *et al.* 2019).

5.1. Rootstock and training system

Discussing the impact of rootstocks on yield efficiency and fruit size, Einhorn (2021) argues that rootstocks are "a critical factor affecting the precocity, efficiency and productivity of pear trees". The main rootstocks used for Nashi are seedlings of *P. betulaefolia, P. bretschneideri*, *P. calleryana*, *P. communis, P. pyrifolia (serotina)* and *P. ussuriensis* (Beutel 1998; Jun & Hongsheng 2002). As well as their effect on tree size/vigour, productivity, yield consistency and fruit quality, rootstocks differ in their effects on drought and cold resistance, and adaptability to different soils and climatic conditions.

One of the main rootstocks used in Australia is *P. calleryana* selection 'D6', which is reported by growers to have good vigour, particularly in lighter soils. In medium to high density plantings aimed at achieving high early production vigorous rootstocks can cause management problems due to overcrowding and shading (White *et al*. 1989), and as 'D6' is a vigorous rootstock it is less suitable for intensive plantings (Hankin 2015). The semi-dwarfing rootstocks 'BP1' (*P. communis* selection from South Africa) and 'BM 2000' (Australian origin, result of open-pollination of likely parents 'Williams' and 'Packham') are used in Western Australia, but growers have reported that 'Nijisseiki' does not perform well on these less vigorous rootstocks. 'Quince A' is also used in the Goulburn Valley on 'Pappel'; the calmer rootstock has been observed to give improved set but russet is increased. Johnson (1983) suggested that *P. pyrifolia* seedlings would be an appropriate choice but noted that a source of reasonably pure seed would be required to avoid variation resulting from hybridisation. In New Zealand rootstock trials, 'Hosui' scions grown on 'Quince A' with 'Buerre Hardy' interstem have been reported to be 60% smaller than 'Hosui' on more vigorous seedling stocks, and yield more fruit per unit canopy volume (White *et al*. 1989).

In a 10-year study of European pear cultivars on several rootstocks (D6, BP1, BM2000 and Quince A) in the Goulburn Valley, Hankin (2015) reported D6 was high yielding for all three scion cultivars examined but resulted in more limb extension growth and more water shoots in the tree - possibly resulting in more skin marks and lower pack-outs. The increased growth led to increased labour costs at pruning to control vigour. In terms of cumulative yield efficiency, Hankin (2015) concluded that the best rootstocks were BP1 for 'Packham', BM2000 and BP1 for 'Williams', and Quince A for 'Corella', but also noted that the rootstocks that performed well in terms of yield efficiency were quite different to those that performed well in terms of yield. This study highlights the importance of rootstock evaluation trials for Nashi cultivars that are widely grown in Australia.

Training system has been shown to have an impact on fruit size. Fruit size at any given crop load has been reported to be significantly higher for 'Hosui' trees on T-trellis than on Y-trellis, however for 'Shinsui', 'Kosui' and 'Nijisseiki', the training system did not significantly affect the relationship between fruit size and crop load (Buwalda *et al.* 1989).

5.2. Timing of crop load management

For fruit to reach its optimum potential an adequate supply of carbohydrates is required for the developing fruit. During flowering and fruit set in early spring, carbohydrates are supplied from tree reserves; once sufficient leaf area has developed assimilates produced by spur and extension leaves are translocated to the developing fruitlets (Webster 2002). Vegetative growth and roots compete with developing fruit for carbohydrates, so to avoid wastage of carbohydrate resources while maximising benefits in fruit size and quality, crop regulation practices should be undertaken early in the season before the completion of cell division (Jones *et al.* 1998); this ensures that tree resources are directed into fruit that will remain on the tree through to harvest rather than into fruit that will be thinned later in the season - the longer the delay in removal of excess flowers/fruit the greater the potential loss in fruit size and firmness.

Pears have three natural fruit drops (Colavita *et al.* 2020). The first drop of un-fertilised flowers occurs soon after petal fall and usually goes unnoticed. The second drop occurs 6–8 weeks after bloom and is often the largest, particularly in trees with heavy crop loads - this drop is known as 'June' drop in the northern hemisphere, or 'December' drop in the southern hemisphere; the third drop occurs preharvest (Bound 2021a). Trees with small crop loads tend to have a very small or no second drop (Bound 2001). The natural shedding that occurs in the first two drops is insufficient to achieve optimum crop loads, fruit size or quality, or to prevent biennial bearing (Bound 2001).

5.3. Economics of crop load management

The value of managing crop load is in attaining consistent production across the life of the orchard, protecting the tree from damage that may result from excessive crop loads, and optimising fruit size and quality (Bound 2021a). The optimum crop load for individual trees is related to tree size and structure, but cropping potential varies between cultivars. Local conditions, tree vigour, training, and nutrition also play a part in determining the optimum crop load (Yoneyama 1989). Excessive crop loads may produce high yields, but fruit size and quality (shape, sugar content, firmness) are compromised resulting in high reject rates and low returns to the grower; conversely if the crop load is too low yields can be reduced and excess vegetative growth occurs (Yoneyama 1989).

Jones *et al.* (1998) outline the risks involved in thinning, noting that under thinning can be more economically damaging than over thinning as it results in small poor quality fruit and biennial bearing in prone cultivars. In the majority of thinning research to date, the economic consequences have received little attention hence relatively little work has been done to identify optimal crop load targets following thinning or to compare distinct thinning treatments on an economic basis (Davis *et al.* 2004).

5.4. Crop load management of Nashi

Nashi set very heavily (Figure 3a) and require thinning to achieve large fruit size – thinning is normally done by hand. In Japan hand-thinning is undertaken from as early as 14 days and up to 40 days after petal fall when it is evident which fruitlets will abort and uneven shape is evident (Johnson 1983). According to Jackson and Palmer (2011), Nashi growers in Japan thin at 1.3 cm fruitlet diameter and again 6-8 weeks later, with the fruit in the centre of the cluster normally retained. Johnson (1983) also notes that fruit from the first few flowers opening in the cluster tend to be flat and fruit from the 3rd or 4th flowers are retained. Australian growers have advised that fruit in positions 2-5 are normally of acceptable shape, but the fruit from the first opening flower tends to be elongated (Figure 3b), while the later opening flowers produce smaller fruit.

Differences in fruit size are recognisable two weeks after pollination (Yoneyama 1989); while fruit thinning can commence as soon as non-fertilised flowers have dropped, 20-30 days after pollination is a more practical timing. To achieve adequate fruit size, 20-30 well developed leaves are required for each retained fruit (Johnson 1983). Yoneyama (1989) also stresses the importance of adequate leaf area, particularly in 'Nijisseiki' and 'Chojuro' which have high flower bud numbers. Based on observation in Japan, Jackson and Palmer (2011) suggested that for trees planted at 2 x 5 m spacing, about 250 fruit per tree should be left.

In apple and European pear, crop load is related back to number of blossom clusters or to tree size using the following two formulae:

- *Number fruit per 100 blossom clusters* = number of fruit / number of blossom clusters x100
- *Number fruit / cm^2 trunk cross-sectional area* (TCSA) = number of fruit / trunk area

However Australian Nashi growers measure crop load as *number fruit / m^2 canopy area*.

(a)  (b) 

***Figure 3**: (a) Typical fruit set in 'Nijisseiki' in Australia.* Photo credit: Steven Singh, Seeka Australia Pty Ltd*;*
(b) Elongated fruit shape from first opening flower in the cluster. Photo credit: Sally Bound, TIA

Current management methods in Australia to ensure optimum crop loading can include spur pruning, bud thinning, flower removal, post flowering hand thinning (normally done twice) and finally, early harvest of poor quality fruit. The thinning process starts during winter when trees are still dormant by removing poorly placed spurs and reducing buds back to 1-2 buds per spur, positioning the retained buds to optimise light and allow fruit to hang cleanly (Figure 4). This is normally followed by flower thinning within the clusters and then fruitlet thinning back to one or two fruit per cluster (Figure 5).

***Figure 4**: Bud thinning in Nashi.* Photo credit: Steven Singh, Seeka Australia Pty Ltd

***Figure 5**: 'Nijisseiki' cluster before (left) and after (right) thinning.* Photo credit: Steven Singh, Seeka Australia Pty Ltd

Yoneyama (1989) discusses bud thinning (disbudding) in the context of removal of unwanted buds and the elimination of water shoots, noting that bud thinning is important to avoid nutrients and resources being taken by unwanted buds. Accessory flower buds can also be a problem, these buds are formed more than a month after the main flowers in the cluster and open late, producing low quality fruit; in some cultivars such as 'Sansui' accessory flower buds can be 30-50% of total flower bud numbers (Yoneyama 1989).

Hand thinning of buds/flowers/fruitlets is labour intensive and according to Bound & Mitchell (2002b), in the 1990s these thinning methods were costing individual growers up to $ 5,000 (Australian) per ha and the industry approximately $1 million annually. Current cost estimates for thinning and budding are >$10,000 per ha, which is substantially higher than many other tree fruit industries. With budding and thinning the key cost drivers for Nashi production in Australia, the industry is looking for ways to reduce costs and thus improve viability of the Nashi industry to enable increased expansion.

6. Tools/techniques for managing crop load

There has been considerable worldwide research on crop load management in apples (*Malus domestica*), resulting in a range of recommendations in many countries. Available information for managing crop load in European pears (*Pyrus communis*) is increasing (Bound 2021a), but there is a lack of information available for Nashi.

Most Nashi cultivars require heavy thinning and this has traditionally been done by hand, a time and labour-intensive practice. There is potential to adapt some of the thinning tools and techniques used in other perennial fruit tree species, particularly the closely related apple and European pear, to reduce the labour requirements and high cost of thinning in Nashi. Valuable information on thinning in European pear can be found in the review by Bound (2021a) and the literature relating specifically to Nashi is summarised in the remainder of this paper with reference to other crops where applicable or where tools/techniques have not yet been examined in Nashi.

6.1. Hand-thinning

One of the most accurate methods of reducing excessive crop loads is hand-thinning of either flowers or fruitlets. In practice, flower thinning is difficult to achieve accurately as it is not known which flowers will set fruit, and if retained flowers have not been pollinated they will eventually abscise (Jones *et al.* 1998), so in apples and European pear hand-thinning is normally commenced later in the season once the danger of spring frosts is over and growers can see what has set on the trees (Jones *et al.* 1998; Webster 2002).

While hand-thinning of fruitlets can optimise fruit distribution on the tree, facilitating precision crop loading (Webster 2002), it is a high-cost strategy as noted previously. Because it is a labour-intensive practice it is also difficult for large commercial orchards to complete hand-thinning before the end of the cell division period and, as cell numbers within the fruit are determined prior to hand-thinning, limits have already been placed on fruit size (Jones *et al.* 1998; Webster 2002). While most studies on the impact of time of thinning on fruit weight have been conducted in apple, several European pear studies have also shown similar results. Meland (1998) reported that later thinning reduced fruit size and sugar content in five cultivars studied, while Schmidt (2020) recommended adjusting crop load of 'Bartlett' early in the season to avoid wasting of resources and to ultimately produce larger, better-quality fruit.

The relationship between fruit size during the growing season and size at harvest is well known, small fruit will never catch up in size to larger fruit (Williams *et al.* 1969; Jones *et al.* 1998), hence the basis for hand-thinning should be fruit size, rather than spacing. In Nashi the benefits of early thinning were noted by Burge *et al.* (1991) who reported a 17% increase in fruit size following flower thinning, but no increase in trees thinned 26 days after full bloom (dAFB). However, McArtney & Wells (1995) found that hand-thinning as late as 56 dAFB, leaving one fruitlet at each fruiting site, increased fruit weight of 'Nijisseiki' and 'Hosui' and increased return bloom in 'Hosui'.

Following blossom removal at the 1st and 2nd or 6th and 7th floral positions in 'Hanareum' and 'Niikata' five days before full bloom (dBFB), Lee *et al.* (2015) reported an increase in fruit weight ranging from 10 to 16% and improved fruit quality, leading them to recommend targeting of the 6th and 7th positions from the basal part of the flower cluster as a practical thinning method for these two cultivars.

Thinning cultivars 'Shinsui', Hosui', 'Kosui' and 'Nijisseiki' to a maximum of 1 or 3 fruit per cluster at two different times, Buwalda *et al*. (1989) reported a negative linear relationship between fruit weight at harvest and number of fruit retained. They also found a reduction in fruit weight following thinning around 60 days after 50% bloom compared to earlier thinning prior to 30 days after 50% bloom and suggested this was probably a result of dilution of limited resources amongst a larger number of fruit during late cell division and early cell-wall development. Identification of successful fruit set and hence desirable fruit shape is one of the limitations to early thinning so, in practice, thinning should be conducted straight after the first natural drop of non or poorly pollinated flowers (Buwalda *et al.* 1989).

***Table 4**: Summary of findings on the impact of hand-thinning of Nashi*

Level / timing	Cultivar	Impact	Reference
Thinned to 1 or 3 fruit/cluster on 28 Oct or 28 Nov Note: 50% bloom dates - Shinsui 29 Sept - Hosui 1 Oct - Nijisseiki 3 Oct - Kosui 5 Oct	Shinsui Kosui Hosui Nijisseiki	• Thinning to 1 fruit/cluster increased average fruit size • Greater fruit size increase with early thinning • Thinning increased yield of export fruit	Buwalda *et al.* 1989
Flower thin at FB or 26 dAFB	Hosui	• FB trt reduced crop load and increased fruit weight	Burge *et al.* 1991
56 dAFB to 1 fruitlet per cluster	Nijisseiki Hosui	• Increased fruit weight of both cultivars • Increased return bloom in Hosui	McArtney & Wells 1995
5 dBFB, targeting blossom at 1st & 2nd position (T1) or 6th & 7th position (T2) from basal part of flower cluster	Hanareum Niitaka	• Increased fruit weight of Hanareum by 10-11%, and Niitaka by 12.6% at T1 and 16.8% at T2 • Increased production of larger fruit in both cultivars • Higher soluble solids in both cultivars • Higher skin colour redness (a*) in Niikata	Lee *et al.* 2015

FB = full bloom; dAFb = days after full bloom; dBFB = days before full bloom

6.2. Chemical thinning

Chemical thinning is standard industry practice in the apple industry and is becoming more accepted for crop load management in European pears (Bound 2021a) but is rarely used for managing crop load in Nashi. Chemical thinning involves the application of caustic or synthetic hormonal PBRs during the bloom and/or post-bloom periods; this is normally followed up with hand-thinning after the December drop to optimise fruit numbers and remove damaged and misshapen fruit (Jones *et al.* 1998). Chemical thinning is extremely weather dependent and there are numerous other interacting factors affecting the degree of thinning, including rootstock, tree health, age, vigour, blossom density, pollination, choice of chemical and application method and conditions (Meland & Gjerde 1996; Jones *et al.* 1998). Hence optimal crop load management with chemicals can be difficult as responses to chemical thinning can be unpredictable. In both apples and European pears there is also considerable variation between cultivars in sensitivity to thinning chemicals (Menzies 1973; Jones *et al.* 1998; Bound 2001; Bonghi *et al.* 2002; Schmidt & Auvil 2011). Menzies (1973) also noted that under Australian conditions pears are more difficult to thin with chemicals than apples.

Thinning chemicals can be classified as either blossom (primary) or post-bloom (secondary) (Jones *et al.* 1998), and work in one of two ways:

- as *growth regulators* that mimic natural plant hormones, altering tree physiological processes, either through production of ethylene, stimulating seed abortion thus reducing the ability of fruitlets to compete for resources, inhibiting photosynthesis, or through other mechanisms (Jones *et al.* 1998; Bound 2001). Hormonal type thinning agents can either be blossom or fruitlet (post-bloom) thinners.
- as *blossom desiccants* (or blossom burners) – caustic chemicals that desiccate the style and stigma, thus preventing fertilisation. However, for some desiccants there may be additional modes of action: extra ethylene may be formed by the injured flower parts, and this may contribute to abscission (Wertheim 1973); a transient reduction in leaf area (and therefore availability of carbohydrates) may indirectly cause drop of very young fruit (McArtney 2006). In general, desiccants do not thin pollinated blossom where fruit set has been achieved prior to spray application. More than one application of a desiccant can be applied during the flowering period to target specific flowers (Bound 2019). The mode of action of desiccants makes them less dependent on weather conditions for their effectiveness than hormonal-type blossom thinners. However, under conditions of high humidity or when rewetting occurs soon after application, they can be re-activated, in some cases causing severe burning, damaging buds, fruit and leaves (Webster 2002).

Application time of chemical thinning agents is critical and depends on the mode of action, for example desiccants are only effective during flowering prior to fertilisation. Some chemicals are used world-wide, but there are differences between countries and growing regions on recommended application timing and concentrations (Bound 2021a); some of these differences are due to fundamental differences in climate and culture in the various growing regions while others are due to differing degrees of uptake of new research and technology. High re-registration costs have also played a role in deregistration of some thinning chemicals in many countries, while others have been de-registered in several counties due to their negative effects on the environment (Webster 2002).

A summary of chemical thinning agents used for pome fruit is provided in Table 5; however none of these chemicals are registered in Australia for use on Nashi and there is very limited research into their efficacy as thinners for Nashi. Growers need to be aware that off-label use of chemicals can lead to crop damage, compliance issues or damage to reputation.

Table 5: *Chemicals used worldwide for thinning of pome fruit (apple and pear). (Source: Bound 2021a).*

Generic name	Chemical name	Trade name (examples)	Type of thinner	Crop
ABA	abscisic acid	Protone	Post-bloom	Apple, pear
ATS	ammonium thiosulfate	Thin-It, Culminate, Biothin	Blossom	Apple, pear
Benzyladenine (BA)	N-(phenyl)-1H-purine 6-amine	MaxCel, Exilis, BAPSol, Abscission, Eurochem 6-BA	Post-bloom	Apple, pear
Carbaryl	1-naphthyl (N)-methyl carbamate	Bugmaster[1], Carbaryl 500SC, Carbaryl 800 WP, Sevin[1,2], Thinsec[3]	Post-bloom	Apple
DNOC*	4,6-dinitro-ortho-cresol	Elgetol[2]	Blossom	Apple, pear

Endothall	7, oxabicyclo (2,2,1) heptane-2-3 dicarboxylic acid	ThinRite[2]	Blossom	Apple
Ethephon	2-chloroethyl phosphonic acid	Ethrel[1], Ethin, Promote	Blossom	Apple, pear
Lime sulfur (LS)	polysulfide sulfur		Blossom	Apple, pear
Metamitron	4-Amino-4,5-dihydro-3-methyl-6-phenyl-1,2,4-triazin-5-one	Brevis	Post-bloom	Apple
NAA	1-naphthalene acetic acid	NAA[1], NAA20, NAA Stop Drop[1], Rhodofix	Blossom	Apple, pear
NAD/NAAm	1-naphthalene acetamide	Amid-thin	Blossom, post-bloom	Apple, pear
Pelargonic acid	nonanoic acid	Thinex[2]	Blossom	Apple
Sulfcarbamide	1-aminomethanamide di-hydrogen tetraoxosulphate	Wilthin[2]	Blossom	Apple
Thiram	bis (dimethyl thio-carbomoyl) disulphide	TMTD	Post-bloom in conjunction with carbaryl	Apple

[1] Australia; [2] USA; [3] Europe, * not available since 1989

6.2.1. Ammonium thiosulphate

The desiccating chemical ammonium thiosulphate (ATS) has been successfully used to reduce crop load in both apple and European pear (Bound 1998; Bound & Mitchell 2002a). Trials in the Goulburn Valley in Victoria over a two-year period showed that ATS was also effective as a blossom thinner of the Nashi cultivar ‘Nijisseiki’ (Bound & Mitchell 2002b); this study demonstrated that, while applying ATS (768 g/L ammonium thiosulphate) at 20% bloom had some thinning effect, application of 2% ATS at either 50% or 80% bloom produced the most consistent thinning across the two crop load variables measured, number of fruit per cm^2 trunk TCSA and number of fruit per 100 blossom clusters. Fruit size was improved by 1.0, 1.5 and 2.0% applications at 50 or 80% bloom. This contrasts somewhat with the findings of Bound & Mitchell (2002a) who reported that 80% bloom application of ATS was too late for effective thinning on the European pear cultivar ‘Packham's Triumph’.

When applying blossom desiccants, application time is critical as desiccants work by desiccating the style and stigma of the flower, thus preventing pollination or growth of the pollen tube (Bound & Jones 2004b). In apples the early opening flowers produce the largest fruit, so these are allowed to set fruit and ATS is applied from 20% bloom with the aim of removing the remaining flowers; often two or three applications are made depending on the length of the flowering period (Bound 1998). However, as the current recommendation for Nashi is to target the 3rd to 5th flowers in the cluster a different approach to timing is required for effective thinning of Nashi.

Leaf burning in ‘Nijisseiki’ was observed by Bound & Mitchell (2002b) at application rates of 2.O% ATS, however the level of damage had no effect on fruit size. In the European pear cultivar 'Packham's Triumph', Bound & Mitchell (2002a) found that concentrations of 1.0 to l.5% prevented fruit set without causing unacceptable phytotoxicity. The efficacy and phytotoxicity of ATS are dependent on temperature, humidity and cultivar (Dussi 2011). Bound & Mitchell (2002b) suggested that the use of multiple applications during the flowering period may result in better thinning at lower chemical rates – however this has not been examined in Nashi.

Table 6*: Summary of findings on the impact of ammonium thiosulphate (ATS) as a chemical thinning agent for Nashi*

Application rate and time	Cultivar	Impact	Reference
0.8%, 1.0%, 1.5% or 2.0% applied at 20, 50 or 80% bloom	Nijisseiki	• Some thinning at 20% bloom, but 2% at 50 or 80% bloom most consistent • Fruit size improved by the 1.0, 1.5, or 2.0% application rates at 50 and 80% bloom	Bound & Mitchell 2002b

6.2.2. Lime sulphur

Although not registered for thinning of pome fruit, lime sulphur (LS) is commonly used by organic apple growers as a blossom thinner (Bound 2020) as it has a desiccating effect, thus preventing fertilisation from occurring.

In Norwegian studies on the European pear cultivars ‘Amanlis’ and ‘Moltke’, Meland & Gjerde (1996) reported that full bloom application of 5% LS thinned adequately, and Garriz *et al.* (2004) concluded that 7% LS applied at 30% bloom was an effective practice for thinning and enhancing fruit quality in ‘Abbé Fetel’ pears in Argentina, However in studies on ‘Williams’ pears in Argentina and the USA, Dussi *et al.* (2008) reported that 10% LS and 80% sulphur applied at 80% full bloom had little effect on reducing fruit set. Lime sulphur has also been reported to affect photosynthesis, with an additive effect following multiple sprays reducing photosynthetic rate up to 50% (McArtney 2006).

6.2.3. Ethephon

Ethephon (2-chloroethyl phosphonic acid) has been successfully used in apples as a chemical thinner for several decades (Jones *et al.* 1998), acting by artificially raising ethylene levels, resulting in flower/fruitlet abscission. As it thins over a long period, it has been successfully applied as both a blossom and post-bloom thinning agent (Wertheim 1973; Jones *et al.* 1998). Multiple studies on the use of ethephon at both flowering and post-bloom have yielded variable results for thinning European pear cultivars. Most of these reported studies are described by Bound (2021a) who suggested that the inconsistency in results observed between the multiple studies may be the result of a range of individual and interacting factors, including application method and chemical coverage, differences between cultivars in ethephon sensitivity, tree vigour and blossom density. It was also noted that weather conditions, not only at the time of application, but also before and after, can impact on the degree of absorption.

In New Zealand trials on Nashi, application of 600 mg/L ethephon 9 days before full bloom (dBFB) has been shown to reduce fruit set in ‘Hosui’, but 300 mg/L had no thinning effect (Burge *et al.* 1991). These authors also report that Kim *et al.* (1988) found a greater thinning response to ethephon applied 14 and 21 dAFB than at FB or 7 dAFB on 'Chojuro'. Working with ‘Nijisseiki’ and ‘Hosui’, McArtney & Wells (1995) found that 400 mg/L ethephon applied 15 dAFB reduced fruit set of 'Nijisseiki' by 37% and 'Hosui' by 15%, with an average of one 'Nijisseiki' fruitlet per cluster being removed. In follow up work examining a range of concentrations from 0 to 800 mg/L, fruit set was reduced in proportion to concentration, with a 62% reduction at 800 mg/L. Reginato & Rojas (1998) reported that FB application of 100 and 200 mg/L ethephon had a good thinning effect on the cultivar ‘Hosui’, but 400 mg/L over thinned. Discussing their results in the context of other studies, McArtney & Wells (1995) noted that Hong *et al.* (1988) reported effective thinning of 'Shinsui' and 'Hosui’ with ethephon applied between 200 and 400 mg/L at 15 dAFB, while higher concentrations caused excessive thinning; they also noted that Kim *et al.* (1988) observed overthinning of 'Kosui' and 'Okusankichi' with 400 mg/L ethephon applied 14 dAFB while two other cultivars were thinned efficiently. In an initial study with ethephon on ‘Shinko’ and ‘Hosui’, Prunty & Marini (2000) reported that application of 678 mg/L at 9 mm fruitlet diameter resulted in a 70% reduction in fruit set; a follow up study on ‘Shinko’ the following year found a linear decline in fruit set per 100 blossom clusters with increasing ethephon concentration from 0-678 mg/L; however, a confounding factor in this study is that all treatments contained carbaryl and superior oil. In ‘Hosui’ grafted on *P. betulaefolia* rootstock, the maximum ethephon response was reached at 200 mg/L with no further increase at higher concentrations (Reginato & Rojas 1998).

McArtney & Wells (1995) reported that ethephon reduced mean fruit weight of 'Hosui' at harvest by 34 g (21%), but 'Nijisseiki' was unaffected. Examining a range of concentrations in a second study on ‘Nijisseiki’, McArtney & Wells (1995) found reduced fruit weight with increasing ethephon concentration. Kim *et al.* (1988, cited in Burge *et al.* 1991) also observed reduced fruit growth and size when examining the thinning effect of ethephon in the cultivar 'Chojuro'; a similar effect was observed on 'Hosui' in Chile by Reginato & Rojas (1998), who concluded that ethephon could inhibit fruit growth. In a New Zealand study with 'Hosui', Burge *et al.* (1991) found that application of 300 or 600 mg/L ethephon 9 dBFB reduced crop load but there was no effect on mean fruit weight.

A reduction in flesh firmness was observed in 'Nijisseiki' with increasing ethephon concentration, but fruit soluble solids content and seed number increased (McArtney & Wells 1995); an increase in the incidence of the fruit disorder flesh spot decay after 12 weeks storage in proportion to the ethephon concentration was also observed. A fruit flattening effect was observed by Reginato & Rojas (1998) in 'Hosui' following FB application of ethephon. A 480% increase in calyx disorder following ethephon applications of 600 mg/L was observed in 'Hosui' by Burge *et al.* (1991). McArtney & Wells (1995) reported differing effects of ethephon on return bloom between cultivars, with increased return bloom of 'Nijisseiki' but not 'Hosui'.

***Table 7**: Summary of findings on the impact of ethephon as a chemical thinning agent for Nashi*

Application rate and time	Cultivar	Impact	Reference
400 mg/L at 15 dAFB	Nijisseiki	Reduced fruit set by 37% Increased return bloom Increased incidence & severity of flesh spot decay after 12 weeks storage at 2°C	McArtney & Wells 1995
400 mg/L at 15 dAFB	Hosui	• Reduced fruit set by 15% • Reduced fruit weight by 34 g (21%)	McArtney & Wells 1995
200, 400, 600, or 800 mg/L	Nijisseiki	• Fruit set reduced in proportion to concentration, with 62% reduction at 800 mg/L • Fruit weight and flesh firmness reduced with increasing concentration • Fruit soluble solids and seed number increased with increasing concentration • Increased incidence & severity of flesh spot decay with increasing concentration • Increased return bloom • Area of individual spur leaves increased by 600 & 800 mg/L • Specific leaf weight increased	McArtney & Wells 1995
100, 200,400 mg/L at FB	Hosui	• Thinning effect proportional to concentration • Fruit weight increased with greater thinning • Reduction in yield efficiency at 400 mg/L • Fruit flattening effect	Reginato & Rojas 1998
300, 600 mg/L applied 9 dBFB	Hosui	• Reduced fruit set • Inhibited fruit growth • High rate (600mg/L) increased calyx disorder	Burge *et al.* 1991
678 mg/L at 9 mm fruitlet diameter. Superior oil added	Hosui Shinko	• Reduced fruit set by 70%	Prunty & Marini 2000
0-678 mg/L at 9 mm fruitlet diameter. *Note all treatments included carbaryl & superior oil*	Shinko	• Fruit set declined linearly with increasing concentration	Prunty & Marini 2000

dAFB = days after full bloom; FB = full bloom dBFB = days before full bloom

6.2.4. NAA

Naphthalene acetic acid (NAA) and its less potent form naphthalene acetamide (NAAm/NAD) are commonly used for thinning in apple, and it is recommended as a blossom spray, preferably at FB but no later than 7 dAFB in Australia as application later than 7 dAFB has been associated with pygmy fruit production (Jones *et al.* 1998). However, in many countries NAA and NAAm are used as post-bloom thinners, being applied at petal fall or later (Wertheim 2000; Costa 2017). According to Webster (2002), NAA causes a temporary check in tree growth which can depress fruit size. Studies with both NAA and NAAm in European pear have produced variable results (Bound 2021a).

In studies on the cv. 'Nijisseiki', McArtney & Wells (1995) reported no effect on fruit set or weight following application of 7.5 mg/L NAA at 15 dAFB, but did observe a reduction in fruit flesh firmness. No thinning effect was observed in 'Hosui' by Burge *et al.* (1991) following application of 7.5 and 15 mg/L at 14 dAFB, and Prunty & Marini (2000) also observed a lack of thinning effect with 8 mg/L NAA applied at 9 mm fruitlet diameter to the cultivars 'Hosui' and 'Shinko'.

In Chile, Reginato & Rojas (1998) applied NAA to 'Hosui' at three concentrations (5, 10, 20 mg/L) and three application times (balloon stage, petal fall (PF), 10 days after petal fall (dAPF)) and reported that the effect of NAA in reducing fruit set was proportional to concentration; a greater thinning effect was observed with the earlier applications. Fruit weight in this study was dependent on fruit load after final fruit set.

***Table 8**: Summary of findings on the impact of NAA as a chemical thinning agent for Nashi*

Application rate and time	Cultivar	Impact	Reference
7.5 mg/L at 15 dAFB	Nijisseiki	• No effect on fruit set or weight • Flesh firmness reduced	McArtney & Wells 1995
5, 10, 20 mg/L at balloon stage, petal fall, 10 dAPF	Hosui	• Greater effect at earlier application times • Thinning effect proportional to concentration	Reginato & Rojas 1998
7.5, 15 mg/L applied at 14 dAFB	Hosui	• Delayed abscission but no thinning effect • Increased calyx disorder	Burge *et al.* 1991
8 mg/L at 9 mm fruitlet diameter	Hosui Shinko	• Not effective	Prunty & Marini 2000

dAFB = days after full bloom; dAPF = days after petal fall

6.2.5. 6-benzyladenine

The synthetic cytokinin 6-benzyladenine (BA) [N-(phenylmethyl)-1H-purine-6-amine] is an effective post-bloom thinner for apples (Bound *et al.* 1991; 1993) and its efficacy as a post-bloom thinner for European pears has also been demonstrated (Bound 2021a).

In a preliminary study of BA on 'Nijisseiki' in the late 1990s at Ardmona in Victoria, Bound & Mitchell (unpublished) examined a range of concentrations (50, 75, 100, 125, 150, 175, 200 mg/L) and application times (5, 8, 11, 14, 17, 20, 23, 26 dAFB) but observed no thinning effects and concluded that the lack of response may have been due to low blossom density in the trial trees (average of 1.52 blossom clusters per cm^2 TCSA), as trees with more intense bloom are easier to thin because of increased competition for resources and thus increased stress (Ward *et al.* 2013).

In contrast to the results observed in the preliminary study described above, Ward *et al.* (2013) noted that BA delivers yields and fruit sizes comparable to hand-thinning and is now used by many Nashi growers in the US state of New Jersey. Ward *et al.* (2013) reported that 200-250 mg/L was effective in reducing fruit set and crop load as well as the amount of follow-up hand-thinning across multiple cultivars studied - the cost of hand-thinning was reduced by up to 50%, saving growers up to US $2,000 per acre.

Time of application for BA is based on fruit size. In apple the recommended size is 7-10 mm diameter of the king fruitlets (Bound *et al.* 1997; Sumitomo chemical 2017) which normally occurs 10-25 dAFB; Ward *et al.* (2013) recommended a fruit size of approximately one-half-inch (12.5 mm) for Nashi but noted that in practical terms, fruit size should be one-third to two-thirds of an inch in diameter (9-16 mm). Temperature is also critical to ensure the efficacy of BA (Bound *et al.* 1997). The recommendation provided by Ward *et al.* (2013) for applying BA to Nashi in the US state of New Jersey is temperatures in the range of 72–82°F (22-28°C) but Bound *et al.* (1997) noted that temperatures needed to be in excess of 15°C on the day of application for efficacy on apple. The Australian label recommendation is predicted daily maximum of greater than 15°C with application on a warming trend (Bound 2020). Ward *et al.* (2013) warn that applying BA at temperatures above 85°F (30°C) can result in over-thinning.

The Canadian label (Table 9) notes that application should be made in the morning or evening when conditions are best for slow drying (cooler temperatures and higher humidity) in order to ensure adequate absorption of the product. Ward *et al.* (2013) note that efficacy of BA varies with environmental conditions following application, indicating that the amount of thinning increases during the three to five days after application when there is less sun and higher temperatures, particularly at night.

There are slight differences in label recommendations across countries – these differences are summarised in Table 9 below.

Table 9: *Label recommendations for 6-benzyladenine (BA) as a post-bloom thinner in pome fruit*

Country	Source	Concentration	Fruitlet size
Australia - apple	https://sumitomo-chem.com.au/sites/default/files/sds-label/maxcel_0217.pdf	150 mg/L (9 L/ha in 1200 L/ha water	7-10mm (10-25 dAFB)
Canada - pear	https://cdn.nufarm.com/wp-content/uploads/sites/16/2017/08/09104809/MaxCel_28851_E_SEP2017.pdf	50-200 mg/L	8-14 mm
South Africa - pear	https://www.philagro.co.za/wp-content/uploads/2013/08/Maxcel_LABEL.pdf	750ml/100L	8-12 mm
US – apple & pear	https://s3-us-west-1.amazonaws.com/agrian-cg-fs1-production/pdfs/MaxCelr1c_Plant_Growth_Regulator_Label.pdf	75-200 mg/L	5-15 mm (10 mm optimal)

Table 10: *Summary of findings on the impact of 6-benzyladenine (BA) as a chemical thinning agent for Nashi*

Application rate and time	Cultivar	Impact	Reference
84 mg/L at 9 mm fruitlet diameter	Hosui Shinko	Reduced fruit set by 40%	Prunty & Marini 2000
0-105 mg/L at 9 mm fruitlet diameter. Note all treatments included Carbaryl and superior oil	Hosui Shinko	Shinko - fruit set declined linearly with increasing concentration Hosui – no effect	Prunty & Marini 2000
0, 200 or 250 mg/L at 12 mm fruitlet diameter	Hosui Kosui	200-250 mg/L reduced fruit set, crop load and amount of follow-up hand-thinning Fruit size and yield comparable to hand-thinning	Ward *et al.* 2009
0, 50, 100, 150, 200 or 250 mg/L at 12 mm fruitlet diameter	Hosui Shinko Yoinashi	Significant thinning obtained only in Yoinashi at 250 mg/L Note that crop load was relatively low in all cultivars	Ward *et al.* 2009
50, 75, 100, 125, 150, 175, 200 mg/L at 5, 8, 11, 14, 17, 20, 23, 26 dAFB	Nijisseiki	No thinning effect, possibly due to low blossom density	Bound & Mitchell (unpublished)

dAFB = days after full bloom

6.2.6. Carbaryl

The carbamate insecticide carbaryl (1-naphthyl (N)-methyl carbamate) is successfully used as a fruitlet thinner in apple but is not effective in European pear (Menzies 1973; Jones *et al.* 1998; Webster 2002). Studies by Burge *et al.* (1991) and Prunty & Marini (2000) have also found that it is ineffective as a thinner of Nashi.

Carbaryl is a persistent pesticide that is toxic to bees and mammals (Tomlin 1994) and has been found in groundwater (Bound & Jones 2004b), making it an undesirable chemical for further study. It has now been withdrawn from use in many European countries (Webster 2002).

Table 11: *Summary of findings on the impact of carbaryl as a chemical thinning agent for Nashi*

Application rate and time	Cultivar	Impact	Reference
0.4 or 0.8 mg/L 15 dAFB 0.4 mg/L 24 dAFB Wetter Agral LN added to all treatments at 1 ml/L	Hosui	Not effective	Burge *et al.* 1991
9 mm fruitlet diameter	Hosui Shinko	Not effective	Prunty & Marini 2000 [abstract]

dAFB = days after full bloom

6.2.7. Abscisic acid (ABA)

Abscisic acid (ABA) is a naturally occurring plant hormone that is involved in the regulation of stomatal opening and closing, enabling plants to lower water loss by closing stomata when exposed to stressful conditions (Blanchard *et al*. 2007). Stomatal closure results in a decline in leaf photosynthesis (Cornic 2000), inducing carbohydrate stress (Einhorn 2020) which can lead to fruit abscission, hence ABA has potential as a chemical thinning agent.

Several studies have been undertaken with ABA in European pear cultivars. Greene (2012) demonstrated a quadratic dose response in 'Bartlett' pear from 50-500 mg/L applied at 10 mm fruitlet diameter, with 250 mg/L producing the same response as 500 mg/L, and while significant thinning was observed at bloom, PF and 10 mm fruitlet diameter, effectiveness increased at the later development stages. Other authors have reported inconsistent results between regions and years (Arrington *et al.* 2017; Theron *et al.* 2018). Arrington *et al.* (2017) reported that within one day of ABA application net photosynthesis (Pn) of leaves was reduced 75-90% but gradually returned to 80% of control levels within 7 days, fully recovering by 14 days. This supports the conclusion of Greene (2012) that ABA has the potential to influence the carbohydrate status within a plant by closing stomates, thus reducing photosynthesis during the time the stomates are closed.

There are conflicting reports on the impact of ABA on fruit weight and other quality parameters: Greene (2012) reported increased fruit weight, flesh firmness and soluble solids in 'Bartlett', while Arrington *et al.* (2017) found that weight was increased but fruit firmness, total soluble solids (TSS) content and titratable acidity were unaffected; Cline *et al.* (2018) reported some improvement in fruit size of 'Cold Snap™', and 'Bosc' but observed a decrease in yield and crop value.

Leaf yellowing, sometimes coupled with defoliation, has been reported by some authors following application of ABA at rates of 250-500 mg/L (Greene 2012; Arrington *et al.* 2017; Cline *et al.* 2018), but Fernandes (2020) saw no negative effects on leaves or fruit following application of 300 mg/L ABA.

A potential interaction between ABA and environmental factors was suggested by Arrington *et al.* (2017), with rewetting and cloudy conditions in the days following application potentially contributing to phytotoxic effects by enhancing ABA uptake. As the degree of sensitivity to chemicals differs between cultivars, cultivar may also influence the response to ABA.

6.2.8. Metamitron

The triazinone herbicide metamitron is a relatively new post-bloom thinner used on apple, and more recently pear has been added to the label (Brevis®, 150 g/kg metamitron). The mode of action is described by Elsysy *et al.* (2020) as temporarily inhibiting photosynthesis through PSII inhibition via electron transport blockage, which reduces maximum potential quantum efficiency of PSII (Fv/Fm). In apple, observing a negative linear response between metamitron concentration and fruit set, McArtney *et al.* (2012) found that Fv/Fm declined two days after foliar application and remained suppressed for up to 11 days after treatment. Elsysy *et al.* (2020) reported that photosynthesis was inhibited for a duration of two to three weeks, although longer persistence was observed in two trials.

Several authors have reported thinning effects on European pear following application of metamitron as a post-bloom spray. Increased thinning across three trial sites was observed by Maas & van der Steeg (2011) with increasing concentration from 175-700 mg/L applied at 10-12 mm fruitlet stage; desirable levels of thinning were also observed with single or repeated applications of 175 to 350 mg/L metamitron at 8-12 mm fruitlet diameter. A linear reduction in photosynthesis and fruit set with increasing metamitron rate (150 - 600 mg/L) was reported by Elsysy *et al.* (2020) in cv. 'Bartlett'. Different responses reported across different trials may be due to cultivar and climatic differences (Elsysy *et al.* 2020).

The thinning efficacy of metamitron is influenced by time of application. In studies on cv. 'Bartlett' application at ~7 mm had little effect on fruit abscission while significant thinning was observed between 10-13 mm fruitlet stage (Elsysy *et al.* 2020). Maas & van der Steeg (2011) also found that metamitron was more effective when applied at 10-12 mm fruitlet diameter than at 6-8 mm. At the smaller fruitlet size, leaf expansion is only just beginning so there is minimal leaf area for chemical absorption (Elsysy *et al.* 2020), hence there is insufficient uptake of metamitron to induce a response.

Well-pollinated trees require higher doses of metamitron than trees in orchards without pollinators (Maas & van der Steeg 2011). Maas & van der Steeg, (2011) suggested the sink activity of the fruit for assimilates is enhanced by the presence of seeds, making it more difficult to promote their abscission by the inhibition of photosynthesis; Yuda *et al.* (1984) noted that fruit without seeds are more prone to abscise than fruit with seeds because of growth regulators produced by the seeds.

The proposal by Botton *et al.* (2011) that activation of the fruit abscission zone is triggered by a critical threshold level of carbohydrates within the fruit cortex led McArtney *et al.* (2012) to suggest that the efficacy of metamitron as a fruit thinner will be dependent on a number of factors, including tree carbohydrate balance at the time of application, daily level of carbon assimilation, and allocation of assimilated carbohydrates between competing sinks such as shoots, fruit, and respiration. This assumption can be applied to all chemical thinners, particularly those with an hormonal effect.

6.2.9. Potential new chemical thinning technologies

Multiple substances have been assessed as potential chemical thinning agents for pome fruit but very few have produced consistent results with minimal or no phytotoxicity (Webster 2002; Schmidt *et al.* 2011; Costa *et al.* 2019). Other chemicals, such as acetic acid, have shown good efficacy but have not been commercialised due to lack of proprietary exclusivity and cost of new chemical development (Kon & Schupp 2019). Several chemicals that have shown potential but require further development are discussed below.

5-Aminolevulinic acid

The efficacy of the natural amino acid 5-Aminolevulinic acid (ALA) as a pear thinner has been demonstrated by An *et al.* (2016). ALA is present in living cells of microbes, plants and animals (Akram & Ashraf 2013; Chen *et al.* 2020), acting as an essential biosynthetic precursor of all organic heterocyclic tetrapyrrole molecules, including chlorophyll, heme and vitamin B12 (Akram & Ashraf 2013).

The mechanism by which ALA thins is inhibition of pollen germination and tube growth via Ca2+ efflux by activating Ca2+ -ATPase (An *et al.* 2016), thus preventing fertilisation. Following several studies An *et al.* (2016) recommended that application of 100 mg/L ALA at 50-75% bloom was most effective for thinning pear. As a non-toxic biodegradable amino acid present in living cells, ALA has considerable potential as a chemical thinning agent as it is likely to meet modern environmental and food quality guidelines.

1-aminocyclopropane-1-carboxylic acid

The precursor to ethylene metabolism, 1-aminocyclopropane-1-carboxylic acid (ACC) has shown some promising results as a potential chemical thinning agent for apple and peach (Cline *et al.* 2018; Costa *et al.* 2019). Studies with ACC on European pear have also been positive: Theron *et al.* (2018) reported that application of 300 mg/L at 8-10 mm fruitlet diameter resulted in a 50% reduction in crop load and an increase in fruit weight in cv. 'Forelle', while Cline *et al.* (2018) found that the same rate of 300 mg/L markedly reduced the crop load of cv. 'Bosc' in two out of three years, but observed no thinning effect for cv. 'Cold Snap™'. Costa *et al.* (2019) suggested that the physiological mechanism of ACC action deserves further investigation, and recommended further studies to optimize ACC concentrations, times of application, and possible interactions with other thinning agents, such as ABA and metamitron.

The United States Environmental Protection Agency (EPA) has granted an exemption from the requirement of a tolerance for residues of ACC in or on apples and stone fruit when used in accordance with good agricultural practices, effective 28 June 2021.

Polysorbates

Studies with polysorbates 20, 60 and 80 [E432, polyoxyethylene (20) sorbitan monolaurate, Tween 20; E435, polyoxyethylene (20) sorbitan monostearate; and E433, polyoxyethylene (20) sorbitan monooleate, Tween 80 respectively] on apple have demonstrated that they have potential as post-bloom thinning agents; these substances are emulsifiers used in the food industry as additives and are classified as GRAS (generally recognized as safe) components.

Undertaking a range of studies over several years on four apple cultivars, Stopar & Hladnik (2021) found a weak thinning effect with 5 ml/L polysorbates when applied at PF and 9 mm fruitlet diameter but adding a third application at 14 mm diameter caused a significant cumulative thinning effect, with most of the thinning attributed to the last application. Further work showed that double applications at 12 and 18, or 18 and 20 mm fruitlet diameter resulted in a significant thinning effect. They did however find a russeting effect on one cultivar, 'Golden Delicious'. They concluded that these polysorbates were efficient thinning agents for all cultivars when applied twice in a later thinning window of fruitlet diameter above 9 mm, and noted that with some additional research effective polysorbate thinning programs could be developed for cultivars that are not too sensitive to fruit russet.

Potassium bicarbonate and calcium polysulphide

Potassium bicarbonate ($KHCO_3$) was included in studies by Stopar & Hladnik (2021) on a range of apple cultivars. They reported that double application of 8, 12 or 15 g/L at first flower and FB thinned 'Gala' and 'Elstar' apple effectively but increased russet in 'Gala'

A FB application of 19 g/L calcium polysulphide (CaS_x) on the apple cv. 'Elstar' was found to be as effective as 15 g/L $KHCO_3$ and 10 g/L ATS (Stopar & Hladnik 2021). However further studies of these substances are required to confirm their efficacy and impact on fruit skin finish and other quality parameters.

6.2.10. Opportunities for chemical thinning in Nashi

The use of PBRs as a thinning tool should be considered as part of a larger portfolio of options that are integrated into a whole sustainable, systematic program approach for controlling vigour and improving cropping (Costa 2017). The action of chemical thinning agents is related to cultivar, physiological state of the tree and the intensity of blossom, but meteorological conditions at application also play a major role. Following application of chemical thinning agents, a higher level of fruit abscission is observed with weather conditions that favour high carbohydrate demand but low supply (ie. when trees are in carbon deficit), in particular low light levels and elevated temperature after treatment (Fallahi & Greene 2010; Dussi 2011). Knowledge of these factors/conditions affecting the tree carbon balance can be used to optimise thinning outcomes (Table 12).

Table 12*. Factors affecting tree carbon balance during fruit development.*

	High carbon supply (hard to thin)	**Low carbon supply (easy to thin)**
Water availability	Adequate water supply	Water stress resulting in tree shutdown
Vegetative growth	Low vegetative growth	Vigorous growth competing for C
Canopy development	Full canopy, leaves attained full photosynthetic potential	Leaves still developing
Crop load	Low crop load – high leaf:fruit ratio	High crop load– reduced leaf:fruit ratio
Solar radiation	Clear sunny days – increased light interception increases photosynthesis	Overcast conditions - low light interception reduces photosynthesis
Day Temperature	Cool: fruit growth slowed so C demand reduced	Hot: encourages stomatal closure, reducing photosynthesis
Night temperature	Low temperatures reduce respiration	High temperatures increase respiration thus increasing C demand

Sources: Jones *et al.* (1998); Lakso (2011); Fischer *et al.* (2012); Darbyshire *et al.* (2018)

Chemical thinning is not without risk (Jones *et al.* 1998), but these risks can be mitigated by use of a structured approach (Jones *et al.* 1998; Bound 2019), commencing a thinning program early at flowering and using a sequential spray program with both blossom and post-bloom thinners. It should be remembered that pruning (including bud thinning) is the first stage of any thinning program.

There are several chemical thinners registered in Australia for apple and stonefruit (Table 13), however none of these are registered for use in Nashi and the cost of registration is high and may not be feasible for a minor crop. While showing good efficacy, chemicals that do not have proprietary exclusivity, such as acetic acid, are also difficult to commercialise due to the cost of new chemical development (Kon & Schupp 2019). As some chemicals are registered for pears in Europe and the USA, it may be relatively straight forward to have pears added to the Australian labels but this will require negotiation with the product manufacturers and most likely trials to produce efficacy data.

Table 13. *Recommended concentrations and application times for available chemical thinning agents in Australia for pome- and stone-fruit. (Sourced from Bound 2020)*

Chemical	**Concentration**	**Time of application**	**Disadvantages**
Armothin	2L/100L water	90–100% bloom (stonefruit)	• Can be phytotoxic to leaves
Ammonium thiosulphate (ATS)	0.75–1.5% v/v	20% & 80% bloom (apple) 80–100% bloom (plum, peach)	• Can cause russet • Timing critical
Benzyladenine (BA)	150 mg/L applied as a fine mist (9 L/ha in 1200 L/ha)	Fuji & Gala 15–22 dAFB red Delicious 10–20 dAFB Golden Delicious 10–20 dAFB	• Temperature dependent: needs >15 °C and rising temperature for 2–3 days after application
Carbaryl	100-130 g / 100 L	7-28 dAFB (pome fruit) Repeat at 7–10 day intervals as required	• Requires warm dry conditions • Toxic to bees, beneficial invertebrates & mammals • Can cause russet • Can reduce seed number • Banned from some export markets
Ethephon	30–50 mg/L for younger trees 100–150 mg/L for mature trees	Balloon blossom to 7 dAFB (apple)	• Tendency to flatten fruit • Higher rates depress fruit size • Not effective at cooler temperatures
Gibberellic acid (GA)	70–400 ml/100L water, minimum spray volume 1000 L/ha	Flower bud initiation stage (stonefruit)	• Applied previous season • May delay harvest
Lime sulfur	2% solution, applied to runoff	20% and 80% bloom	• Can cause russet

Metamitron	1.1-2.2 kg/ha	8-16 mm fruitlet diameter (apple)	• Can cause minor leaf phytotoxicity • Thinning effect dependent on radiation
Naphthalene acetic acid (NAA)	4–5 mg/L for easy to thin cultivars up to 12 mg/L for difficult to thin cultivars	FB to 5 dAFB (apple) 2 sequential sprays may be required – the first applied at FB and the second 3–5 dAFB	• Can depress fruit size • Can reduce seed number • Pygmy fruit if applied after 10 dAFB • Interacts with Cytolin • Can cause russet • Rewetting causes over-thinning
Thiram	recommended label rate	As for carbaryl (apple)	

dAFB = days after full bloom; FB = full bloom

Notwithstanding the above comments, chemical thinning is still likely to provide Nashi growers with a means of reducing hand thinning costs, but studies will need to be undertaken to determine optimal rates and application times for each chemical plus the potential of retaining fruit in the centre of the cluster. The most likely chemical candidates are ATS, BA, metamitron and possibly NAA. The newer chemicals described above, ALA, ACC, polysorbates and potassium bicarbonate are also worth investigating further.

6.3. Mechanical thinning

Mechanical thinning provides an environmentally friendly means of reducing crop load and a range of mechanical devices have been trialled in different tree crops with varying degrees of success. Mechanical thinning can provide considerable savings in labour costs associated with hand-thinning; Seehuber *et al.* (2015) have reported the cost of mechanical thinning to be half that of hand thinning based on 20 ha and 10 years depreciation of the mechanical thinner. While mechanical thinning is applicable to both flowers and developing fruit, it can cause considerable damage to trees and when used for fruitlet thinning tends to remove the larger fruit, leaving the smaller less desirable fruit (Webster 2002). Jacobus de Villiers (2014) and Wouters (2014) describe a range of mechanical systems including trunk and limb shakers, spiked drum shakers, rope curtains, water jet thinning, hot air blowers and string thinners.

Several disadvantages of trunk shakers noted by Lopes *et al.* (2019) include excessive thinning, reduction in marketable grade fruit, irregular thinning pattern - particularly near the top of the tree, loss of larger fruitlets, and significant leaf removal which can negatively affect fruit growth. Trunk and limb shakers have been successfully used in stone fruit but are not recommended for pome fruit as fruit is easily bruised (Dennis 2000). Spiked drum shakers tend to create an uneven fruit distribution by removing more fruit from the outside of the canopy than the inside (Wouters 2014).

The Darwin string thinner developed by an organic apple grower in Germany and the BAUM device developed by the German University of Bonn have both shown potential on several fruit species (Jacobus de Villiers 2014; Costa 2017). Using flexible strings/cords rotating around a vertical spindle, the thinning intensity of the Darwin thinner can be adjusted by changing the rotational speed of the spindle, the speed of the tractor or the arrangement of the cords. The BAUM device consists of a 3m vertical spindle with three horizontal rotors, which can be set independently of each other (Jacobus de Villiers 2014). The rotors can be swung individually out of the tree row, thus providing flexibility for selective thinning of one side of a tree row and different canopy sections (lower or higher, inner or outer part of the tree) (Damerow & Blanke 2009). The BAUM device enables precise control over the number of flowers removed by choosing between a selection of brush type, rotor speed, rotor position and tractor speed. The BAUM device is able to remove peripheral flowers as well as flowers in the centre of the tree close to the trunk where fruit is normally of lower quality due to shading (Jacobus de Villiers 2014). Examples of successful rotor and tractor speeds for thinning in European pear are provided by Bound (2021a).

The majority of studies with mechanical thinning devices have been undertaken on peach and other stone fruit, with very few studies in pome fruit (Bound 2021a). Timing of use of the different mechanical devices varies between bloom and fruitlet stages of growth (see Table 14). String thinners have been shown to reduce the time required for hand-thinning by up to 50% (Jacobus de Villiers 2014) and are probably the most feasible mechanised thinning solution in terms of thinning efficacy, speed, and ability to control damage (Greene & Costa 2013; Wouters 2014; Costa *et al.* 2019).

Table 14. *Application time for different mechanical thinning devices.*

Flower stage	Fruitlet stage
Rope curtain	Limb/trunk shakers
Darwin string thinner	Spiked drum shakers
Baum string thinner	
Compressed air pulses	

The ideal tree architecture for successful mechanical thinning is a two-dimensional hedgerow type system. Voluminous three-dimensional canopies impede machine access to blossom clusters, particularly in the centre of the canopy (Webster 2002). Suitable tree training methods include spindle, solaxe, vertical axis and central leader (Bertschinger *et al.* 1998; Seehuber *et al.* 2015). Fruit morphology can also be important in the success of mechanical thinning. The long flexible peduncles of the European pear cv. 'Packham's Triumph' have been reported to be a major limitation to mechanical thinning (Menzies 1973). Seehuber *et al.* (2015) attributed successful mechanical thinning of cvs. 'Conference' and 'Alexander Lucas' partly to the steep upright long peduncles, particularly when compared with the shorter flower stalks of apples.

As spur leaf development occurs during the flowering period in pome fruit this presents a challenge for flower thinning with mechanical thinners because spur leaves have an important localised influence on fruit set, particularly early in the season as developing fruit are unable to receive photosynthate from elsewhere in the tree (Feree & Palmer 1982). Loss of 75% or more of the leaf surface has been reported to reduce both fruit set and quality in apple (Bound 2021b).

A drawback of string thinners is that they can also cause damage to leaves and bark, thus providing an entry point for disease such as fire blight (*Erwinia amylovora*) and canker (*Nectria gallingea*) (Wouters 2014). An increase in fire blight infection of apple trees of 380% following mechanical thinning with a Darwin string thinner was reported by Ngugi & Schupp (2009).

A limitation of both the Darwin and BAUM units is their inability to accommodate the requirements of individual trees – although Bound (2021a) suggests that in this respect they are no different to current chemical thinning practices where orchard blocks are treated as one unit, each tree receiving the same amount of chemical. A start to overcoming this limitation is the development of a vision system for real-time determination of flower density combined with a decision support tool to calculate optimum thinning intensity based on current flower density and a mechanical thinning unit controlled in real time (Gebbers *et al.* 2014). A commercial system is now available - the Darwin SmaArt Camera System (Fruit-Tec, Markdorf, Germany) that detects the blossom density of individual trees, passing the data to an on-board computer that calculates the optimum spindle speed and controls the thinning unit (Kon & Schupp 2019).

Mechatronic systems are also under development to overcome the issues of non-selectivity and tree damage; Wouters (2014) has developed a novel mechatronic device offering a high degree of selectivity with minimal tree damage using a sensor capable of detecting floral buds and pulses of compressed air to remove buds. As the floral buds are removed at their natural attachment point there is little damage. Based on the measured floral bud distribution, mechatronic systems such as this can realise precision thinning by choosing the required settings pm the pneumatic thinning device, and cost analysis has indicated that pneumatic thinning can be an economically feasible alternative to traditional hand thinning (Wouters 2014).

Despite the drawbacks of the current commercially available string thinners, there are still advantages to mechanical thinning in that it is not weather dependent, thinning can be undertaken early in the flowering period as soon as flowers can be identified on the tree, and the thinning effect can be observed immediately after treatment, allowing additional thinning measures to be undertaken more rapidly if required. This technology also provides a low environmental impact method for crop load management and is a good fit for organic orchards. With the move towards mechatronics to overcome the problems of non-selectivity and tree damage in combination with a transition towards two-dimensional tree architecture there is potential in the future for mechanical thinning to provide an environmentally friendly and efficient means of managing crop load.

6.4. Photosynthetic inhibition through shading

Limiting carbohydrate supply at critical fruit growth stages through shading has been shown to reduce set and/or result in abscission of fruitlets (Byers 1990; Greene *et al.* 2011). Most shading studies have been undertaken on apple, but the results should also be applicable to both European pear and Nashi, although the time and duration of shading may vary.

According to Byers *et al.* (1990) apple trees can be almost completely defruited by shading of whole trees from 25-35 dAFB, and cloudy periods as short as three days may greatly affect apple fruit set under natural conditions. Timing of shading can be critical, total fruit drop has been observed in apple with 100% shading at 28 dAFB, while 100% shading for five days starting at 14 dAFB resulted in an ideal level of fruit set equivalent to hand-thinning after June (December) drop (Bertschinger *et al.* 1998). Byers *et al.* (1991) reported a 7-17% reduction in fruit set following shading with 92% shade cloth for 2-3 days at 14, 21 and 28 dAFB, but 2-3 days of shade at 8, 35 or 42 dAFB had no influence on fruit drop. There is a lack of consistency in the literature in how timing of shading is reported, some studies have used dAFB while others have reported fruit size. Three days of shading the whole tree when fruit were 20 mm diameter caused 98% fruit abscission (Byers *et al*. 1991), and several authors cited by Greene *et al.* (2011) state that the 8 to 15 mm fruit size is the critical stage when developing fruit are easily thinned. It has been calculated that 2-3 days of 92% artificial shade has been calculated as being equivalent to 3-4 consecutive days of cloudy periods (Byers *et al*. 1991). Depending on seasonal conditions, fruit size will vary at similar timings each season, so fruit size may be a better indicator of sensitivity to carbohydrate stress.

Wünsche et al. (2004) observed a reduction in leaf carbon assimilation in apple trees sprayed with the kaolin product Surround®; although trees were treated in mid summer close to harvest to ameliorate fruit sunburn, kaolin based aprays may have potential to limit light availability, thus simulating shading, if applied when trees are sensitive to carbohydrate stress.

More work is required to determine the length of the period of shading and the optimal timing for each cultivar, bearing in mind that this may also be influenced by seasonal weather conditions. Determination of the relationship between fruit size and days after full bloom over several seasons may be useful for consistency of application of shading treatments for each cultivar.

6.5. Thermal shock

Thermal shock has been investigated over a two year period as a method of preventing fertilisation by arresting pollen tube growth in apple (Kon *et al.* 2020). Short duration forced heated air treatments were applied to blossoms 24 hours after pollination using a variable-temperature heat gun. Results were variable across the two years, but in the first year thermal shock of 56°C of 2 or 4 seconds duration inhibited pollen tubes from reaching the style base; the inconsistent effect across years was attributed to treatments being applied too late in the second year due to optimal conditions for pollen tube growth. Excessive injury to spur leaf tissue was observed following treatment for 2 seconds at ≥ 84°C or 4 seconds at ≥ 70°C. Pollen tube growth was reduced or arrested at temperature and duration combinations that caused minimal damage.

Kon *et al.* (2020) concluded that a 2 second burst at 56°C would prevent fertilisation without visible injury to spur leaves and suggested that the use of pollen tube growth models as timing aids for thermal shock should be considered for future work. They also noted that the canopy structure and distance of the heat source from the target were important considerations, so high density orchards with narrow tree-wall canopies would facilitate the application of thermal shock as a thinning method. Combined with vision systems that are undergoing development to detect blossoms (such as those described by Wouters 2014), thermal shock may have potential for selective thinning of Nashi blossoms.

6.6. Pruning

While the primary function of pruning is to improve canopy light distribution and control tree vigour, maintaining balance between vegetative and reproductive activity, it should be considered to be the first stage of any crop load management program (Jones *et al.* 1998) as it can also be used to manage floral bud numbers. Costa *et al.* (2019) states "…p*runing is one of the most important agronomic tools that can finely affect flower bud load in order to facilitate later thinning operations"*. Reducing floral bud numbers through dormant winter pruning is an environmentally friendly method of reducing crop load and importantly, it reduces competition for assimilates between flowers/fruitlets thus maximising benefit in terms of assimilate distribution. Pruning to a specified bud number allows growers to start the process of fruit thinning early to reduce competition among flowers and fruitlets resulting in increased resources for the remaining fruit and improved fruit size and quality.

In order to manage pruning appropriately it is important to understand the growth habit of each cultivar as there are marked differences in growth habit between Nashi cultivars. Beutel (1998) notes that fruit are borne on spurs on 2-6 year old wood, with best sizes being produced from 1-3 year old spurs on wood 1-2 inches (2.5-5 cm) in diameter. The cultivars 'Hosui', 'Kosui', and 'Shinsui' are lateral bearers while 'Nijisseiki' is predominantly a spur-bearer with comparatively low vigour. 'Hosui' and 'Kosui' have also been described as tip bearers with a pronounced tendency to fruit on young wood (Klinac *et al.* 1995).

Growers in Victoria have noted lower fruit set in blocks where the tops of the trees are left unpruned (Figure 6) or where winter pruning is delayed. The mechanism for the reduction in fruit set is likely to be the result of shading reducing the amount of light, and thus photosynthesis, in the canopy. This observation may provide another tool for controlling crop load, however studies will need to be undertaken to determine the long term impact on trees and fruit quality.

***Figure 6**: Unpruned tops in Nashi block.* Photo credit: Steven Singh, Seeka Australia Pty Ltd

Following a 17-year study on natural fruitlet abscission in apple, Lordan *et al.* (2019) concluded that apple fruit set and final numbers could be relatively well modelled with flower density, representing the tree's physiological history, and a carbohydrate model, representing early season weather effects, hence a high number of floral buds results in a high number of final fruits despite later chemical thinning. According to Robinson *et al.* (2021), the number of fruiting buds that remain after pruning influence fruit thinning requirements, fruit quality, tree vigour and return bloom. This finding can be used to implement a strategy of precision pruning to reduce the flower bud number per tree to a pre-defined flower bud number through removal of shoots/limbs.

The technique of removing individual buds or spurs is termed bud (spur) extinction and was introduced by Lauri and Lespinasse (1999; 2000) after observing that regular bearing cultivars have high natural spur extinction and the remaining floral structures bear fruit and produce bourse shoots that flower the following season (Lauri *et al.* 1995; 1997). By reducing bud density through manual removal of floral buds during late winter or early spring, artificial bud (spur) extinction (ABE/ASE) imitates natural bud extinction and is a precision crop load management technique as it precisely defines both how much fruit is set on the tree and where it is positioned. ABE has the potential to replace chemical thinning as a crop load management tool in apples (Tustin *et al.* 2012; Bound 2019). In a comparison of chemical thinning and ABE in apples, Bound (2019) found that ABE is comparable to managing crop load through chemical thinning programs, but has the advantage that costs reduce in subsequent years after the initial tree set-up. It also has added advantages in that it is not weather dependent and removes the risk of negative impacts that chemical thinners can have on fruit size, shape and skin finish.

Australian Nashi growers already practice spur removal and some also remove individual buds after initial pruning through to bud burst to reduce the number of buds on the spurs (termed bud flicking). The techniques currently used by Nashi growers in relation to spur and bud thinning may be able to be refined, but growers are looking to reduce labour costs through the implementation of other tools to manage crop load.

7. Conclusions

A systematic program approach for controlling vigour and managing crop load can be developed using a range of tools/techniques. Many of the tools used in other fruit tree crops can be modified or adapted to suit the physiology of Nashi. Early thinning offers distinct advantages in relation to fruit size and other quality parameters such as firmness and sugar content. Both chemical and mechanical thinning have potential for inclusion in Nashi thinning programs as they offer the advantage of early thinning during the flowering period. Chemical thinning can also extend to post-bloom thinning in situations where the crop load is still too heavy after the flowering period. A sequential spray program spreads the risk in seasons where it is difficult to find a window with suitable application conditions.

Chemical thinning will most likely offer a reduction in thinning costs by reducing the time required for hand-thinning, but the risk of the negative impacts that chemical thinners can have on fruit size, shape and skin finish cannot be removed. It is also difficult to target specific flowers/fruitlets within a cluster with chemicals. Growers need to be aware that chemical thinning is not a panacea to replace hand-thinning. The benefits of chemical thinning can be maximised through an understanding of the physiological mechanisms involved for each active ingredient along with knowledge of optimal application timing and dose rates for each chemical thinning agent (Table 13). As there are differences between cultivars in the degree of sensitivity to each chemical, rigorous studies will need to be undertaken for each cultivar/chemical combination. A knowledge of conditions that impact the carbon balance of the tree, and the ability to make use of carbon deficit conditions is likely to improve the predictability of chemical thinning. Development of a carbon balance model such as Malusim, the dynamic simulation model of apple tree carbohydrate supply and demand balance developed by Lakso and Robinson (2015), would allow more precise prediction of thinner response under specific environmental and physiological conditions. To avoid the risk of damage to crops, compliance or reputation, growers should not trial unregistered chemicals; small plot research trials need to be undertaken by a reputable research organization or consultant for the production of data to enable a label change to include Nashi. However, even once label recommendations are available for specific chemicals, growers will still need to undertake their own small-scale preliminary trials before extending chemical thinning programs to an entire block or orchard. Mapping of blossom density in combination with a decision support tool to enable a sprayer to target specific trees and/or sections of trees will allow targeted spray application, overcoming the problem of non-selectivity and accounting for the thinning requirements of individual trees.

Mechanical thinning with either Darwin or BAUM style string thinners has definite potential during the flowering period, particularly as these devices can be used as early as flower emergence (plant growth stage 5 in the BBCH scale). Like chemical thinning, the issue of non-selectivity needs to be addressed, however the development of mechatronic systems should overcome most problems that occur with currently available mechanical thinners. One drawback of mechanical thinners is that they are most suited to two-dimensional tree architecture, so are unlikely to be successful in orchards with large three-dimensional plantings.

Shading at critical times has potential, and this can be implemented in several ways: (i) through the use of netting/shadecloth, although this method can be clumsy and time consuming to place and remove the cloth; (ii) application of kaolin based sprays; or (iii) delayed pruning of the tree tops. However, for options (i) and (ii) studies are required for each cultivar to ascertain the critical stage when developing fruit are easily thinned to enable determination of the length of the period of shading and the optimal timing.

All thinning programs should commence with targeted pruning during the dormant winter period to reduce floral bud numbers. Bud thinning in the form of spur extinction should continue to be used for precise placement of fruit in optimal positions and to set up the required number of clusters.

8. Recommendations for future research

A systematic approach to crop load management using a range of tools/techniques can reduce both risk and cost. The keys to good fruit size, shape and internal quality are good canopy light interception which is achieved through pruning, early removal of unwanted flowers/fruit and good pollination. There are several options worthy of further examination for crop load management in Nashi, some of which can be undertaken directly by growers and others which will require further research. However, it should be noted that as the chemical options detailed below are not registered for use on Nashi, small plot research trials need to be undertaken by a reputable research organization or consultant for the production of data to enable a label change to include Nashi; growers should not trial these chemicals until Nashi has been added to the label or the Australian Pesticides and Veterinary Medicines Authority have issued a minor use permit.

1. **Full economic analysis of the cost of current crop load management practices in Australian orchards**: to enable any benefits of changing practices to be properly quantified a full understanding of the costs of the different crop load management techniques currently used and their impact on fruit quality and pack-out across all growing regions would assist the industry.
2. **Pruning** is the first stage of any crop load management program and there are two options worthy of further investigation:
    - Revisiting pruning as a first strategy to reduce spur/bud numbers and to optimise bud placement. There may be the opportunity to simplify older more complex spurs, thus ultimately reducing the amount of bud flicking required.
    - Examination of the impact of delayed pruning of tree tops; this will need to include studies on the long term impact on trees, flower initiation and fruit quality as well as the effect on fruit set.
3. **Dormancy breakers** are used by most growers, but there is some disagreement as to the most effective product/s for Nashi. Hydrogen cyanamide (Dormex®/Duomax®) is not registered for use on pears in Australia. Comparative trials of Erger, Waiken and mixes of mineral and vegetable oil should be undertaken in all regions with the aim of finding suitable alternatives to hydrogen cyanamide.
4. **Fruit growth rates** in relation to flowering (days after full bloom) - a database of fruitlet size relating to days after full bloom should be established for each growing region for the main cultivars grown and correlated with climatic conditions. Such a database will provide useful information for Recommendations 5, 7 and 8.
5. **Chemical thinning**: several chemicals have potential as chemical thinning agents for Nashi and replicated small plot trials should be established to determine efficacy and optimal application timings and rates. These studies need to be undertaken by a reputable research organization or consultant for the production of data to enable a label change to include Nashi. Application of unregistered chemicals may lead to damage to crops or reputation, or result in compliance issues.
    - Australian trials have already demonstrated that *ATS* will thin Nashi when applied during the flowering period. However further work is required to determine whether:
      (a) suitable rates can be found that will thin without causing fruit russet
      (b) it can be used to target the first fruit in the cluster and fruit at positions ≥ 6 in the cluster - this will require a compressed flowering period.

- *Metamitron* has recently had 'pears' added to the label, so it is legal to apply this product. However growers should undertake small scale trials to ensure its effectiveness for their orchards and growing conditions - strict attention should be paid to optimal application conditions. Development of trial protocols/guides will assist growers who wish to undertake their own trials.
- The post-bloom thinner *BA* should be examined at multiple rates and timings (fruit sizes) ensuring that strict attention is paid to optimal application conditions.
- *Potential new chemicals*: Trials examining the efficacy of *ALA*, *ACC*, *polysorbates* and *potassium bicarbonate* for thinning Nashi may have potential. These substances have either already been declared food safe or have been recognised as environmentally friendly chemicals.

Negotiation with chemical manufacturers of products registered for other crops should be undertaken to determine whether it is feasible to add Nashi to the Australian label.

Contact should also be made with the Australian Pesticides and Veterinary Medicines Authority (APVMA) for information on what studies are required for production of efficacy data. Minor use permits may be applicable for some chemicals, and others may not require registration.

6. **Mechanical thinning**: as there are reported to be several Darwin string thinners in the Goulburn Valley, assessment of a string thinner for flower thinning during the early flowering period is recommended to clarify whether it can thin Nashi effectively without excessive damage to fruit. Any trials undertaken with a mechanical thinning device should employ an experienced operator and examine both tractor and rotor speed at a number of timings.
7. **Further studies into Nashi tree physiology** to allow adaption of **carbon balance models** such as the Maluslim model to suit Nashi.
8. **Limiting light availability to induce carbohydrate stress**: Application of chemically inert kaolin based particle films such as Surround® WP may provide a safe environmentally friendly method of inducing fruitlet abscission through a reduction in photosynthesis. However before trials with this type of product are planned it is essential to undertake studies to determine the length of the period of shading and the optimal timing for each cultivar that will induce fruitlet abscission, bearing in mind that this may also be influenced by seasonal weather conditions. Determination of the relationship between fruit size and days after full bloom for each cultivar over several seasons may be useful for consistency of application of shading treatments.
9. **New cultivars**: as 'Nijisseiki' is the cultivar that presents the greatest issues in crop load management, serious consideration should be given to phasing out 'Nijisseiki' and replacing with cultivars that are easier to manage. Newly released cultivars from breeding programs in other countries are worth investigation, particularly as the Japanese breeding program has been assessing self-thinning cultivars.

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Appendix 1: The BBCH scale as applied to Nashi

The general BBCH scale considers 10 principal growth stages, numbered from 0 to 9 with secondary growth stages defining short developmental steps characteristic of the respective plant species, which are passed successively during the respective principal growth stage Meier *et al.* (1994). These secondary stages are also coded using the figures 0 to 9, hence the combination of figures for the principal and the secondary stages results in a two-digit code.

***Table 1**: Principal growth stages of the general BBCH scale (Source: Meier 2018)*

Stage	Description
0	Germination / sprouting / bud development
1	Leaf development (main shoot)
2	Formation of side shoots / tillering
3	Stem elongation or rosette growth / shoot development (main shoot)
4	Development of harvestable vegetative plant parts or vegetatively propagated organs / booting (main shoot)
5	Inflorescence emergence (main shoot) / heading
6	Flowering (main shoot)
7	Development of fruit
8	Ripening or maturity of fruit and seed
9	Senescence, beginning of dormancy

If two or more principal growth stages occur in parallel, they are indicated by using a diagonal stroke (example 10/54) (Figure A1).

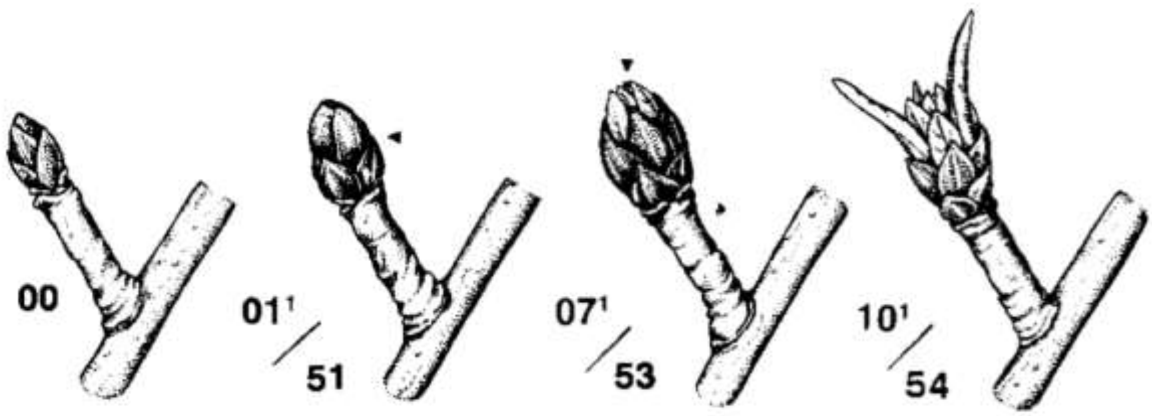

***Figure A1**: Phenological growth stages of pome fruit (BBCH scale) showing stages of bud development (00, 01, 07), leaf development (10) and inflorescence emergence (51, 53, 54) (from Meier et al. 1994; Meier 2018)*

Not all primary stages in the general scale are applicable to all species – the applicable stages for pome fruit are described in Table A2.

Table A2*: Phenological growth stages and identification keys of pome fruit [Source: Meier 2018]*

Principle Growth Stage	**Secondary growth stage**
0: Bud development	00: Dormancy. Leaf buds and thicker inflorescence buds closed and covered by brownish scales 01: Beginning of leaf bud swelling: buds visibly swollen, bud scales elongated, with light coloured patches 03: End of leaf bud swelling: bud scales light coloured with some parts densely covered by hairs 07: Beginning of bud break: first green leaf tips just visible 09: Green leaf tip about 5 mm above bud scales
1: Leaf development	10: Green leaf tips 10 mm above the bud scales; first leaves separating 11: First leaves unfolded (others still unfolding) 15: More leaves unfolded, not yet at full size 19: First leaves fully expanded
3: Shoot development)	31: Beginning of shoot growth: axes of developing shoots visible 32: shoots abouts 20% of final length 33: Shoots about 30% of final length 3.. Stages continuous till … 39: Shoots about 90% of final length
5: Inflorescence emergence	51: Inflorescence buds swelling; bud scales elongated, with light coloured patches 52: End of bud swelling: light coloured bud scales visible with parts densely covered by hairs 53: Bud burst: green leaf tips enclosing flowers visible (Fig. 1). 54: Mouse-ear stage: green leaf tips 10 mm above bud scales; first leaves separating 55: Flower buds visible (still closed) 56. Green bud stage; single flowers separating (still closed) 57: Pink bud stage: flower petals elongating; sepals slightly open; petals just visible 59: Most flowers with petals forming a hollow ball
6: Flowering	60: First flowers open 61: Beginning of flowering: about 10% of flowers open 62: About 20% of flowers opening 63: About 30% of flowers opening 64: About 40% of flowers opening 65: Full flowering: at least 50% of flowers open, first petals falling 67: Flowers fading: majority of petals fallen 69: End of flowering: all petals fallen
7: Development of fruit	71: Fruit size up to 10 mm; fruit fall after flowering 72: Fruit size up to 20 mm 73: Second fruit fall 74: Fruit diameter up to 40 mm; fruit erect (T-stage: underside of fruit and stalk forming a T) 75: Fruit about half final size 76: Fruit about 60% final size 77: Fruit about 70% final size 78: Fruit about 80% final size 79: Fruit about 90% final size
8. Maturity of fruit and seed	81: Beginning of ripening: first appearance of cultivar-specific colour 85: Advanced ripening: increase in intensity of cultivar-specific colour 87: Fruit ripe for picking 89: Fruit ripe for consumption: fruit have typical taste and firmness
9. Senescence, beginning of dormancy	91: Shoot growth completed; terminal bud developed; foliage still fully green 92: Leaves begin to discolour 93: Beginning of leaf fall 95: 50% of leaves discoloured 97: All leaves fallen 99: Harvested product

***Table A3**: Principle phenological codes for bud, flower and fruit development for Nashi according to the BBCH scale, as identified by Martinez-Nicolás (2016).*

Principle Growth Stage (PGS)	
Bud development (PGS 0)	00: Dormancy. Leaf buds are closed and covered by brownish scales (Fig. 1). 01: Beginning of leaf bud swelling (Fig. 1). 03: End of leaf bud swelling: greenish-brown scales slightly separated. 07: Beginning of bud burst: first green leaf tips just visible 09: Green leaf tip about 3mm above bud scales
Flower emergence (PGS 5)	51: Inflorescence buds swelling; buds closed, greenish scales visible (Fig. 1). 53: Bud burst: green sepals tips enclosing flowers visible (Fig. 1). 54: Sepals visible, but still united (green bud). 56. Flowers still closed; sepals slightly begin to separate (Fig. 1). 59: First petals visible. Flowers with petals forming a hollow ball (Fig. 1).
Flowering (PGS 6)	60: First flowers open. Flowers are white (Fig. 1). 61: Beginning of flowering: about 10% of flowers open (Fig. 1). 65: Full flowering: 50% of flowers open (Fig. 1). 66: Fading flower. Some petals fallen or dry (Fig. 1). 69: End of flowering. All petals fallen or dry. Fruit set.
Fruit development (PGS 7)	71: Fruit set: beginning of ovary growth; green ovary; the petals have fallen (Fig. 1). 72: Fruit at 20% of final size (Fig. 1). 74: Fruit at 40% of final size (Fig. 1). 75: Fruit at 50% of final size (Fig. 1). 77: Fruit at 70% of final size (Fig. 1). 79: Fruit about 90% final size.

***Figure A2**: Primary and secondary phenological growth stages of Nashi according to the BBCH scale (Photos sourced from Martinez-Nicolás 2016)*

00

01

 51	 53
 56	 10
 59	 59/60

61

65

66

71

72

74

 75	 77
 81	 89