PRODUCTION AND POSTHARVEST HANDLING OF CHINESE CABBAGE

(\textit{Brassica rapa var. pekinensis})

A review of literature prepared for the Rural Industries Research and Development Corporation.

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EXECUTIVE SUMMARY

Chinese cabbages which form a head can be classified as the short, wong bok or tall, michihili cultivars. Apart from physical differences, these two types generally differ in their growth rates, disease susceptibility and ease with which they can be grown in colder temperatures. However, between cultivars of these two types, significant variation in these factors also exist.

Chinese cabbage is planted either through directly sowing the seed or transplanting the seedling after a period of propagation in a polyhouse. While transplanting is more expensive, it allows greater control over the important early growth stages of the plant. Final head size can be manipulated through planting density. Closer plant spacings produce smaller heads, however irregular plant spacings can cause variable head sizes and dense plantings are more likely to result in diseases. The amount of fertiliser the crop needs depends on soil type, nutrient status, previous cropping practices and irrigation efficiency.

Bolting is the term used for flower stalk initiation and development. It is primarily caused by cold temperatures and is the main limiting factor in growing Chinese cabbage into winter. Management practices such as the use of bolting tolerant cultivars, container-grown seedlings raised under warmer temperatures for several weeks prior to field transplanting and the use of plastic row covers in the field have been effectively used to reduce bolting in Chinese cabbage.

Tipburn is a field disorder which causes browning of the margins of young inner leaves and in its most severe form results in necrotic breakdown of leaf tissue and subsequent secondary invasion by bacteria. The primary cause of tipburn in Chinese cabbage is a low supply of calcium to the young, inner leaves, particularly during rapid growth and head formation. Climatic factors which include water stress or high transpiration rates increase tipburn while large diurnal fluctuations in relative humidity reduces tipburn. Cultural practices which reduce root restriction and promote even growth and development, such as good irrigation practices and proper application of nitrogen in its correct form, result in healthy plants without tipburn. Although foliar applications of calcium can reduce tipburn, the cost/benefits appear to be small.

Gomasho is a physiological disorder which is characterised by brown to black specking of the white leaf midribs of Chinese cabbage heads, especially during cooler months. Symptoms can occur in the field or during storage. Mild symptoms at harvest will generally develop further, becoming severe after 10-12 days. High application rates of both nitrogen and phosphorous fertilisers and a pH around eight can exaggerate the disorder and it has also been associated with high tissue copper levels and low levels of boron. Despite considerable amounts of research, the cause of this disorder is still unknown. At present it is best controlled by using tolerant cultivars and good cultural practices. Excessive use of fertilisers, particularly ammonium-nitrate should be avoided and the pH of the soil maintained at around pH 7.

Chinese cabbage can be infected by a number of bacterial, fungal and viral diseases which affect other cruciferous crops. Cultural practices and crop management can play a role in preventing or controlling
infection and where infection occurs, subsequent spread. Much of this concerns the selection of tolerant
cultivars and the maintenance of field hygiene to remove major sources of infection such as secondary
host plants and diseased crop material. The use of chemicals can also help, but the effectiveness depends
upon the nature of the particular disease and the methods and rate of application of the chemical.

Common pests of Chinese cabbage include various aphid species, the Diamondback moth and the
Cabbage White butterfly. These insects use the crop as part of their life-cycles and cause major direct
crop losses through feeding. In addition, aphids transmit plant viruses such as Cauliflower Mosaic Virus
(CaMV) and Turnip Mosaic Virus (TMV), both of which can inflict severe losses in Chinese cabbage.
Insecticides are used to control these pests but several problems currently exist. In the case of aphids, a
very small number can cause severe virus outbreaks, so even excellent control of aphid numbers will not
appreciably reduce viral infection. Diamondback moth, the most important pest of brassica crops
worldwide, has demonstrated resistance to a wide range of insecticides currently in use. As a result,
research is continuing worldwide into such areas as new biological control agents, breeding for resistant
brassica cultivars and pheremone sprays which disrupt the moth’s mating cycle.

Australian cultivar evaluation trials on Chinese cabbage have involved selection for slow-bolting, late
maturing cultivars in order to extend the growing season into cooler months and selection for tolerance
to a range of disorders, such as gomasho, tipburn and bacterial softrot. There has been a noticeable lack
of research into postharvest storage of Chinese cabbage cultivars in the past, however recent research in
Victoria funded by RIRDC has addressed this issue.

Product quality at harvest largely influences quality loss after harvest. Good postharvest practices of pre-
cooling and rapid establishment and maintenance of the desired temperature, gas concentrations, relative
humidity and adequate air circulation are critical factors in prolonging storage of Chinese cabbage. In
general, it should be pre-cooled to around 0-1°C immediately after harvest with minimal moisture loss.
This temperature and a relative humidity of 98 to 100% should be maintained during storage and
transport. For prolonged storage, controlled atmospheres have been beneficial. Perforated and
unperforated polyethylene bags have been used in cold storage to reduce weight loss and improve
saleable yields. Research into extending storage life through MA packaging is lacking in the literature
for Chinese cabbage, although its application to other brassica crops has been successful. There appears
to be considerable potential to improve the storage and market quality of Chinese cabbage using MA
packaging.
1. Introduction

As the name suggests, Chinese cabbage originated in China. The earliest records in Chinese literature suggest the fifth century, where it occurred naturally in cultivation as a cross between Pak Choi (Brassica rapa var. chinensis) and turnip (B. rapa var. rapifera). The early Chinese cabbages were loose-heading. Evolution and selection applied by different farming regions to produce suitable seasonal cultivars lead to the many cultivars existing today, each with their own subtle differences (Larkcom, 1991). The classification of Chinese cabbage is confusing, with one name used for several different cultivars or a single cultivar given different names. For example, the Chinese cabbage subject of this review (B. pekinensis or B. rapa var. pekinensis) has many common names including celery cabbage, Chinese leaves, Pe-tsai, Pak choi and Bok choy. Celery cabbage, Pak choi and Bok choy have also been used to refer to the distinct species, B. chinensis or B. rapa var. chinensis in some texts. B. pekinensis refers to Chinese cabbage which form a head. It is a biennial or annual cool season crop, grown as an annual in Australia. Head size and shape vary greatly depending on cultivar, from the short 'barrel' or Wong bok types to the long slender 'rocket' or michihili types. Outer leaf colours range from dark to pale green and inner leaves are paler.

The Wong bok types form compact, broad to oblong heads, on average 20-25 cm long and 15-23 cm wide. The outer leaves are closely wrapped, usually over the top, to make a dense heart of paler leaves. They are fast-maturing (as early as eight weeks in ideal conditions) and in general remain vegetative for longer than michihili types when exposed to cold temperatures (the importance of this is discussed in Chapter 3, section 3.1 Bolting). The michihili types have long erect leaves and form a compact, tapering head around 38–46 cm long and 10–15 cm wide. They are relatively slow growing, taking more than 10 weeks from sowing to harvest in ideal conditions. Cross breeding between cultivars has resulted in the wide range of characteristics seen in modern Chinese cabbage cultivars today, where outer leaves range in colour from dark to pale green and leaf shapes range from smooth and almost round to long and narrow, or frilled and wavy. The leaf midribs have broad, swollen bases which often overlap to form a solid butt (Larkcom, 1991).

Chinese cabbage is the most consumed vegetable in China, and has become popular in America and Europe over the last 10-15 years. China produced nearly 38 million tonnes in 1991 and Japan produced around one million tonnes in the same year, which included heading and non-heading types eaten only for their leaves\(^1\). In Australia, large-scale commercial production has been mainly in W.A. and N.S.W., with some production in Queensland and only a few isolated crops grown in Victoria.

\(^1\) data provided by Grant Vinning, Asian Markets Research.
2. Production

2.1 Climate

Chinese cabbage vary in temperature requirements. Many cultivars require temperatures in the range 13-20°C, with cultivars prone to bolting (see Section 3.1) requiring warmer conditions (Larkcom, 1991). Crops grown into colder periods should be protected from low temperatures and cold winds, which increase the likelihood of bolting. Where day temperatures consistently exceed 35°C, tropical 'cold sensitive' cultivars should be grown. At these temperatures, temperate, 'cold tolerant' cultivars are unlikely to form heads and are prone to disease. Chinese cabbage should not be grown in areas of low rainfall unless irrigation is available because the roots of most cultivars are very shallow and are not tolerant of drought (Larkcom, 1991).

2.2 Soil type

Chinese cabbage require deep, rich, well-drained soil because they are susceptible to root rots, however they will not tolerate excessive water stress due to a shallow root system (Anon., 1984a) and high levels of organic matter are recommended to improve water retention (Nguyen, 1992). Chinese cabbage has been successfully grown on a range of soil types from sandy soils to heavier textured Western Australia loams (McKay and Phillips, 1990). A soil pH of 5.5 to 7.0 is ideal. Lime should be applied if pH is below 5.5 as calcium and other nutrients can be deficient or unavailable in acid soils (Waters et al, 1992). Liming may also reduce the effect of clubroot if the disease is present (Sherf and Macnab, 1986). A fine, well-prepared raised bed can be used to minimise soil compaction, to overcome poor drainage and improve air flow around the plant base to help minimise bacterial disease (Larkcom, 1991).

2.3 Planting Method

Chinese cabbage can either be directly sown or transplanted. If direct sown, it is common for two to three seeds to be sown per seed station, 12-15 mm deep in the soil and thinned by hand (McKay and Phillips, 1990). Waters et al. (1992) recommends sowing the seed at a rate of 500 to 750g/ha which gives a plant spacing of 35 cm (for 500g/ha). If transplanted, the seedlings are often raised in polyhouses or glasshouses for three to four weeks before transplanting into the field (McKay and Phillips, 1990). Transplanting is more expensive than direct drilling, but results in more even spacing and allows control over environmental factors, such as cold temperatures, during early seedling growth which may induce bolting. In addition, direct seeding requires more seed, larger scale irrigation and more pest, disease and weed control. Chinese cabbage generally does not tolerate bare root transplanting unless there are cool and cloudy conditions with little air movement and adequate soil moisture. Bare root transplanting causes greater transplanting shock and transplants will initially have slower growth than container raised transplants (Waters et al, 1992).
2.4 Transplant container size

Kratky et al. (1982) found that there was no improvement in yield when Chinese cabbage seedlings were grown in containers beyond three weeks. Chinese cabbage transplants grown in containers less than 7.5 cm in diameter became stunted after three weeks and with a reduced final head weight, reduced yield and saleable yield and took longer to mature. Larger seedling size, less root binding, less seedling stunting, a greater total availability of nutrients and less transplant shock may be associated factors leading to increased yields from the use of larger containers; similar results have been reported in experiments with cauliflower (Weibe, 1981).

2.5 Plant and row spacing

Cultivar, season and grower practices all determine plant spacing. Early maturing cultivars require less space than later maturing cultivars. Common spacings in the field include: 30 cm between plants and rows (Waters et al, 1992), 37.5 between plants within the same row and 30 cm between rows to produce one kg heads and 45 by 30 cm to produce plants with larger head sizes (Anon., 1984a). McKay and Phillips (1990) recommended a row spacing of 40cm and plant spacings around 35cm for wong bok types and 30cm for michihili types which equates to 500g/ha of seed for wong bok types. These spacings resulted in trimmed head weights between one and 1.8 kg which were preferred for export. As planting density decreases, head weight increases significantly (Kratky et al, 1982). At a plant spacing of 43 cm, head weights were 76-79% greater than at 28 cm, that is, 1.25 to 1.5 kg compared to 0.7 to 1.25 kg. Irregular plant spacings resulted in variable head sizes and dense plantings were more likely to result in bacterial and fungal diseases.

2.6 Crop rotation

Continuous cropping can lead to disease build-up (Anon., 1984a), as can close rotations with other cruciferous vegetables such as cabbage, broccoli and cauliflower (McKay and Phillips, 1990). Rotation of Chinese cabbage with non-cruciferous crops is one of many ways in which the build-up and outbreak of diseases can be avoided or minimised.

2.7 Irrigation

Efficient irrigation will improve growth of Chinese cabbage and help prevent nutritional and physiological disorders (Anon., 1984a). A study on free-draining sandy soils of the Swan Coastal Plain in Western Australia showed that efficient irrigation practices reduced the need for applying fowl manure by 50 percent and nitrogen and potassium fertilisers by two thirds compared to inefficient irrigation methods (Phillips, 1990). Chinese cabbage is a shallow rooted crop and may require frequent watering. Measurements of soil water with devices such as tensiometers are often used as a basis for determining irrigation frequency. Adequate watering is particularly important during head formation to
ensure the best quality heads. If irrigation is inadequate or if the water contains too much salt, tipburn may result (McKay and Phillips, 1990). Too little water can reduce yield and excess water during head formation can cause root death, resulting in poor quality heads (Waters et al, 1992). Direct-drilled crops should be watered daily until seedling emergence (Long, 1984) and subsequently at levels required for growth (Lomman and Rogers, 1978). If leaf scald is a problem during hot weather, it may be preferable to irrigate at night (Waters et al, 1992).

2.8 Fertiliser

The amount of fertiliser needed depends on soil type, nutrient status, previous cropping practices (Waters et al, 1992) and irrigation efficiency (Phillips, 1990). Large amounts of potassium, nitrogen and phosphorous are needed by Chinese cabbage (Waters et al, 1992). Where animal manure, for example poultry manure, is used, it can be applied in rows or broadcast at least two weeks prior to planting (McKay and Phillips, 1990). Nguyen (1992) recommends that a fertiliser with an N:P:K ratio of 5:5:5 should be broadcast at a rate of 1.5 tonnes/ha before planting. In addition, regular applications of nitrogen and potassium fertilisers after crop establishment are desirable and daily applications through the irrigation water (fertigation) is an efficient way to supply nutrients and greatly reduce the amount of nutrients leached into the ground water (McKay and Phillips, 1990). Excessive use of nitrogen fertilisers has been associated with increased symptoms of the disorders tipburn (Tao et al., 1986; Anon., 1984b; Anon., 1984c., Anon, 1984d), gomasho (Phillips, 1990; Phillips and McKay, 1989) and soft rot (Phillips, 1990; Anon., 1984c). Gomasho, an important physiological disorder, has also been associated with high application rates of phosphorous (Phillips and McKay, 1989).

2.9 Weed Control

Weed control on Chinese cabbage is essential, particularly during the initial phase of slow growth. The crop can suppress further weed establishment when a good ground cover is achieved (Waters et al, 1992) and as a result, occasional manual weeding may be all that is required (Anon., 1984a). Birkenhead and Morgans (1991) reported that contact herbicides such as gramoxone, dichlor and glyphosate can control weeds before the beds have been prepared or before the crop has emerged. Pre-emergent and post-emergent herbicides for controlling weeds of cruciferous crops have been used successfully in the Perth area (McKay and Phillips, 1990), although it has been reported that Chinese cabbages may be damaged more easily by herbicides than other cabbages (Anon., 1984a).
3. Field Disorders

3.1 Bolting

Many growers refer to bolting as being a state of advanced flower stalk development, generally at the particular point where the cabbage head becomes unmarketable. In fact, the process of bolting is actually synonymous with flower stalk initiation and development and as such, a Chinese cabbage is said to have begun to bolt when the flower stalk within the head starts to elongate. This is a normal stage in the reproductive cycle of Chinese cabbage which provides the means for flower development and eventual self-perpetuation of the species. As the stalk continues to grow, it thickens and divides into a number of secondary stalks within the head of the cabbage, each stalk eventually developing floral buds. Bolting is of economic importance to the Chinese cabbage industry because advanced flower stalk development results in an unmarketable head. Advanced bolting results in a well developed flower stalk, penetration of the flower stalk through the top of the head as well as distortion and cracking, most noticeably at the base of the head.

Bolting is initiated by a period of exposure to cold temperature and therefore becomes a concern if Chinese cabbage production is extended into colder months. There does not appear to be a definite sequence or relationship between head formation and floral bud initiation (Opena et al, 1988). That is, the floral buds which develop as bolting progresses may occur either before or after the true head of the cabbage begins to form. If buds differentiate before heading begins, loose and unmarketable heads result, but heads will still form if the plant has developed a sufficient number of leaves, often stated at between 40 and 60 (Guttormsen and Moe, 1985b; Nakamura, 1977 cited in Elers and Weihe, 1984a). In general, average daily temperatures below 15°C will induce reproductive growth in temperate Chinese cabbage cultivars (Lorenz, 1946; Guttormsen, 1981; Guttormsen and Moe, 1985a; Guttormsen and Moe, 1985b; Moe and Guttormsen, 1985; Eguchi et al, 1962; Elers and Weihe, 1984a). The period of exposure needed for bolting to begin decreases as the mean temperature decreases.

At present, several options exist which may allow the production of Chinese cabbages into colder seasons, including the use of bolting tolerant cultivars and cultural practices which reduce the exposure of the plants to cold temperature. In particular, the use of container-grown transplants, raised under conditions which do not induce bolting prior to field planting, have allowed some control. Reproductive development in brassica plants is usually triggered by environmental factors such as temperature and photoperiod (Friend, 1985) but can be influenced by factors such as cultivar (Guttormsen and Moe, 1985b; Mero and Honma, 1984; Lorenz, 1946) and stage of growth or transplant size (Eguchi et al, 1962; Elers and Weihe, 1984b; Benoit and Ceustermans, 1981; Guttormsen, 1981; Guttormsen and Moe, 1985b; Kratky et al, 1982; Lorenz, 1946; Mero and Honma, 1984).
3.1.1 Temperature effects

Temperature is the major influence on bolting in Chinese cabbage (Elers and Wiebe, 1984a), with the response to cold temperature being cumulative. In general, two weeks exposure to temperatures of 13°C or lower induce bolting (Nakamura, 1976) and this process will only be initiated when the chilling requirement for the plant is met (Guttormsen, 1981). The chilling requirement needed to initiate bolting in Chinese cabbage is referred to as its vernalisation requirement. Vernalisation is therefore the cumulative effect of cold temperature over sufficient time to initiate the reproductive phase of the plant. It occurs naturally as part of the plant’s development, literally meaning “to bring to the spring condition” (Debenham, undated p202). The onset of flowering is affected equally by both day and night temperature, with an increase in either from 12°C to 21°C, delaying time to first flowering by 15 and 17 days respectively. An increased day temperature does not nullify the vernalising effect of low night temperatures, but delays bolting and flowering.

For cold tolerant cultivars, grown for early production into colder months, it is generally accepted that average daily temperatures greater than 15-18°C significantly reduce flower initiation and bolting compared with lower temperatures (Guttormsen, 1981; Guttormsen and Moe, 1985a; Guttormsen and Moe, 1985b; Moe and Guttormsen, 1985; Eguchi et al, 1962; Elers and Weibe, 1984a). Guttormsen (1981) found that exposing Chinese cabbage to 18°C over a four week period was sufficient to prevent premature bolting of a cold tolerant cultivar exposed to subsequent day/night temperatures of 15/12°C. The optimum temperature range is 18-20°C for early growth, 15-16°C during early head development, and 10-13°C for final head development (Waters et al, 1992). Cold sensitive cultivars grown for summer production require higher temperatures to prevent premature bolting than cold tolerant cultivars. Guttormsen and Moe (1985b), showed that plants held at temperatures of 24°C for up to three weeks prior to chilling at 15°C for one week, still resulted in premature bolting of cold sensitive cultivars. Moe and Guttormsen (1985) found that temperatures above 15°C reduced bolting to practically nothing for cold tolerant cultivars, whereas all cold sensitive plants bolted at 21°C. Temperature is the dominant influence on final head weight (Elers and Weibe, 1984b), with high day and low night temperatures favouring the heading process (Opena et al, 1988) and day temperature affects the growth of young plants more than night temperature (Guttormsen and Moe, 1985b).

3.1.2 Sensitivity to vernalisation with relation to stage of growth

Sensitivity to cold temperature begins during germination but it is not until the emergence of the radicle that a complete vernalisation can occur (Elers and Weibe, 1984a). Field experiments by Eguchi et al., (1962) and work by Benoit and Ceustermans (1981) suggest that sensitivity generally increases with plant age. However, work by Guttormsen (1981) and Guttormsen and Moe (1985a) reported that three week old transplants showed less bolting than one week old transplants when subsequently exposed to vernalising temperatures. This work indicates that bolting may be reduced by prolonging the raising period at non-vernalising temperatures. Elers and Weibe (1984a) found that in growth chamber
experiments, plant age (0 to 21 days) at the beginning of vernalisation does not have a significant effect on the time from the end of vernalisation to the beginning of flowering, however it does increase the final leaf number and therefore the tendency to form a head (Elers and Weibe, 1984b).

### 3.1.3 Interaction between temperature and photoperiod

Research into the interaction between temperature and photoperiod on bolting indicates clearly that photoperiod plays a secondary role (Elers and Weibe, 1984a,b; Guttormsen, 1981; Moe and Guttormsen, 1985; Lorenz, 1946) and that the level of influence depends on the amount of cold temperature the plant has been exposed to (Elers and Weibe, 1984a,b; Moe and Guttormsen, 1985). These studies have demonstrated that day length only influences bolting when temperatures are cold enough to have a vernalising effect. Under such temperatures, short days reduce bolting and long days promote it. However, there are conflicting views as to whether the greatest influence of photoperiod occurs during vernalisation, or after it. An overseas study (Moe and Guttormsen, 1985) has shown that a short day treatment of 10 hours during a three week vernalisation period prior to transplanting markedly reduced the incidence of bolting for both cold tolerant and cold sensitive cultivars compared to a natural daylength of 15-17 hours. This study suggests that a short day treatment may be used during propagation to reduce the risk of premature bolting if a higher temperature cannot be provided during propagation or after transplanting in the field. This is disputed by Elers and Weibe (1984a), who argue that the effect of short days is too small to be economical. They found that day length had a more significant effect on bolting after vernalisation had already occurred. Fully vernalised plants (exposed for 20 days to 5°C) subsequently exposed to short day length periods took twice as long to flower as plants exposed to longer days. In addition, when vernalisation was partial (12 days at 5°C), cabbages remained vegetative under subsequent exposure to short days, whereas long day plants bolted, albeit at a later time than when fully vernalised.

Bernier et al. (1981) reported that exposure to high temperatures and low light flux or short days immediately after vernalisation, produces a devernalisation response in some plants. In effect, this research indicates that vernalisation is reversible and this response has been documented in Chinese cabbage (Lee and Sheo, 1957). Elers and Weibe (1984a) demonstrated a devernalising response in Chinese cabbage due to a short day treatment applied after incomplete vernalisation and further research (Elers and Weibe, 1984b) showed a similar effect when Chinese cabbage plants were exposed, after vernalisation, to temperatures consistently above 18°C for three weeks.

Temperature and photoperiod also act together during propagation to influence final leaf number and the growth of the transplant (Elers and Weibe, 1984a,b; Moe and Guttormsen, 1985). Elers and Weibe (1984a) found that the final number of leaves on plants which were exposed to short day length periods after vernalisation was twice the number for those exposed to longer days after vernalisation. There was no difference in final leaf number when cabbages were exposed to short or long days during vernalisation. In a follow-up study, Elers and Weibe (1984b) noted a slight increase in final leaf number when a short day treatment during vernalisation was applied. This was associated with shorter flower
stalks and a lower plant weight at maturity compared to long day plants. Moe and Guttormsen (1985) also found that exposing transplants to short days during vernalisation results in lower transplant weights than exposing them to longer day lengths. Increasing the temperature during the propagation period above levels required for vernalisation had little effect on the final weight of transplants exposed to short days. Interestingly, when Elers and Weihe (1984b) compared final cabbage weight at a given flower stalk length, they found that day length during propagation was not influencing plant weight. Rather, the dominant influence was temperature. From the above studies it may be surmised that the real benefits of short days are that they extend vegetative growth and the production of a greater number of leaves, thereby increasing the likelihood of head formation, whereas longer days cause plants to grow faster and therefore bolt earlier.

3.1.4 The use of row covers

Row covers may extend the growing season into cooler months by raising soil and air temperatures within the cover. They aid in heat retention and give protection from the wind during the day but have little effect on night temperatures so bolting may still be a problem in cold weather. Under the correct local climatic conditions, bolting has been shown to decrease when transplants were covered with plastic row covers in the field (Anon., 1984a; Fritz and Honma, 1984).

3.1.5 Light intensity

A variation in light intensity after a period of vernalisation influences flowering and bolting in Chinese cabbage in the same way as it does typical qualitative long day plants. A reduction in light intensity results in a decrease in flower stem length and therefore a longer time to bolting compared to an increased light intensity. Fast bolting cultivars are more responsive to lower light intensity from the same source than slower bolting cultivars (Pressman and Shaked, 1988). Increased light intensity also promotes broad leaf growth and heading whereas a low light intensity encourages the growth of narrow leaves and a reduced head yield (Kato, 1981).

3.1.6 Root temperature and bolting

The shoot apex is generally considered to be the organ in plants which senses cold temperature (Vince-Prue, 1975). However, the root zone of Chinese cabbage may also respond to vernalisation and devernalisation temperatures (Pressman and Negbi, 1981). Warming the roots of Chinese cabbage to 30°C delays bolting and flowering in subsequent natural day lengths of 12-14 hours and long day lengths of 16 hours, even if the tops of plants are exposed to vernalisation temperatures from durations of 10 to 30 days.

3.1.7 Summary

Chinese cabbage - a review of literature
Bolting is of economic importance to the Chinese cabbage industry because it can render the cabbage heads unmarketable. Temperature is the dominant factor in bolting induction due to its influence on reproductive development. Constant average temperatures greater than 15-18°C are necessary to prevent bolting even in cold tolerant cultivars and higher temperatures are required for cold sensitive cultivars. The colder the temperature, the less the exposure time required for flower stalk initiation. Therefore bolting is of practical importance when growing Chinese cabbage into colder months of the year.

Photoperiod plays a minor but important role in the reproductive development of Chinese cabbage. Long days shorten the period between vernalisation and bolting and short days lengthen it. Short days extend vegetative growth and stimulate the production of a greater number of leaves, thereby increasing the likelihood of head formation, whereas longer day lengths result in faster growing plants which bolt earlier.

It is unclear whether, as the transplant gets older during propagation, it becomes more or less sensitive to cold temperature and therefore more or less likely to bolt. Field experiments have indicated both an increasing and decreasing sensitivity to cold temperatures in transplants up to three weeks old after sowing and experiments in growth chambers suggest that sensitivity remains the same. Management practices such as the use of bolting tolerant cultivars, container-grown seedlings raised under non-vernalisng temperatures for several weeks prior to field transplanting and the use of plastic row covers in the field have been effectively used to reduce bolting in Chinese cabbage.
3.2 Tipburn

Tipburn is a field disorder in cruciferous crops which causes browning of the margins of young inner leaves and in its most severe form results in necrotic breakdown of leaf tissue. These conditions often make the crop susceptible to secondary invasion by bacteria. Tolerance to tipburn exists in both wong bok and michihili cultivars of Chinese cabbage.

Research indicates that a deficiency of Calcium (Ca) can cause tipburn. Under normal conditions, the transpiration stream delivers Ca preferentially to the outer leaves as they have much greater transpiration rates which result in reduced quantities to the low transpiring inner leaves. Kuo et al (1981) showed that the lowest Ca levels are found in the marginal areas of the inner leaves and Maynard et al. (1965) and Cox et al. (1976) working on cabbage and lettuce respectively, found that symptoms of tipburn are confined to these areas.

Preferential accumulation of Ca in the outer leaves at the expense of the inner leaves can be caused by high transpiration rates because the root pressure flow required for Calcium uptake is reduced under these conditions. Under conditions of high root pressure, Ca is delivered preferentially to immature, rapidly growing tissues such as the inner leaves. Both high air temperature and low humidity increase transpiration rates in Chinese cabbage. Inhibiting transpiration from the outer leaves of Chinese cabbage through manipulation of air temperature and humidity may cause more Ca to move into inner leaves and reduce tipburn because root pressure flow is enhanced. Palzkill et al (1976) and Palzkill and Tibbits (1977) demonstrated this by covering Chinese cabbage leaves with plastic to increase humidity during the day and Kuo et al (1981) showed a similar reduction in tipburn by covering leaves at night. It has been suggested that a diurnal fluctuation in water status in the low transpiring leaves of Chinese cabbage produced by low day and high night relative humidity may explain why plants grown under these conditions have few calcium-related disorders (Palzkill et al., 1976). Root pressure flow can also be limited by low soil water, by water with a high salt concentration, as well as by flooding soil (Kuo et al, 1981). All these conditions result in reduced ion uptake and an increase of tipburn symptoms.

It has been postulated that tipburn results from environmental conditions which are conducive to rapid growth (Cox et al.,1976; Anon, 1984c). Kuo et al (1981) found that plants covered with plastic, which had no tipburn, had lower fresh and dry weights than uncovered plants which may lend support to this argument. Furthermore, tipburn is most severe during the faster spring growth which accompanies bolting (Pressman et al., 1993). This indicates that bolting may be increasing tipburn by bringing about factors which further reduce the Ca content of the young leaves. In this high growth period, differentiation and development of the inflorescence competes with the young leaves for Ca which preferentially moves to the developing shoot apex after the majority has gone to the large, outer leaves.

Restricting root growth also increases tipburn even though the root restriction simultaneously reduces growth rate. This is because restricted roots have a higher content of suberin, a cork like substance which is impermeable to water and this limits the uptake and supply of Ca to the inner leaves. However, tipburn is not merely a function of water stress in plants with restricted root growth since abscisic acid levels, an indicator of stress, is not higher in these plants (Aloni, 1986). A study on soil depth and total soil volume
found that a soil volume greater than 45 litres/plant, which allowed adequate root growth, reduced the incidence of tipburn (Anon, 1984c).

Tipburn in Chinese cabbage has also been linked to ammonium toxicity. Toxic concentrations of ammonium ions can damage plant roots which in turn cause reduced calcium levels in the plant. Tao et al. (1986) found that the incidence of tipburn increased as the concentration of inorganic (ammonium) nitrogen increased. This supports other findings that restricting root growth, limiting root uptake and reducing root pressure flow all result in tipburn symptoms. In addition, during faster growth root damage by ammonium ions will have a greater effect because uptake demand is high. Research at the Asian Vegetable Research and Development Centre in Taiwan (Anon., 1984c) found that vigorous growth in Chinese cabbage could be reduced by limiting soil moisture and basal nitrogen. A follow-up study demonstrated that this could be achieved through a split application of liquid ammonium-nitrogen (NH$_4$-N) and nitrate-nitrogen (NO$_3$-N) (Anon., 1984d). Under this treatment, cabbages grew constantly and produced heavy heads with no tipburn symptoms. The researchers found that an optimum ratio of ammonium to nitrate was required for maximum yield and the type of nitrogen source and the timing of the application were more important than the application rate. The highest yields of Chinese cabbage with the lowest symptoms of tipburn occurred when ammonium nitrogen was used as the sole source of nitrogen during the early stages of Chinese cabbage growth, followed by an increase in the ratio of nitrate to ammonium up until one week before head formation. After head formation only nitrate nitrogen was used, because it was found that tipburn symptoms were greatest in head leaves with high accumulated levels of ammonium nitrogen.

The benefit of direct foliar sprays such as Calcium Nitrate as a means to reduce tipburn is an issue of contention. Pressman et al. (1993) found that spraying Calcium Nitrate directly onto young Chinese cabbage leaves prevents or reduces tipburn, whereas McKay and Phillips (1990) argue that any benefit is generally very small compared to the associated costs.

3.2.1 Summary

The primary cause of tipburn in Chinese cabbage is a low supply of calcium to the young, inner leaves particularly during rapid growth and head formation. Climatic factors which include water stress or high transpiration rates increase tipburn while large diurnal fluctuations in relative humidity (resulting in increased root pressure flow and translocation of calcium to the inner leaves) reduces tipburn. Cultural practices which reduce root restriction and promote even growth and development, such as good irrigation practices and proper application of nitrogen in its correct form (an optimum ratio of ammonium to nitrate is required) result in healthy plants without tipburn. Although foliar applications of calcium can reduce tipburn, the cost/benefits appear to be small.
3.3 Gomasho

Gomasho or ‘fleck’, as it is known in the industry, is a physiological disorder which is characterised by brown to black specking of the normally white leaf midribs of Chinese cabbage heads, especially during cooler months. It has become an important disorder in W.A. since 1985 and has resulted in rejection of whole crops for export (Phillips and McKay, 1989). Japanese research has failed to identify the cause, although tolerant cultivars have been selected. This is supported by research at the Manjimup Horticultural Research Centre in W.A. (McKay and Boyd, undated a; McKay and Boyd, undated b) and in Tasmania (Simmul, 1989), where tolerant, moderately susceptible and susceptible cultivars have been screened. Symptoms can occur in the field or during storage. Mild symptoms at harvest will generally develop further, becoming severe after 10-12 days. Symptoms have also been linked to high rates of early leaf development (McKay and Phillips, 1990). High applications of nitrogen fertiliser can exaggerate the disorder, especially ammonium nitrate, as can a pH around eight and high rates of phosphorous (Phillips and McKay, 1989). Gomasho has also been associated with high tissue copper levels and low levels of boron (Phillips, 1990). Matsumoto (1988) identifies two types of symptoms during development. Type one occurs in the midrib of immature leaves and is associated with rapid early growth of the leaf tissue. Type two occurs in mature leaves and is associated with a decrease in the ratio of outer to inner leaves. Despite considerable amounts of research, the cause of this disorder is still unknown. At present it is best controlled by using tolerant cultivars and good cultural practices. Excessive use of fertilisers, particularly ammonium-nitrate should be avoided and the pH of the soil maintained at around pH 7.
4. Common Diseases

4.1 Bacterial Diseases

4.1.1 Black rot

Black rot is caused by the bacterial organism *Xanthomonas campestris* and is the most severe bacterial disease of crucifers worldwide. When there is plentiful rainfall or heavy dews and temperatures are between 16-21°C, the disease can spread rapidly and cause high crop losses. In young seedlings, cotyledon margins turn black and the cotyledons shrivel and fall off. In plants with more fully developed leaves the internal tissue near the infection site turns black or brown. In the field, large yellow sections at the leaf margins are noticeable, especially in plants that remain wet for extended periods (Sherf and MacNab, 1986). Soft rot bacteria can enter the black rot lesions, resulting in extremely soft tissue and slimy decay and rendering the head worthless (Snowdon, 1991). Infection can occur through wilted outer leaves if water is not adequate, tissue damaged by tipburn or fertiliser burn (particularly from excessive nitrogen applications) and through wounds inflicted by insects or by mechanical damage during harvesting and handling (Anon., 1984a; McKay and Phillips, 1990). The organism survives over winter on and in seed, in plant debris left in the field and in weeds.

The bacteria is spread throughout the plant via the xylem (water carrying) vessels to the stem, roots and leaves. In plants raised from infected seed, bacteria move from the cotyledons to the young leaves as the seedlings emerge and begin to grow. When an early infection occurs in the field, the bacteria move from the infection site throughout the plant. The bacteria can also cause infection through damaged plant tissue and is spread by splashing or running water, insects, in infected seed and transplants, in equipment or by handling infected plants. Water is needed for the disease to develop, although temperature appears to be more important (Sherf and MacNab, 1986).

Infection is greatly enhanced by hot, humid weather (Fritz and Honma, 1987) and while the disease will develop at temperatures between 5 and 36°C, the optimum temperature range is 27-30°C.

Sherf and MacNab (1986) reported that the disease could be controlled by growing transplants from seed treated with hot water and through a combination of sodium hypochlorite and “Thiram®”. Belder and Bartha (1983) found that a copper-based spray applied every 7-10 days effectively controlled black rot once symptoms appeared. Bacteria can persist in plant debris for more than one year so soils used should not have had crucifers grown in them for two years. Crops should be grown in soils with good drainage and good sanitation practices such as removing infected plants, ploughing debris into soil after harvest and the use of clean equipment should be employed (Sherf and MacNab, 1986; Snowdon, 1991). Chinese cabbage cultivars such as WR Green 60, Spectrum and Green Rocket have been found to be tolerant of bacterial rots (McKay and Phillips, 1990).
4.2 Fungal diseases

4.2.1 Clubroot (*Plasmodiophora brassicae*)

Clubroot is one of the most serious diseases of crucifer crops world-wide and is caused by *Plasmodiophora brassicae*, a slime mould fungus. In Victoria, clubroot has been recorded on crops such as cabbage, broccoli, Chinese cabbage, cauliflower, brussel sprouts, turnip and radish (Porter, 1986). This fungus is soil-borne and enters plants through fine hairs on young roots or through wounds in the root or stem and causes the roots to become abnormally large. Severely distorted roots cannot absorb minerals or water from the soil, resulting in stunted plants that usually form small heads (Sherf and MacNab, 1986). McKay and Phillips (1990) have found that plants often wilt during the hotter part of the day. It is a difficult proposition to maintain pathogen-free fields if other fields or properties in the area are infected. The organism spreads readily through infected seedlings, in flood water or even in soil or manure on equipment or the boots of workers. Once in the soil the clubroot organism can survive for at least twenty years, even when no host is present, and can infect susceptible plants, including cruciferous weeds during this time (Porter, 1986). The disease is favoured by acid soils and moist conditions (Waters et al., 1992) and soil temperatures between 20 to 25°C, although infection can occur at temperatures as low as 12°C (Porter, 1986). Chinese cabbage is one of the most highly susceptible crops to clubroot (Sherf and MacNab, 1986). The use of tolerant cultivars, such as Yuki and Hector and good crop hygiene and cultural practices help to minimise the impact of this disease (McKay and Phillips, 1990; Belder and Bartha, 1983). To control the disease, the soil pH should be maintained at around seven, cruciferous weeds should be removed from in or around the crop, the crop should not be excessively watered, transplants should be grown in pathogen-free soil and the transplant water should be chemically treated to control clubroot infections (Sherf and MacNab, 1986; Belder and Bartha, 1983; Porter, 1986). Porter (1986) found that solarisation (the use of clear plastic to heat the soil to temperatures lethal to soil borne disease during periods of high temperature) combined with low dosage rates of the chemical “Dazomet®”, can effectively control clubroot. The use of at least a seven-year planting rotation free from any crucifers helps in minimising clubroot infection, but is not a very practical solution to this problem. Breeding for resistance to clubroot is difficult because many races of the fungus may exist in the same area.

4.2.2 Blackleg (*Phoma lingam*)

Blackleg is caused by the fungus *Phoma lingam*. Infection causes long, light brown sunken lesions or cankers in the stem of plants near the soil line and small light brown to greyish spots which contain a large number of black pycnidia or fruiting bodies form on the leaves. Badly affected plants often wilt suddenly and die or topple over as the head enlarges (Sherf and MacNab, 1986; Belder and Bartha, 1983). Free moisture, such as persistent dew, favours the reproductive phase of the fungus (Sherf and MacNab, 1986). The fungus is seed-borne, but also exists in cruciferous weeds, in manure of animals fed on infected leaves and can survive in plant debris for three years (Belder and Bartha, 1983; Sherf and
Chinese cabbage - a review of literature

MacNab, 1986). The fungus grows and reproduces on the seed and in the soil, using the cotyledons as a fruiting place. Millions of conidia are exuded from the fruiting bodies and can be splashed by water or blown in the wind to other plants (Sherf and MacNab, 1986). Belder and Bartha (1983) report that chemical treatment with “Quintozene®” can remove the fungus from seeds and hot water treatment of seeds is also effective. Infected plants should be removed from the field and plant debris ploughed in after harvest. Animals should not be fed on infected leaves if their manure is to be used as fertiliser. Well draining soils should be used since the fungus is most destructive in wet soils (Sherf and MacNab, 1986). At least a three year rotation with plants that are not in the cabbage family should be adopted since the fungus can remain the soil for several years (Belder and Bartha, 1983; Sherf and MacNab, 1986).

4.2.3 Yellows or Fusarium wilt (Fusarium oxysporum f.sp. conglutinans) Yellows or Fusarium wilt (Fusarium oxysporum f.sp. conglutinans)

The disease Yellows or Fusarium wilt is caused by the fungus Fusarium oxysporum f.sp. conglutinans. Symptoms include leaf yellowing and defoliation on older plants and yellowing, stunting and death of seedlings. Lower leaves curl and leaf stems are often twisted to one side, resulting in stunting on one side of the plant. Infected leaves drop prematurely, resulting in a head which is almost totally defoliated. In heavily infested soil, complete destruction of susceptible plants can occur. The fungus can cause harm to crops at temperatures between 16 and 35°C. Symptoms are most severe in temperatures greater than 24°C and may not appear on plants grown in cool soil until the soil warms up. The fungus can live for a number of years in the soil, or in seed and seedlings and once it is established in an area, it spreads rapidly in rain, floods and equipment to unaffected areas. The pathogen usually enters the plants through young roots but can also cause infection through wounds in older roots and moves via the xylem to the stems and leaves. To help control this disease, infected seedlings should not be planted in areas where the disease is not yet present. Once the disease is present, the only successful control method is to use disease tolerant cultivars. Seed treatments, rotations and fungicides do not control this disease (Sherf and MacNab, 1986).

4.2.4 Watery soft rot or White rot (Sclerotinia sclerotiorum) Watery soft rot or White rot (Sclerotinia sclerotiorum)

This disease, caused by the fungus Sclerotinia sclerotiorum, affects crucifers in nearly all parts of the world except the warmest tropics and can occur in the field, during transit or in storage. Water-soaked sections initially develop over the stem and leaves nearest the ground. In later stages of the disease, leaves wilt, the plant collapses and the head becomes covered with a mass of cottony fungus containing numerous irregular shaped hard black bodies called sclerotia which are clearly visible. This can also occur in transit and storage and can be spread from head to head while in a box or package. The fungus requires abundant moisture and thrives where there is frequent rain or fog. It can cause infections between temperatures of 0 and 28°C, with the optimum range between 16 and 21°C (Sherf and MacNab, 1986). Infection can occur through air-borne spores arising from the seed-like sclerotia, which live from
season to season on living plants and plant debris and can survive in the soil for many years (Sherf and MacNab, 1986; Belder and Bartha, 1983). The fungus requires damaged and decaying tissue for the initial infection before it can invade healthy tissue (Belder and Bartha, 1983). To control this disease, the crop should be planted into soil with good drainage and rotated with resistant or immune crops (Sherf and MacNab, 1986; Belder and Bartha, 1983). The crop should not be over irrigated and preferably not irrigated in the afternoon and plant debris should be ploughed into the soil after harvest (Belder and Bartha, 1983). Head dips before storage have not successfully controlled the disease in cabbage (Sherf and MacNab, 1986), although benomyl has been reported to be an effective chemical treatment when the disease first appears in the field (Belder and Bartha, 1983).

4.2.5 Downey Mildew (Peronospora parasitica)

Downey mildew is caused by the fungus *Peronospora parasitica*, which can severely damage seedlings and causes leaf spotting as plants approach maturity in cool weather. Secondary soft rots can enter lesions in the head and cause damage in transit and storage. Downey mildew affects nearly all of the cultivated and weed plants of the crucifer family although different strains of the organism exist, some of which are specific to certain crop groups. A white mildew is found mostly on the undersides of leaves at the early stage of infection and later the top sides of leaves become yellowish and younger leaves may drop off. Older leaves usually remain on the plant and the infected area enlarges as it becomes tan and papery, killing whole leaves if it is severe enough. On cabbage heads, sunken black spots varying in size from minute dots to two centimetres or more in diameter may develop. The fungus survives between crops and overwinters as thick-walled resting spores in roots or in old diseased plant parts. It grows when new crop roots begin to develop and is carried above ground on new shoots where it invades leaves and produces spores which are carried in the air. The fungus spreads and reproduces best when there is persistent high moisture such as fog, rain or dew and when night temperatures do not rise above 24°C (Sherf and MacNab, 1986). Well-drained soils and a crop rotation, with crucifers planted three years apart, help control the mildew and fungicides such as “Mancozeb®”, “Zineb®”, copper oxychloride and cupric hydroxide have been reported to be successful as chemical control agents (Belder and Bartha, 1983).

4.2.6 Alternaria leaf spot (Alternaria brassicae)

*Alternaria* leaf spot, also referred to as black spot in cabbage, brown rot in cauliflower and head rot in broccoli, is caused by the fungus *Alternaria brassicae*. Losses occur through damping off in seedlings or a stunting of growing plants and spotting of lower leaves and the heads of older plants. If a seedling is affected, it will not grow into a normal sized plant and therefore will not yield well. On mature head leaves, small yellow areas are formed initially which later enlarge into concentric circles that are black and sooty in colour but it is not usually economically important unless the disease is severe enough to warrant heavy trimming (Sherf and MacNab, 1986). Even after trimming, heads can undergo significant rotting during storage (Snowdon, 1991). The fungus survives in cruciferous weeds and requires
persistent moisture such as rain or dew for more than nine hours for infection to occur. It does not develop well below 8°C, has an optimum growth at 24-28°C and is inhibited above 36°C (Sherf and MacNab, 1986). The fungus produces large spores that can be blown in the wind, splashed by water or carried by equipment and animals through the field and can also be spread through infected seeds. To help control this disease, seed should be treated with hot water, cruciferous weeds should be removed from and around fields and rotations undertaken with non-cruciferous crops (Belder and Bartha, 1983; Sherf and MacNab, 1986). McKay and Phillips (1990) recommend treating the seed with “Thiram®”, while Belder and Bartha (1983) report that “Mancozeb®”, “Zineb®” and copper oxychloride have proven successful fungicide chemicals when field symptoms first appear.

4.2.7 Ringspot (Mycosphaerella brassicicola)

Ringspot is caused by the fungus Mycosphaerella brassicicola and occurs on all above ground plant parts, especially older leaves. Initially, it appears as a mass of spores which look like snow white specks arranged in concentric circles. Older spots turn greyish-brown with a green border and small fruiting bodies form into a series of concentric black dots surrounded by one or more rings of white dots (Belder and Bartha, 1983; Sherf and MacNab, 1986). Leaves become yellow and die, leaving the grey-green spots on the dead leaf (Belder and Bartha, 1983). Affected veins and petioles become hard and brown and can distort and twist leaves if they split (Sherf and MacNab, 1986). The development of symptoms is significantly arrested during cold storage, however substantial deterioration can still occur over long storage periods (Snowdon, 1991). The fungus overwinters in diseased plant parts, plant debris and seed. It is spread by air-borne spores, requires high levels of moisture for infection to occur and develops best at temperatures between 16 and 20°C, although it will cause infections at temperatures greater than 12°C. Spores are killed at 28°C (Sherf and MacNab, 1986). Seeds should be treated with hot water and planted into fields which have been free from crucifers for at least two years. “Benomyl®”, copper oxychloride and cupric hydroxide have been reported to provide high levels of control in the field when sprayed at the first sign of symptoms or after wet weather (Sherf and MacNab, 1986; Belder and Bartha, 1983).

4.2.8 Cercosporella leaf spot (Cercosporella brassicae) and Cercospora leaf spot (Cercospora spp.)

Cercosporella leaf spot is caused by the fungus Cercosporella brassicae and is present in nearly all temperate and subtropical countries. It causes circular spots with grey to brown or almost papery white centres with slightly darkened margins. If the infection is severe, the affected leaves may turn yellow and drop to the ground. The species of Cercospora which infects Chinese cabbage is called Cercospora brassicicola and also infects mustard, rape, turnip and to a small extent, cabbage. It causes circular to angular spots on leaves which are pale green to grey or white, usually with a brown border. These fungi are carried in a small percentage of seeds and can overwinter in cruciferous weeds. Spores are carried by wind or rain and the greatest infection occurs in conditions with abundant moisture and temperatures between 13 and 18°C. To help control these diseases, cruciferous weeds should be removed from around
crops and crops should be planted into soil which has good drainage (Sherf and MacNab, 1986). Mancozeb, zineb and copper oxychloride have been reported to help control leaf spot in crucifers (Belder and Bartha, 1983; Sherf and MacNab, 1986).

4.2.9 White Leaf Spot (*Pseudocerosporella capsellae*)

White leaf spot is caused by the fungus *Pseudocerosporella capsellae*. It is characterised by white to brown spots about 10mm in diameter which develop initially on the older leaves and in severe cases can cause death of the whole leaf. Moist conditions are favourable for the disease to spread and the fungus survives on seed and plant debris of cruciferous plants. In Western Australia, the disease is more prevalent on Chinese cabbage in wet autumn and early winter conditions, but can be controlled by fungicides applied when symptoms first appear (McKay and Phillips, 1990). Other control methods include the removal of cruciferous weeds from near susceptible crops, ploughing crop residue into the soil after harvest and using hot water treatments on seeds before planting.

4.2.10 Rhizoctonia fungal diseases (*Rhizoctonia solani*)

The species of *Rhizoctonia* which affects cruciferous plants is *Rhizoctonia solani* and causes damping off and wirestem in seedlings and bottom rot and head rot in either the field or in storage. Damping off is also caused by species of *Phythium* and can cause the seed and seedling to rot (Waters et al., 1992). It develops most rapidly in seedlings grown in wet soil at or above 24°C and causes light brown water-soaked stems near the soil line and the seedlings wilt, topple and die (Waters et al., 1992; Sherf and MacNab, 1986). Wirestem causes the stem above and below the soil line to shrivel and darken and the outer stem tissue falls off to reveal a dark, wiry, woody inner stem. This causes the plant to take on a stunted appearance and although most survive, they do poorly in the field. Bottom rot develops in the field when new infections in outer head leaves result from contact with moist, infected soil, or as a continuing infection from wirestem infected seedlings. The lower leaves wilt, decay and turn black. Most heads affected by bottom rot will not recover and later develop head rot. Head rot develops between head formation and maturity and causes outer head leaves to wilt, become pale and turn brown to black near the main stem, eventually resulting in leaf death. These dead leaves drop off, exposing the stem beneath the head and brown *Rhizoctonia* mycelium and sclerotia may develop over the whole head surface. Secondary rot bacteria usually invade the diseased tissue, resulting in a slimy, smelly mass.

The fungus persists indefinitely in the soil and survives as sclerotia which are very resistant to cold, heat, drought and most chemicals. When conditions are favourable, the sclerotia germinate and form delicate threads that can cause infection through wounds, intact tissue and natural openings of roots and leaves. The optimum temperature for infection is between 25 to 27°C but infection can occur between 12 and 32°C. Sherf and MacNab (1986) report that seed should be treated with hot water to minimise seed-borne
infection and seedlings be grown in soil which has been chemically treated to reduce the possibility of infection. Belder and Bartha (1983) report that “Quintozene®”, “Captan®”, “Dazomet®” and chlorinated-C3-hydrocarbons have been used to control damping off. For bottom rot and head rot control, seedlings infected with wirestem should be removed and seedlings should not be planted in soil where crucifers have grown for the past three years (Sherf and MacNab, 1986). The chemical quintozene has been reported to help in the control of wirestem (Belder and Bartha, 1983).

4.2.11 Turnip Anthracnose (Colletotrichum higginsianum) Turnip Anthracnose (Colletotrichum higginsianum)

Turnip Anthracnose is caused by the fungus Colletotrichum higginsianum and can be very destructive in Chinese cabbage. It causes small, dry, circular and pale-grey to straw coloured leaf spots and in severe cases causes the entire leaf to die. The fungus overwinters in fallen, infected leaves and cruciferous weeds and can be spread through the use of infected seed. Removal of cruciferous weeds, hot water treatments for seed, adequate soil drainage and long crop rotations help to control the disease. Fungicides such as “Maneb®” and “Zineb®” have been reported to successfully control turnip anthracnose when applied at plant emergence and then every seven days (Sherf and MacNab, 1986).

4.3 Viral Diseases

4.3.1 Turnip Mosaic Virus and Cauliflower Mosaic Virus Turnip Mosaic Virus and Cauliflower Mosaic Virus

The most important viral diseases affecting Chinese cabbage are caused by turnip mosaic virus (TuMV) and cauliflower mosaic virus (CaMV), which can occur alone or, more severely, together (Snowdon, 1991). Symptoms can be similar for both diseases, with black specking and stippling of heads at harvest or during storage (Sherf and MacNab, 1986). Affected plants may show dark necrotic lesions which can merge and kill large sections of leaf, causing distortion and failure to heart (Anon., 1984a). Early infections can reduce yields by 75 percent although late infections have been reported to have little affect on yield (Sherf and MacNab, 1986).

TuMV strains cause a range of diseases in cruciferous plants and have been referred to as mosaic, black-ringspot, mustard mosaic and cabbage A virus mosaic, among others. Infected plants are stunted with coarsely mottled and distorted leaves (Snowdon, 1991; Sherf and MacNab, 1986). At temperatures of 13 to 18°C the mottle is indistinct. However, in stored cabbage, black sunken spots develop on leaves throughout the head which are much larger than those caused by CaMV.

Only members of the cabbage family are infected by CaMV, with several strains known as cabbage B virus, Chinese cabbage virus and broccoli mosaic virus. Infected plants develop leaf mottling along the veins on the undersurface and the veins on the outer leaves become pale (vein clearing). A black stipple develops on leaves throughout the cabbage head in storage, with the specks much smaller than those caused by TuMV. Cauliflower mosaic virus, unlike TuMV, is not transmitted by seed. It has a higher
thermal inactivation point than TuMV and in all but one case is restricted to cruciferous plants, whereas TuMV has a wide host range (Sherf and MacNab, 1986).

Both viruses are transmissible by 40 to 50 species of aphids, which are most active during autumn and spring, in particular the green peach aphid (*Myzus persicae*) and the cabbage aphid (*Brevicoryne brassicae*). Both viruses are regarded as being non-persistent. This means that they are acquired by the aphid after only a very short period of feeding, often less than one minute and can be immediately transmitted from the mouthparts to an uninfected plant. In addition, the aphid loses virulence after a few hours unless it is reinfected by feeding on infected plants again. After infection, the plant can show symptoms of virus in less than nine days. Mild winters in temperate regions can result in early virus epidemics because aphid populations may be already high (Walkey, 1991).

The use of tolerant cultivars and good crop hygiene will help reduce disease outbreaks of these viruses and seed should be obtained from a reputable and knowledgeable seed producer to reduce the possibility of using seed containing TuMV. New crops should not be planted alongside old crops, infected plants should be removed, plant debris after harvest should be ploughed back into the soil and other sources of infection such as weeds should be removed from around crops (Belder and Bartha, 1983; Sherf and MacNab, 1986). The use of pesticides to reduce aphid number during feeding is not an effective method to reduce the impact of TuMV and CaMV, because a small population of aphids is sufficient to cause large virus outbreaks. In addition, the very short acquisition and transmission times for these viruses and the high reproductive rates of aphid populations makes pesticide usage even less effective (Sherf and McNab, 1986; McKinlay, 1992) and uneconomical.
5. Common Pests

5.1 Cabbage Aphid (*Brevicoryne brassicae*) and Green Peach Aphid (*Myzus persicae*)

The wingless form (aptera) of the cabbage aphid is between 1.6 and 2.6 mm long and is grey-green in colour, with characteristic black, transverse, dorsal bars on its abdomen and thorax. The alate, or winged form, is 1.6 to 2.8 mm long, with a dark coloured head and thorax and black, transverse, dorsal bars only on its abdomen. The wingless form of the green peach aphid is smaller than the cabbage aphid, between 1.25 and 2.5 mm long and has a barrel shaped body which can vary in colour from a uniform pale green to pink. The winged form has a similar size and colour to the wingless form, except it has a black patch on the centre of its abdomen (McKinlay, 1992).

Infestations are usually seen on the leaf as small, bleached, necrotic spots at the feeding sites. The leaves turn yellowish and curl in, thus protecting the aphid colonies (McKinlay, 1992). Infected plants may stop growing and if aphid populations are high enough, the plants wilt and die. A lower level of infestation can result in unmarketable heads, through the presence of both live and dead aphids and by contamination of plant heads with cast skins, wax and honeydew, the latter a sugary excretion that can provide an ideal medium for fungal growth (Hely et al., 1982).

In Australia, *B. brassicae* reproduces parthenogenetically (reproduction from unfertilised ova) throughout the year, giving birth to active, live young called nymphs. On the other hand, overwintering *M. persicae* can reproduce either parthenogenetically or by a sexual (egg laying) phase which is typical of aphids in colder parts of the world (Walkey, 1991; Hely et al., 1982; McKinlay, 1992). Aphid populations peak during spring in temperate Australian climates, with a smaller peak in autumn and lower levels in summer and winter. Nymphs rapidly develop and reproduce to form a colony of wingless aphids. When the colony is crowded or adverse weather conditions occur, the aphids will migrate by crawling to adjacent plants or by producing winged forms, spreading rapidly throughout the crop (Walkey, 1991; Hely et al., 1982).

In addition to direct crop damage, aphids transmit plant viruses. *B. brassicae* and *M. persicae* are vectors of the non-persistent cruciferous viruses, Cauliflower Mosaic Virus (CaMV) and Turnip Mosaic Virus (TuMV). The time taken for a feeding aphid to acquire these viruses is very short, often less than a minute and the virus is transmitted immediately the aphid moves from the infected plant and feeds on an uninfected plant (Walkey, 1991). After acquisition, the insect can only transmit the virus for a few hours, so to remain effective vectors of these viruses, the aphids need to be continually reinfected by feeding on infected plants (McKinlay, 1992).

Aphids are attacked by several natural predators including the common spotted ladybird, *Harmonia conformis* and wasp parasitoids such as *Diaeretus rapae*. However, they do not cause a significant reduction in aphid populations until a large amount of crop damage has already occurred (Hely et al., 1982).

Insecticides can be successful in reducing aphid populations (Belder and Bartha, 1983) and therefore can reduce direct crop damage. However, they do not impact significantly on the prevention of virus
transmissions. This is because chemicals will not result in 100 percent kill of the aphid population and only very small aphid numbers are needed to cause significant virus outbreaks.

5.2 Diamondback Moth (*Plutella xylostella*)

Diamondback moth, *Plutella xylostella*, is the most important pest of brassica crops worldwide (Talekar and Shelton, 1993; McKinlay, 1992) and feeds only on cruciferous crops and weeds (Hely et al., 1982; Talekar and Shelton, 1993). It is believed to have originated in the Mediterranean area and its ability to migrate and disperse over long distances has made it one of the most cosmopolitan plant pests (Talekar and Shelton, 1993).

The caterpillar phase of *Plutella* attacks and skeletonises leaves of cruciferous crops from the seedling stage to crop maturity and can result in widespread losses. Adult moths are about 9mm long and greyish brown, with three light brown to white, triangular marks on the trailing edge of each forewing which are visible as diamond shapes when the wings are folded at rest. The hindwings are fringed with grey hairs. In spring, after mating, the moth lays between 90 and 130 eggs on the underside of leaves, which hatch in about five or six days (Osmelak, 1985) and the caterpillars feed on the surface tissue of the leaves and sometimes burrow into the spongy mesophyll cells below the epidermis to feed, creating a window effect in the leaf. If disturbed while feeding, the caterpillars drop from the leaf and hang by fine silken threads (Belder and Bartha, 1983; Talekar and Shelton, 1993; McKinlay, 1992, Hely et al., 1982). The caterpillars are green in colour and grow to about 12 mm long, before constructing a flimsy cocoon on the leaf surface and pupating inside them. The adult emerges after a week or two (Hely et al., 1982) and becomes active at dusk and into the night (Talekar and Shelton, 1993). The time it takes to complete a lifecycle depends on temperature. In the hot regions of southern Europe and America, *Plutella* can complete its lifecycle in 12 to 15 days and there may be as many as 15 generations in the one year (McKinlay, 1992). In Victoria, the moth completes seven lifecycles during the year, with rapid build up of population and damage during summer when the life cycle is as short as a month. Lower populations and less damage occur in winter when the life cycle is considerably longer (Endersby and Ridland, 1994a).

*Plutella xylostella* is attacked by a range of parasites although only a few are effective in the field (McKinlay, 1992). Ichneumon wasp parasitoids of the genera *Diadegma*, *Cotesia* and *Diadromas* are among the most prominent and effective biological controls and have been introduced into Australia where they have resulted in heavy parasitism of *Plutella* and a marked decrease in damage to crucifers (Talekar and Shelton, 1993). Research is continuing worldwide into new biological control agents as well as breeding for resistant brassica cultivars and methods to disrupt the mating cycle of the moth by using pheremones (Douglas, 1994).

In many countries, including Asia and the United States, *P. xylostella* is resistant to every synthetic insecticide used against it in the field and is the first insect to develop resistance to the bacterial insecticide, *Bacillus thuringiensis*. Talekar and Shelton (1993) reported that in the 1940s, prior to the use of synthetic insecticides, Diamondback moth was not a major problem on crucifer crops. However, when wide spread use of chemicals was introduced in the 1950s, many of the natural enemies of *Plutella* were
removed, allowing the moth to become well established. A continued high reliance and frequent use of insecticides as control agents, coupled with the moths’ high fecundity and reproductive potential, eventually led to insecticide resistance and control failures. In Australia, resistance has been a problem in Queensland and South Australia for a number of years, but has only become a problem in New South Wales and Victoria in the last few years. In February and March of 1994, 60 to 70 percent of Victorian cauliflowers were not harvested due to damage by *Plutella*, despite the use of insecticides. In addition, contact with insecticides is very difficult because the caterpillars mainly feed within the head or on the underside of leaves (Osmelak, 1985; Douglas, 1994). Current research in Victoria is looking at evaluating the extent of resistance in *Plutella* to a wide range of chemical groups (Douglas, 1994). Integrated control methods are important in Australia to protect existing chemicals from resistance and to maximise their life span. Endersby and Ridland (1994b) state that transplants should be grown away from the main brassica plantings and treated with a bacterial insecticide. According to these researchers, insecticides from different chemical groups such as the synthetic pyrethroids, biologicals, organophosphates and carbamates should be alternated regularly in the spray programme and applied efficiently to maximise their effectiveness. In addition, cruciferous weeds such as wild radish and wild mustard should be destroyed and crop residues should be ploughed into the soil after harvest because these are potential food sources for the moth.

5.3 Cabbage White Butterfly (*Pieris rapae*)

Cabbage White Butterfly, *Pieris rapae*, originated in Europe and is now spread widely throughout the world (Hely et al., 1982). It feeds on the foliage of all cruciferous crops, in particular cabbage, cauliflower and broccoli (Swaine et al., 1991) and large amounts of its excrement, called frass, can render plants unmarketable (McKinlay, 1992). The butterfly is yellow to cream in colour, with black spots on the forewings and a wingspan of about 50 mm. Females have two black spots on the forewing and males have one and both have one black spot on the hindwings (Hely et al., 1982; McKinlay, 1992). The female lays yellow, bottle shaped eggs singly on the underside of leaves, which hatch in about 10 to 15 days (McKinlay, 1992). The caterpillar is pale green, with faint yellow stripes down the back and sides and has a velvety appearance due to a covering of fine hair (Hely et al., 1982). Early stages can be confused with Diamondback moth (*Plutella xylostella*) larvae, although older larvae of *Pieris rapae* are distinguished by their mature size of 3cm in length. *P. rapae* usually feeds around the heart or growing point of the plant leaving the veins untouched, causes larger holes than *Plutella* larvae and does not produce a window effect in the foliage (Swaine et al., 1991).

When the larva reaches its mature size, it pupates by forming a chrysalis which is attached by a silken girdle to a pad of silk on the leaf and is not easily seen because it closely matched the colour of the foliage (McKinlay, 1992). Alternatively, the chrysalis may be attached to posts or other structures in the field (Swaine et al., 1991). The adults are strong fliers and may be found many kilometres from a suitable host (Hely et al., 1982). In Australia, *P. rapae* causes most damage from spring to autumn and is most active in warmer
temperatures, causing less damage in winter (Swaine et al., 1991) and there can be several generations in the year (Hely et al., 1982).

*P. rapae* is parasitised by several imported wasp species, including *Pteromalus puparium*, a parasite of pupae and *Apanteles glomeratus* and *A. rubecula*, parasites of the larvae (Hely et al., 1982). Formulations of naturally occurring viral and bacterial diseases have proven successful overseas, including a granulosis virus of *P. brassicae* and the bacterial insecticide *B. thuringiensis*. Insecticide sprays used for Diamondback moth (*Plutella xylostella*) have also been reported to control Cabbage White Butterfly (Douglas, 1994). McKinlay (1992) reports that insecticide sprays should be applied at egg hatch, before the caterpillars enter the heart of the plant.
6. Recent Cultivar Evaluation Trials in Australia

Australian cultivar evaluation trials on Chinese cabbage have involved selection for slow-bolting, late maturing cultivars in order to extend the growing season into cooler months (Daly and Tomkins, unpublished; Simmul and Beattie, 1987; McKay and Boyd, undated a; McKay and Boyd, undated b; Rogers et al., 1989). Research in Western Australia (McKay and Boyd, undated a; McKay and Boyd, undated b), Victoria (Daly and Tomkins, unpublished) and Tasmania (Simmul, 1989), has looked at selection for tolerance to gomasho. Tolerance to tipburn has been studied in W.A., S.A. and Victoria (Phillips and McKay, 1989; Rogers et al., 1989; Daly and Tomkins, unpublished). Tolerance to bacterial soft rots has been researched in W.A., Victoria and Tasmania (Phillips and McKay, 1989; Daly and Tomkins, unpublished). Research into postharvest storage of Chinese cabbage cultivars has been conducted in Victoria (Daly and Tomkins, unpublished).

6.1 Western Australia

McKay and Boyd (undated a) found that high yielding cultivars possessing both gomasho and bolting tolerance and suitable head shapes were the wong bok types WR 70 days, RS1446 and China Pride. The wong bok cultivar Treasure Island and the michihili cultivar Green Rocket were among the most tolerant of gomasho within their respective types; however Green Rocket was the most susceptible to bolting. Slightly lower yielding cultivars possessing suitable attributes were Spectrum and the two major cultivars grown for January to early March sowings in W.A., WR Green 60 and Treasure Island, which are all wong bok types. Treasure Island was the latest maturing cultivar (117 days), followed by Green Rocket (110 days), with the rest maturing about a week earlier. The wong bok cultivars Kasumi II and Ming Emperor had the greatest bolting tolerance but were very susceptible to gomasho and soft rot. Treasure Island had a low tolerance to tipburn.

6.2 Tasmania

Simmul (1989) assessed a number of Chinese cabbage cultivars for tolerance to internal rotting, gomasho and bolting during the June to August period where high incidence usually occurs. The cultivars RS1446, WR 60 and China Pride were found to be more tolerant of internal rotting and gomasho than the other cultivars tested. Harvesting in early July resulted in a high percentage of marketable heads, however all cultivars bolted by mid August, with none suitable for market.

6.3 South Australia

Rogers et al. (1989) assessed Chinese cabbage cultivars for a range of disorders for both winter and spring plantings. The wong bok cultivar Hong Kong is recommended for winter and spring plantings. Both Hong Kong and Ming Emperor demonstrated resistance to bolting and tipburn. For the michihili cultivars, Jade Pagoda and BF123 had high yields with the lowest incidence of tipburn but tended to
6.4 Victoria

Daly and Tomkins (unpublished), based on field and storage trials conducted over two years, found that there is excellent potential for the production of Chinese cabbage in the east Gippsland cropping region of Victoria. Tolerance was found to exist in the Chinese cabbage cultivars tested for a range of disorders. Cultivars performed well in early autumn plantings, producing good sized heads which were free from disorders and had high marketable yields. Yuki, Treasure Island and WR Green 60 (wong bok cultivars) were superior cultivars for late autumn plantings, however bolting remained the most significant factor limiting production into winter.

The michihili cultivars Green Rocket and Monument were more susceptible to bolting than the wong bok cultivars. Treasure Island was the only cultivar which showed symptoms of tipburn. This was associated with a one month period of water stress prior to harvest. All cultivars displayed a good tolerance to bacterial rots.

High humidity air storage at 0°C for seven weeks was used to determine the relative storage potential of the Chinese cabbage cultivars. The main limiting factor to storage in most cultivars was gomasho. This invariably resulted in severe storage losses in the cultivars Hector, Kasumi II, Monument and Green Rocket. Yuki, Treasure Island and WR Green 60 were more tolerant to gomasho and performed well in storage, although WR Green 60 displayed enzymic browning along the midribs, characteristic of chilling injury.

The response of Chinese cabbage cultivars to controlled atmosphere storage over a nine week period was also assessed. Preliminary results appear to indicate that there are no real benefits in using CA storage over conventional high humidity air storage under the given experimental conditions. In addition, some cultivars displayed symptoms of high CO₂ injury during subsequent shelf-life simulation. The main symptom was accelerated breakdown and rotting of leaf tissue by opportunistic bacteria.
7. Harvest and handling

Product quality at harvest largely influences the rate of quality loss after harvest. Even the best postharvest handling and storage techniques can only minimise produce quality loss, they can never improve on it. This is especially important to the export of Chinese cabbage by sea freight which requires quality loss to be minimal after an extended period of storage, distribution and shelf-life. Therefore, it could be argued that factors which influence the production of Chinese cabbage are as important as postharvest factors in determining the final quality of the cabbage. These preharvest factors have been discussed in the preceding chapters of this review.

Kader et al. (1989) state that the main factors in maintaining quality and extending the storage life of vegetables include harvesting at optimum maturity, minimising mechanical injuries and providing the optimum temperature and relative humidity regimes throughout the marketing chain. Secondary factors include the modification of ambient Oxygen (O₂) and Carbon dioxide (CO₂) and/or ethylene (C₂H₄) concentrations to optimum levels for the particular produce.

7.1 Harvest

Chinese cabbage is usually harvested by hand using a harvest aid (Nguyen, 1992), although it may lend itself to mechanical harvesting because the plants stand erect, with little variation in shape between cabbages within the same cultivar (Waters et al, 1992). Often the cut and trimmed heads are placed onto a conveyor which feeds into bulk bins (McKay and Phillips, 1990). The outer leaves are trimmed from the head and the butt is cut flush with the outer leaf bases for both the export and local market. Heads should be fully turgid at harvest and placed in store before desiccation (Anon., 1984a). It is preferable to harvest Chinese cabbage in cool weather and to maintain a cool moist environment until it is placed in cool storage in order to reduce wilting (Nguyen, 1992). It should be pre-cooled to its optimum storage temperature of 0 to 1°C as soon as possible after harvest. Warm, fast growing conditions have been shown to reduce storage life and increase trimming losses. Cool, moist conditions with uniform growth in the month prior to harvesting are ideal. Leafy vegetables, with a high surface area to volume ratio, such as Chinese cabbage can be pre-cooled rapidly in a number of ways including vacuum cooling, forced air cooling and hydrocooling. Rapid pre-cooling minimises internal breakdown and bacterial soft rot and extends storage life (Anon., 1984a). Sozzi et al. (1980) found that an extended storage life can be achieved if Chinese cabbage is harvested at a more compact head stage.

7.2 Cool storage

Storage trials on Chinese cabbage show the importance of maintaining a very high relative humidity in the storage environment (Van den Berg and Lentz, 1977; Hansen and Bohling, 1980). Van den Berg and Lentz (1977) reported that during refrigerated air storage, relative humidities of 98-100% result in lower storage losses than humidities of 90-95%. Wastage due to decay and trimming was between 25-75% by
weight in heads after three months storage at 90-95% humidity, compared to losses of 20-40% in heads stored at humidities of 98% or above. These losses took the form of wilting and yellowing of leaves at low RH and mould on leaf edges and black spots on leaf veins. Furthermore, storability depended on the cultivar. Fast maturing cultivars could not be stored as long as slower maturing cultivars (Hansen and Bohling, 1980). A storage duration of 4.5 months in air for slow maturing cultivars was achieved at temperatures below zero, but at temperatures between 0 and 1°C, storage was possible for only two months. Respiration measurements confirmed the importance of below-zero temperatures for delaying the ageing process in Chinese cabbage. Respiration at 3.5°C was double that at -1°C. Freezing damage was avoided by thawing the Chinese cabbages for four days at 3.5°C. Apeland (1984b) and Schouten (1985) found that a storage disorder characterised by enzymic browning of leaf midribs was a result of chilling injury. The critical temperatures varied with different cultivars and the total exposure time to critical temperatures was closely related to storage losses.

7.3 Controlled Atmosphere Storage

The benefits of controlled atmosphere (CA) storage of produce are derived primarily from a reduction in the product’s respiration rate and associated factors which relate to normal ripening and senescence. In addition, specific O₂ and CO₂ concentrations can reduce the incidence and severity of certain physiological disorders and reduce susceptibility to pathogens. However, atmospheres unfavourable to a given commodity can induce physiological disorders, increase susceptibility to pathogens and promote physiological breakdown. The extent of benefits will depend upon the commodity, cultivar, stage of maturity, initial quality, O₂ and CO₂ concentrations, temperature and duration of exposure to these conditions (Kader et al, 1989). Current applications of CA technologies for brassica vegetables include extended storage life for Chinese cabbage, cabbage, broccoli and cauliflower. Wang (1983) found that at 0°C, a 1% O₂ atmosphere extended the storage life of Chinese cabbage to five months. After three months storage in air, extensive trimming of leaves was required to maintain saleability. Under CA, ascorbic acid and sugar levels declined at a slower rate, decay was reduced and the rate of chlorophyll loss reduced compared to storage in air (Wang, 1983; Wang and Ji, 1988). However, Apeland (1984a) detected off-odours and off-flavours after 1% O₂ storage, caused by anaerobic respiration. Rapid pre-cooling of Chinese cabbages, a rapid establishment and maintenance of the low O₂ atmosphere and an upright arrangement of heads to facilitate air circulation were factors that Wang (1983) contributed to the success of 1% O₂ storage. However, Weichmann (1981) argued that an upright arrangement of heads is not practical because it takes up too much space in storage and that a layering arrangement, while less conducive to maintaining quality, is more efficient on space.

The maximum level of CO₂ that Chinese cabbage can tolerate in air for extended storage periods at 1°C is 2% but levels greater than this can be used for short storage periods (Weichmann, 1977). This study demonstrated that trim losses decreased and shelf-life improved compared to other treatments when the CO₂ concentration was raised as high as 7.5% for storage durations less than 40 days. However, after longer storage periods (80-120 days), this atmosphere caused browning of the leaf tissue followed by tissue breakdown. Chinese cabbages stored in carbon dioxide concentrations of 5% combined with an
oxygen content of 2% also resulted in lower dry matter contents than for cabbages stored in air. In addition, concentrations of 2% O₂ combined with 2% or 5% CO₂ for storage periods of 40 or 80 days produced the best quality cabbages when assessed after a one week shelf-life, however these atmospheres did not extend total storage life beyond that attainable in air.

In support of the findings of Weichmann, Pelleboer and Schouten (1984) found that storage concentrations of 6% CO₂ for 120 to 160 days resulted in a shorter shelf life than lower CO₂ levels, confirming that a high CO₂ level for long periods is harmful to Chinese cabbage.

Mertens (1985) reported that CA storage did not reduce the level of vein browning compared to air after three months at 0-1°C. A correlation between nitrate nitrogen content and vein discolouration was discovered by Mathiassen (1986) and indicated that when nitrate nitrogen exceeded 25%, head quality was poor. Furthermore, Jeurissen (1991) showed that high rates of nitrogen were linked to a rapid loss of leaf colour after cold storage.

Research at relatively warmer temperatures (2.5 and 5°C) found that a more practical storage atmosphere which still provided acceptable storage life and cabbage quality was 2.5-4% CO₂ and 17-18.5% O₂ (Apeland, 1984a).

7.4 Modified Atmosphere Packaging

In principle, the benefits of CA storage can be achieved using modified atmosphere (MA) packaging if it maintains near optimum O₂ and CO₂ levels. Detrimental effects may occur if the atmosphere is not within the level tolerated by the commodity. Work with other brassica crops has shown positive storage effects when suitable films and packages have been developed (Kader et al, 1989). Broccoli is an example of a brassica crop which is highly perishable and deteriorates rapidly after harvest but responds favourably to modified atmospheres. Many factors lower the quality of broccoli with chlorophyll degradation and consequent yellowing of the florets most important. At times, rots and browning of the cut surfaces of stems also contribute (Isenberg, 1979; Ryall and Lipton, 1979; Makhlouf et al., 1989b; Tomkins et al., 1989) and heads become unsaleable within two to three days of harvest at temperatures often encountered during marketing (Wang and Hruschka, 1977). Quality loss is significantly reduced using controlled atmospheres at a range of temperatures (Lipton and Harris, 1974; Isenberg, 1979; Makhlouf et al., 1989a) and recent studies have confirmed that MA packaging significantly increases storage life and reduces quality loss (Aharoni et al., 1985; Rij and Ross, 1987; Forney et al., 1989). A study on the effects of different polymeric films, used as sealed carton liners, on the quality of fresh broccoli showed that the creation of a favourable MA environment during storage reduced yellowing and rots of heads and discolouration of the cut surfaces of stems. MA effects were still evident after a simulated marketing phase resulting in the extension of shelf-life to at least three days at 20°C after 30 days storage (Tomkins et al, 1993). Research into the effects of MA packaging studies on Chinese cabbage have generally been limited to attempts to reduce water loss. Perforated, polyethylene bags have been used at 0-1°C to successfully reduce weight loss and improve saleable yields (Sozzi et al, 1980).

After 80 days, saleable yields were 76% of pre-storage levels, however losses in yield were considerable after storage beyond 80 days due to bacterial rots. Unpacked heads withered severely as a result of
excessive moisture loss, reducing saleable weight by half. Considering the success achieved using MA packaging for other brassica crops, the potential exists to develop MA packaging applications which will significantly increase the storage life and market quality of Chinese cabbage.

7.5 Packing and Marketing

In Australia, export Chinese cabbage is usually packed into one-piece, 25kg, unwaxed cardboard cartons and wrapped in grease-proof paper (McKay and Phillips, 1990). Two-piece telescopic cartons with a waxed inner may be used to ensure the carton does not collapse during transport as a result of moisture absorption from the produce. Imming et al. (1989) report that for retail outlets, all the tough outer leaves should be removed, while for the wholesale market, some of the outer leaves may be left attached to provide some protection to the head. Most export Chinese cabbage is sea-freighted in refrigerated containers, although some is air-freighted if demand is high enough (McKay and Phillips, 1990). Chinese cabbages are normally sold by carton weight with head weights around 1.5kg suitable for both domestic and export markets.

7.6 Summary

Product quality at harvest largely influences quality loss after harvest. Factors which determine the growth and development and harvest quality of Chinese cabbage have been discussed in Chapters 1 - 6. Good postharvest practices of pre-cooling and rapid establishment and maintenance of the desired temperature, gas concentrations, relative humidity and adequate air circulation are critical factors in prolonging storage of Chinese cabbage. In general, it should be pre-cooled to around 0-1°C immediately after harvest with minimal moisture loss. This temperature and a relative humidity of 98 to 100% should be maintained during storage and transport. For prolonged storage, controlled atmospheres are beneficial and best results are obtained with 2% O₂ and CO₂ concentrations of 2 to 5%. One percent O₂ at 0°C and air storage at -1°C have shown similar results to low O₂ and increased CO₂ at 0°C. However, symptoms of anaerobic respiration have been reported during storage in 1% O₂ and chilling injury during prolonged storage in air at temperatures below 0°C. At these temperatures, a period of thawing at 3.5°C is necessary in order to minimise the risk of chilling injury.

Perforated and unperforated polyethylene bags have been used in cold storage to reduce weight loss and improve saleable yields, although bacterial rots cause significant wastage after 80 days. Research into extending storage life through MA packaging is lacking in the literature for Chinese cabbage, although its application to other brassica crops has been successful. There appears to be considerable potential to improve the storage and market quality of Chinese cabbage using MA packaging.
8. References


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