HDC Review
Iceberg Lettuce: improving post-harvest quality
FV 198

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A. Practical section for growers

The objective of the review was to critically evalute the literature on post-harvest quality of lettuce to identify areas where further work is needed to provide the basis for further technical advance to improve the quality of iceberg lettuce, particularly for export, and to reduce costs.

The literature sources covered books, reports of U.S.A. Agricultural Experiment Stations, USDA Market Research Reports and California Iceberg Research Programme as well as over 500 scientific papers from the CABI, AGRICOLA, Ei Compendex (an Engineering database) and Food Science and Technology Abstracts. Much of the relevant literature covers all lettuce, about one third is directly applicable to iceberg and a good deal of this provides either trivial information or is of limited value to UK growers simply because it caters for a lower base of technology in relatively unsophisticated markets.

Proposed new work

From the literature the key components in establishing a post-harvest protocol are:

1) **harvest at the optimum stage of maturity**

however, this is not sufficiently well defined to offer predictive value and little is known of the effect of pre-harvest factors and how they interact with 2,3 and 4 below.

2) **remove field heat rapidly to give head temperatures of 0°-2.5°C**

however, it is not known if time of day of harvest, interval between harvest and cooling and rate of cooling have significant influence on subsequent quality.

3) **overwrap to reduce moisture loss**

however, only limited published information is available on how film type and box type, both in relation to cost, affect storage life.

4) **maintain storage temperatures during transit in range 0°-2.5°C, $C0_2$ concentration below (1%) and C_2H_4 concentration below 1ppm**

however, knowledge of how well these conditions <u>are</u> maintained during transport is not well documented.

The scientific information provides principles to guide the direction for technical advance and identifies gaps in knowledge but it is evident that the technical 'know-how' in certain relevant areas of growers/manufacturers eg packaging is ahead of published reports in the literature. A number of options for further research/investigation are presented for discussion.

1. Introduction

From 1992 to 1995 exports of lettuce, principally Iceberg, rose from 0.5 to 4.2 thousand tons with an estimated value of c £3m (Anon, 1996). Most of the crop is moved as single loads but some is as mixed loads with other leaf vegetables. To maintain and expand this market there is a need to ensure that after transport the produce meets or exceeds the quality standards required but because it is a bulk commodity this is required to be done cost-effectively.

Problems directly associated with the post-harvest treatment and 'shelf-life' storage include weight loss/wilting of leaves, brown stain, which is attributed to high carbon dioxide (CO_2) levels and russet spotting, attributed to high ethylene (C_2H_4) concentrations. There are a number of other disorders associated with the post-harvest period viz blackening of the wrapper leaves (low oxygen concentrations (0_2)) rib necrosis (cause unknown), pink rib (cause unknown) in addition to tipburn and wastage through disease. All of these disorders occur from time to time following long-haul transport in the USA but the extent of these disorders in the UK and Europe is not documented though hearsay evidence indicates that they are not major problems.

The majority of the scientific investigation on the subject and the development of the technology has been carried out in the USA. In assessing how this information could be applied to UK produced crops for export, account needs to be taken of the difference in product specification between USA and UK, for example, multiple retailers in the USA will retrim and repack. More recently there has been scientific interest in post-harvest aspects of the iceberg crop in Europe but it is limited by comparison with that in the USA and concentrates largely on problems associated with cut lettuce/mixed leafy salads which are not reviewed here.

The objectives of this review are to outline the principles of storage for iceberg lettuce, discuss developments in technology to improve post-harvest quality and identify areas where further investigation would be worthwhile. The small amount of work on controlled atmosphere storage reported in the literature has been excluded from this review.

This review has covered, in addition, to the books and scientific papers listed in Section 7, the following sources of information.

1. Reports of the Agricultural Experiment Station, Davis, California and Cornell 1920's-present.

2. USDA Market Research Department Research Reports 1960-present.

3. Technical Memoranda of the Campden Food Preservation Research Association.

4. Reports of the California Iceberg Lettuce Research Programme 1983 -present.

5. Searches of CABI and AGRICOLA databases. It has not covered a detailed review of package types, packaging materials, loading arrangements on trucks, engineering/physics of vacuum and other methods of cooling, refrigeration plant or storage systems but searches of Ei Compendex 1969-97, an engineering database and Food Science Technology Abstracts 1970-97, have been made for relevant information.

6. A major source of information is 'Post Harvest Technology of Horticultural Crops', (1992) 2nd Edition Ed A A Kader, University of California: Division of Agriculture and Natural Resources. Publication 3311. ISBN 0-931876-99-0.

   Over 500 references have been examined but only a proportion of these offer information of significant value and so the discussion here concentrates on the listed references in Section 7 in addition to 1- 6 above.

2. Respiration and water loss from harvested heads

In lettuce, as in other leafy commodities, the rate of deterioration of the harvested head is broadly proportional to the respiration rate. At 0°C respiration rates for head lettuce are c. 20 mg CO_2 kg^{-1} tissue h^{-1}, compared with for example <5mg CO_2 kg^{-1} tissue h^{-1} for dried fruit, and they double for every 10°C rise in temperature (Burton, 1982). Rapid rates of respiration will deplete carbohydrate reserves and reduce flavour.

In a number of species ethylene (C_2H_4) is produced during ripening which regulates senescence processes but only small quantities are produced by lettuce (less than 0.1 uL C_2H_4 kg^{-1} h^{-1}) but ethylene can cause post-harvest disorders (see Section 4).
Once the head is harvested water loss is rapid from the outer leaves, reaching, for example, 7.5% of the initial weight per day at 60% rh, 15°C. Usually, 3-5% loss of moisture from the outer leaves results in visible wilting and lettuce are unsaleable at this level of loss. When the outer layers have dried this provides a barrier for further water transfer and further water loss is up to 10-20 times slower and hence the advantage conferred by overwrapping lettuce heads to reduce water loss. A detailed analysis of water and respiratory losses is given in Burton (1982).

The key to prolonging storage life in lettuce, as in other leafy crops, is to lower head temperature to reduce the rate of respiration i.e. removing field heat. The rate of loss of water from tissues is also lower the lower the temperature of the tissue. Thus, cooling has the effect of both reducing respiration and water loss. Cooling has another beneficial physiological effect in that injury from C_2H_4 (see later) is lower the lower the temperature.

3. Cooling

Various methods of cooling to remove field heat have been used but vacuum cooling techniques pioneered in USA, are now almost universally employed for iceberg production worldwide. Vacuum cooling depends upon the evaporation of water from the tissue for removal of heat from the produce. At low pressures water vaporises (boils) at temperatures below 100°C, the heat for evaporation being provided by the produce. At 1kPa water vaporises at 0°C. In the vacuum cooling process large quantities of water vapour need to be removed (usually by rotary pumps) otherwise the air would become saturated and cooling cease. The first patent for the process was granted in 1944 to Morris Kasser in San Francisco and the first plant was built in Salinas in 1948. Subsequently other patents for modifications to the process viz., misting devices operating during the vacuum cooling cycle to reduce product weight loss were granted. When lettuce heads are exposed to vacuum (typically 5mm Hg, <1.0 kPa) water rapidly evaporates, tissue cools and in the process there is a loss of water of about 1% for every 5°C drop in temperature (Dewey, 1950; 1952; Barger, 1961;1963; Wills et al., 1981; Burton 1982). The rate of cooling depends primarily on the amount of surface area to its volume and the resistance to water movement in tissues.

Typically in vacuum cooling there is a sharp rise in wet bulb temperature in the vacuum chamber (referred to as the 'flash' point), caused by a sudden release of moisture and heat from the lettuce when the vapour pressure of the air drops below that of the leaf. Further reduction in pressure then leads to a rapid loss of water which is usually complete in 20-30 minutes. Unlike evaporation under ambient pressure which is largely from the surface of the tissue, losses of water under vacuum cooling occur throughout the head though the uniformity of removal of water is greater in loosely than tightly packed heads. Thus, despite the fact that losses of water of 3% may occur as a result of cooling by 15°C from a head temperature of 15°C to zero, wilting of the outer leaves is not evident. Weight loss under vacuum cooling can be reduced by adding water to the heads prior to loading into the cooler or by including a fine spray of water during the vacuum cycle. Very hard heads, which restrict water transfer, need longer cooling periods. Adjustments to the vacuum cooling technique by repeating cycles, 'bouncing', may be necessary to ensure complete cooling. Seal wrapping lettuce before cooling will also reduce the rate of cooling though the use of perforated materials reduces this effect considerably. In the USA heads are typically 'boxed' in cardboard containers and those that have large side vents in the boxes allow more rapid cooling than those with standard 6mm x 25mm vents (Isenberg et al., 1982).

Vacuum cooling heads to 1-2.5°C is widely recommended. Techniques for measuring product temperature are described by Thompson & Rumsey (1984). However, if harvesting is done when head temperatures are high, water loss will be excessive without supplementation of water prior to the vacuum cycle (Parsons et al., 1960; Barger, 1963; Isenberg et al., 1982; Turk & Celik, 1993). Other authors quote values of cooling to 4°C as being suitable though lower temperatures were not tested (Stanley, 1987).

Dewey (1952), Isenberg et al., (1982) provide information on the engineering aspects of vacuum coolers.

It is not documented how the duration of the cooling cycle or 'bouncing' influence subsequent product quality and although site and season are reported (Barger, 1961) to influence the rate of cooling this has not been widely confirmed nor is it clear if after cooling these 'site' effects have any subsequent influence on product quality and shelf life.

4. Post-harvest disorders

Several storage disorders have been described and researched in the United States. No published information is available in the UK and only a few studies have been undertaken in EU countries. Photographs of these disorders are published in Lipton et al., (1972).

Brown stain - this occurs as a result of high carbon dioxide (> 1%) even at low holding temperatures (3°C) (Brecht. et al., 1973) and may be exacerbated by low oxygen levels (5%)

(Stewart et al., 1972; Stewart & Uota, 1971; Ke and Saltveit, 1989b). Staining in patches usually occurs on both surfaces of the leaf, often near the mid rib. It is often confused with russet spotting (see below).

Differences in susceptibility between the varieties used in California in the 1970's were noted but no recent information has been found. However, site and season also influenced incidence but the data do not permit analysis of which aerial/soil factors are important or whether site factors are confounded with different harvesting and cooling practices (see Stewart & Matoba, 1972).

Russet spotting - this occurs as a result of exposure to ethylene (Morris et al., 1978; Kasmire & Williams, 1983). Brown spots and larger lesions occur anywhere on the leaves except those of the heart and the spots are often pitted. Concentrations of 0.1 ppm C_2H_4 can cause the disorder, well below concentrations that have been recorded in packed heads in cartons (0.05 to 0.40 ppm) (Morris et al., 1978). Its effects are reduced by maintaining low O_2 atmospheres (1.5%) (Ke & Saltveit, 1989a). Recent work indicates that the effects of C_2H_4 are not mediated through peroxidase activity (Ferrer et al., 1996).

Pink rib - this characteristically occurs in overmature heads and is represented as a diffuse pink colouration at the base of the mid ribs. It is accentuated by high temperatures post-harvest and low O_2.

Several other disorders are reported viz., low oxygen injury (below 0.25% O_2), internal rib necrosis, rib discolouration and rusty brown discolouration. These are either sporadic in nature or reported to be confined to varieties not grown in the UK.

5. Factors influencing post-harvest shelf life and quality

i) Fertilisers

It might be expected that nitrogen in particular, through its influence on cell size and number in a leaf, and the proportion of cell wall material volume to total tissue volume, would influence post-harvest quality. However, there is little information on the subject. Poulsen et al., (1995) report that 'keeping quality' at 5°C and 20°C is greater the lower the applied N used in the range 50 - 200 kg ha^{-1}. Gull & Guzman (1988) and Gull et al., (1990) report that in Florida, lettuce grown on mineral soil stores better than that grown on peat but this comparison is complicated by other environmental and plant variables.

ii) Irrigation

As application of water influences cell expansion and leaf water status it might be expected that management of irrigation would affect post-harvest quality. Little published information has been found though Sagiv et al., (1981) report that trickle-irrigated plots in which 80% of class A pan evaporation of water was replaced gave better quality than more and less liberal watering. However, this information is of little predictive value for UK conditions.

iii) Time of harvest

Kasmire & Cantwell (1992) relate storage life to stage of maturity of the head on a 5 point scale, the lowest being no head formation, high respiration rate with poor storage to maximum storage life for firm heads, though a further delay in harvest is considered to increase the risk of russet spotting and pink rib. However, no published information of experimentation on head maturity at harvest in relation to storage life has been found and the definitions of head maturity stage published are too imprecise to have predictive value.

iv) Time of day of harvest

The physiological status of an iceberg lettuce will change diurnally. Water status and head temperature are likely to be lowest early in the morning compared with mid afternoon but by contrast leaf sugar content will be at its lowest (Forney & Austin, 1988). It might be expected that such changes in 'status' during the day would influence subsequent storage if harvesting was done at different times of the day. Certainly high sugar levels correlate with improved storage (Yano & Hayami, 1978) and Forney & Austin (1988) report that early morning harvested lettuce were more susceptible to brown stain injury. There is little other information available to indicate whether it would be profitable to manipulate the timing of harvest within the day to improve head quality or whether such effects are negated by vacuum cooling procedures and subsequent treatment.

v) Interval between harvesting the heads and cooling

In view of the information on respiration and water loss in relation to head temperature outlined in Section 2 rapid removal of field heat immediately after harvest is essential. No references to the effects of delays in harvest prior to vacuum cooling on subsequent shelf life have been identified.

In view of the known effects of delays from harvesting to cooling in other crops it is unlikely that the absence of information on the subject in lettuce indicates that there is no effect. The potential influence of delay in vacuum cooling at known head temperatures, holding air temperatures, tissue water status and air vapour pressure deficit on shelf life needs to be investigated and quantified.

vi) *Rate of cooling*

Whilst different 'products' associated with differences in batch average head temperature head tissue packing density, water content, over wrapping and boxing will affect the rate of cooling under standard conditions, there is no published information indicating whether these affect subsequent shelf life during transport.

vii) *Treatment of heads*

Sponging the freshly cut butt of lettuce with acetic acid (50 mL/L) and with vinegar reduced butt browning in overwrapped lettuce during subsequent storage at 2°C for 7 days, followed by 3 days at 13°C (Castaner et al., 1996). The use of growth regulators has also been shown to be beneficial viz., auxins (Saltveit, 1988) but their use is unlikely to be a practical proposition.

viii) Overwrapping

The primary purpose of overwrapping is to reduce water loss from the head and hence the use of materials such as polyethylene and polypropylene which have high resistance to water vapour transfer but not O_2 and CO_2 transfer. Even though a range of materials with different numbers of perforations have been examined which show a range of permeability to water, few detailed comparisons of different film types have been made (Hinsch et al., 1976; Wang et al., 1984; Stanley, 1989; Artes & Martinez, 1996) and have been restricted to comparisons of polypropylene, polyethylene, and polyolefin films. Stanley (1988) demonstrated using cv Saladin that polyolefin films gave better quality after 7 to 9 days at 5°C than stretch wrap PVC or slit polyethylene film.

ix) Packaging

No published information on optimum box size, structure, material used in construction, and number and size of ventilation holes for the transport of head lettuce has been found. Bulk-bin handling has been explored but there are problems with compression damage (Stout et al., 1973).

x) Stacking/truck loading and the transport environment

The main problems of maintaining lettuce quality over prolonged transport periods in the USA are reported to be due to inadequate provision of a uniform environment in the transport container. This was associated with variation in temperature (Hinsch & Harris, 1979; Hinsch et al., 1981) caused by poor stack arrangement, poor stacking on pallets and crushing of cartons causing irregularities in air flow (Rij et al., 1976). Truck insulation and placement of pallets in relation to source of refrigerant air and ducting arrangements (Hinsch & Harris, 1979) also have a significant impact in contributing to uniformity of the environment. Mixed loads (Lipton & Harvey, 1977) can also cause problems. However, usually compatibility of product by optimum shipping temperature and capacity for ethylene generation is sufficiently well matched in UK sourced loads (possibly containing in addition to iceberg lettuce, celery, cauliflower, carrot) not to present a significant problem.

The temperature control systems used rely on a single or series of control sensors but these are not always a reliable guide to actual temperatures in the pallet stacks and there is a need to independently monitor product temperature. If such records consistently showed that truck temperatures showed variation from the required temperature alternative control systems could be devised.

Most of the published information indicates that temperatures of 4°-5°C give approximately 5-7 days storage life of vacuum-cooled produce without noticeable deterioration in product life but lower temperatures extend the storage period. (Parsons et al., 1960; Browning, 1986; Stanley, 1988; Castaner et al., 1996; Artes & Martinez, 1996 and others). However, it is not clear to what extent the period of low temperature influences subsequent shelf life and there are no published relationships between temperature, humidity and storage life.

Carbon dioxide injury (brown stain) has been shown to be a problem during transporation in the USA and CO_2 concentrations typically can reach 0.4 - 3.9% (Stewart et al., 1972) and higher levels (8%) have been reported in polyethylene-lined containers held for short periods at 20°C (Aharoni & Yehoshua, 1973).

Russet spotting caused by ethylene concentrations > 1 ppm has also been reported as a significant problem during transportation and concentrations in the range 0 - 5 ppm have been recorded (Ahrens & Thompson, 1990). However, the problems are reduced at low temperature and provided ethylene from external sources viz, gas powered stacking trucks, cigarette smoke, internal engine combustion fumes (sucked in by truck ventilation systems) is minimised or eliminated problems, should be minimal. Reid (1992) provides information on ethylene monitoring equipment.

6. Proposed new work

The following options need to be discussed with Lettuce R&D Group:

i). Where 'industry' information is available, relate crop quality at point of delivery with transit time, transit environment, crop source.

ii). Monitor transit environment for temperature, humidity, CO_2 and C_2H_4.

iii). Identify cheaper packaging materials with the required characteristics - in cooperation with growers/manufacturers.

iv). Assess the impact of any changes in i), ii) and iii) above on quality and cost.

v). In grower-based surveys and trials assess the impact of practices at harvest and during cooling on subsequent storage life/quality.

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Over 500 references have been examined. A selection of those is given here and key references given in text are marked by an asterisk; others given provide complementary information.

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