Cabbage

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Scientific Name and Introduction: *Brassica oleracea* L. var. *capitata* L., red, green (domestic or Danish-type) and oxheart (conical or pointed-head type) cabbage, and *B. oleracea* var. *sabauda* L., savoy cabbage, are biennials of the Brassicaceae (Cruciferae) family (Munro and Small, 1997; Pritchard and Becker, 1989). The edible portion includes the leaf blades, stalks and core (stem) inside the head. Cabbage is grown in most major temperate vegetable growing areas and is available year-round in most markets. The major cabbage-producing countries, in order of production, are China, Russian Federation, India, Japan and South Korea (Ghosh and Madhavi, 1998). In the U.S., the major fresh-cabbage producing states are New York, California and Texas and the major sauerkraut producing states are New York and Wisconsin (http://www.usda.gov/nass/pubs/agstats.htm).

Quality Characteristics and Criteria: Cabbage leaves should be green, dark purple or crinkly, depending on the cultivar (Pritchard and Becker, 1989; Ryall and Lipton, 1979). The head should be firm and heavy for its size. The heads are crisp and fresh if they squeak when rubbed together (Boyette et al., 1999; Ryall and Lipton, 1979). The presence of a waxy bloom on the leaves is desirable. Yellow leaves on green cultivars suggest extensive trimming of the outer leaves. The presence of a seedstalk is undesirable.

Horticultural Maturity Indices: Determination of maturity in Brassicas is not simple and no one index of maturity is reliable (Ludford and Isenberg, 1987) At maturity, a cabbage head should be firm and weigh 0.5 to 3 kg (1 to 6.6 lb), depending on cabbage type and cultivar. It is suggested that the optimum head density of green cabbage destined for storage ranges between 0.72 and 0.80 kg L^{-1} (Pritchard and Becker, 1989). Immature heads, besides being smaller and softer, have an excessive tendency to wilt and less characteristic odor (Pritchard and Becker, 1989). Over-mature heads are more susceptible to splitting; pathogens, physiological disorders and seed stalk formation (Boyette et al., 1999; Intl. Org. Std., 1991; Pritchard and Becker, 1989).

Grades, Sizes and Packaging: Grades include U.S. No. 1 and U.S. Commercial, based on defects (physical and decay), excessive wrapper leaves and off-size heads (http://www.ams.usda.gov/standards/vegfm.htm). Size classification is optional. For the pointed-head type (oxheart) cabbage: Small < 0.7 kg (1.5 lb); Medium is 0.7 to 1.4 kg (1.5 to 3 lb); and Large > 1.4 kg (3 lb). For domestic and Danish-types (green) cabbage: Small < 0.9 kg (2 lb); Medium is 0.9 to 2.3 kg (2 to 5 lb); and Large > 2.3 kg (5 lb). Cabbage heads are shipped in sacks, wax-coated corrugated cardboard cartons and wire-bound crates of various sizes up to 22.7 kg (50 lb) (http://www.ams.usda.gov/mnreports). Some cabbage is shipped in heavy fiberboard bulk pallet bins holding 227 to 455 kg (500 to 1,000 lb) (Boyette et al., 1999).

Pre-cooling Conditions: Cabbage should be cooled as soon as possible after harvest to reduce wilting. If cabbage is harvested under cool conditions, it can be placed in storage and cooled without pre-cooling. Hydro-cooling before storage or forced air-cooling in storage can be used to rapidly remove field heat (Boyette et al., 1999).

Optimum Storage Conditions: Cabbage should be stored at 0 °C (32 °F) with 98 to 100% RH. Storage at -1 °C (31.1 °F) may cause freezing, while storage at 1 °C (33.8 °F) may promote senescence-related storage losses, especially if held in long-term storage, eg., 6 mo (R. Prange, unpublished data). High RH minimizes decay and trimming losses (van den Berg, 1987). Light in the storage reduces physiological disorders,

mainly leaf yellowing, and weight loss (Prange and Lidster, 1991). Cabbage is stored in bins or in bulk (Intl. Org. Std., 1991). Only three to six wrapper leaves should be left on the head (Hardenberg et al., 1986). All loose leaves should be trimmed away before storage because they will interfere with air circulation between heads. Air circulation in the storage should be sufficient to maintain constant and uniform temperature and RH around all cabbage heads. Bulk-stored cabbage should be ventilated in a vertical direction and the depth should not exceed 3 m (9.8 ft). Bin-stored cabbage should be arranged to maximize uniform air flow around each bin. Storage-life depends on cultivar (eg., early-maturing cultivars tend to have shorter storage-life than late-maturing cultivars), quality (eg., freedom from decay), and storage conditions (Boyette et al., 1999; Intl. Org. Std., 1991; Pritchard and Becker, 1989). The end of storage-life is signaled by increased respiration rate, core elongation and sometimes rootlet development on the core butt (Guffy and Hicks, 1985; Pritchard and Becker, 1989).

Controlled Atmosphere (CA) Considerations: Cabbage is probably the most common vegetable to be stored under CA (Saltveit, 1997; Thompson, 1998). O_2 levels of 1.5 to 5% + CO_2 levels of 0 to 8% have been recommended. Therefore, the mid-range of 2 to 3% O_2 + 4 to 5% CO_2, is probably a good general recommendation. Low O_2 reduces color and trimming loss and inhibits root growth, while elevated CO_2 reduces rot, decay and sprouting (Saltveit, 1997). Atmospheres with < 1.5 to 2% O_2 and/or > 8 to 10% CO_2 may injure stored cabbage. Low O_2 and high CO_2 injury is slow to appear and the extent of the injury depends on the cultivar and maturity (Masters and Hicks, 1990). For example, low O_2 injury does not occur in oxheart cabbage until after 35 days when held in 0% O_2 (100% N_2) at 0 to 4 °C (32 to 39.2 °F) (Schouten et al., 1997), and green cabbage does not show low O_2 injury until after 2, 3 or 6 mo, if held at 0 °C (32 °F) in 0.5, 1.0 or 1.5% O_2, respectively (Masters and Hicks, 1990; Menniti et al., 1997). Similarly, CO_2 injury is seen after 2 mo if held at 0 °C (32 °F) in 20% CO_2 or after 2.5 mo (Menniti et al., 1997) or 6 mo (Masters and Hicks, 1990) in 10% CO_2. Symptoms of low O_2 and high CO_2 injury are off-flavors and off-odors as well as visible damage (Lougheed, 1987; Ludford and Isenberg, 1987; Masters and Hicks, 1990; Menniti et al., 1997; Schouten et al., 1997). Both low O_2 and high CO_2 produce very similar visible damage, beginning in the meristematic tissue located at the apex of the stem in the middle of the cabbage. Damage spreads to outer leaves and appears as black spots (low O_2) (Schouten et al., 1997) or bronzing (high CO_2) (Masters and Hicks, 1990). Lougheed (1987) suggested there may be no interaction between low O_2 and high CO_2 in injury, but Kaji et al. (1993) showed that high CO_2 (5 to 15%) keeps shredded cabbage in good condition if O_2 is high (5 to 10%).

Retail Outlet Display Considerations: Damaged outer wrapper leaves should be trimmed. Trimming may expose lighter green inner leaves but natural or artificial light can increase the chlorophyll content and green color (Perrin, 1982). The greatest concern is loss of moisture that can be prevented by wrapping each head in a clear plastic film; frequent water sprinkling and/or displaying in a refrigerated cabinet.

Chilling Sensitivity: The freezing point is -0.9 to -0.83 °C (30.4 to 30.5 °F) (Hardenburg et al., 1986; Pritchard and Becker, 1989). Even though cabbage with core temperatures of -1.1 °C (30 °F) before harvest can show no evidence of freeze damage (Pritchard and Becker, 1989), storage at -1.0 °C (30.2 °F) is not advisable because it can produce freeze damage, especially on outer leaves (R. Prange, unpublished data).

Ethylene Production and Sensitivity: Cabbage produces very little ethylene at < 0.1 μL kg^{-1} h^{-1} at 20 °C (68 °F) (Kader, 1992). Kubo et al. (1990) detected only a trace amount of ethylene from cabbage at 25 °C (77 °F). When heads are stored in the dark at 5 °C (41 °F) in sealed plastic bags, ethylene reaches only 1 μL L^{-1}, regardless of cultivar (Meinl and Bleiss, 1986). Cabbage should not be exposed to ethylene after harvest. Ethylene increases respiration (Inaba et al., 1989), and concentrations as low as 1 μL L^{-1} accelerate senescence and quality loss, eg., leaf yellowing, wilting and abscission, more in air than in CA (Hicks and Ludford, 1980; Pritchard and Becker, 1989). In shredded cabbage, reduced ethylene production and phenylalanine ammonia-lyase (PAL) activation is linked to less tissue browning (Takahashi et al., 1996)

Respiration Rates:

Temperature	mg CO_2 kg^{-1} h^{-1}
0 °C	4 to 6
4 to 5 °C	9 to 12
10 °C	17 to 19
15 to 16 °C	20 to 32
20 to 21 °C	28 to 49
25 to 27 °C	49 to 63

To get mL kg^{-1} h^{-1}, divide the mg kg^{-1} h^{-1} rate by 2.0 at 0 °C (32 °F), 1.9 at 10 °C (50 °F), and 1.8 at 20 °C (68 °F). To calculate heat production, multiply mg kg^{-1} h^{-1} by 220 to get BTU per ton per day or by 61 to get kcal per metric ton per day. Data are from Hardenburg et al., 1986.

Physiological Disorders: As summarized by Bérard (1994), there are some physiological disorders of stored cabbage for which the causal agent is not known, eg., black midrib, black speck of cabbage (pepper spot, spotted necrosis), gray speck, and necrotic spot. The occurrence of these disorders can be influenced by cultivar and cultural practices, especially mineral nutrition. Some physiological storage disorders are clearly frost-induced, eg., black blotching, black spot, epidermal detachment, frost blemishing and redheart. Bérard (1994) also describes storage disorders caused by dormancy, ethylene and head maturity.

Postharvest Pathology: The major cause of postharvest decay in cabbages is the gray mold fungus (*Botrytis cinerea*) (Geeson, 1983; Snowden, 1991). Gray mold can be minimized by using less susceptible cultivars, using preharvest fungicides, practicing strict hygiene, avoiding mechanical or frost damage, rapid cooling to 0 °C (32 °F) and using CA storage (Snowden, 1991). Another fungus, Alternaria rot, a.k.a. dark, black or gray leaf spot (*Alternaria* spp.), infects a wide range of cruciferous vegetables and can cause significant storage losses (Geeson, 1983, Snowden, 1991, Cerkauskas, 1994). Since this disease is commonly transmitted through infected seed, it can be minimized by using disease-free seed, rotation with non-cruciferous crops, preharvest fungicides, destruction of diseased material before storage and rapid cooling to 0 °C (32 °F). There are other fungi (eg., ring spot), bacteria (eg., bacterial rots and watery soft rot), and a virus (tobacco mosaic virus) that can cause significant losses (see Ceponis et al., 1987; Dennis, 1983; Snowden, 1991).

Quarantine Issues: None

Suitability as Fresh-cut Product: Shredded cabbage is suitable as a fresh-cut product, packaged in air or MAP. Gorny (1997) indicates MA treatment efficacy as 'good' in extending storage-life of shredded cabbage and provides respiration rates at different temperatures, atmospheres and varying amounts of shredding (see below).

Temperature	**Atmosphere**	**Degree of shredding**	**mg CO_2 kg^{-1} h^{-1}**
2 °C	air	quarter head	8
		rough cut (1 x 3 cm)	16 to 18
		fine cut (0.5 - 1.5 cm)	18 to 24
5 °C	air	quarter head	10 to 12
		rough cut (1 x 3 cm)	22 to 34
		fine cut (0.5 - 1.5 cm)	26 to 40
5 °C	5 % O_2	quarter head	12 to 14

	+ 5 % CO_2	rough cut (1 x 3 cm)	26 to 30
		fine cut (0.5 - 1.5 cm)	30 to 40
10 °C	air	quarter head	19 to 23
		rough cut (1 x 3 cm)	42 to 48
		fine cut (0.5 - 1.5 cm)	51 to 57
23 °C	air	quarter head	54 to 63
		rough cut (1 x 3 cm)	117 to 153
		fine cut (0.5 - 1.5 cm)	153 to 171

Special Considerations: None

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