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Response of Stored Cauliflower (*Brassica oleracea* L., Botrytis Group) to Low-O_2 Atmospheres[1]

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Abstract. **Cauliflower curds stored up to 3 weeks at 2.5, 5, or 7.5°C in atmospheres with 2, 4, or 6% O_2 were not superior to curds stored in air. Curds stored in 1% O_2 almost always developed off-odors and off-flavors when cooked; those stored in 2% O_2 occasionally showed this response. Visible injury developed in 1% O_2. This level of O_2 also favored soft rot. Oxygen concentration did not significantly affect the color, firmness or pH of the tissue. The effects of low O_2 on cauliflower are contrasted with those obtained earlier with broccoli. A hypothesis is proposed that holds that the difference in sensitivity of these and other closely related vegetables to low O_2 and high CO_2 is related to the presence of chlorophyll in the tissue.**

Cauliflower stored in CO_2-enriched atmospheres becomes gray, mushy, and off-flavored when cooked (8). Since broccoli (*Brassica olercea* L., Italica group), a close relative of cauliflower, tolerates high CO_2 and low O_2 (7), the response of cauliflower to low O_2 is important, because these vegetables might be stored or shipped together. We therefore determined the influence of storage in low–O_2 atmospheres on the culinary quality of cauliflower.

Materials and Methods

Samples. Cauliflower grown in the Salinas Valley (Feb., March, Oct., Nov. 1974) or near Fremont (Jan. 1974 and 1975), California, was obtained at packing sheds on the day of harvest. Several cultivars were represented in the various tests. After the leaves were cut off, the heads were washed in a chlorine solution and overwrapped with perforated film as part of normal packing procedures. In warm weather, the samples were refrigerated during transport to Fresno, where they were held at 5°C until the start of the test on the following day. The curds were halved, and each half from a given curd was placed in a different glass jar for storage. Some of the halves were identified with numbered metal tags to permit comparison of halves of the same head held in different atmospheres. Eight half-heads were placed on plastic supports in each jar. The jars were lined with wet paper towels to maintain a high relative humidity. Preliminary tests had shown that weight loss under these conditions did not exceed 2%. Samples were stored by 10 AM on the day following harvest.

Storage conditions. The cauliflower was held in 21 (air), 6, 4, 2 or 1% O_2, with N_2 comprising the remainder of the mixtures. Preliminary tests had shown that lower concn of O_2 (<1%) would invariably result in severe decay during storage and/or severe off-odors and off-flavors when the curds were cooked. The techniques used in mixing, administering and monitoring the gasses were those used earlier (5). However, in our tests, diffusion of air back into the jars was prevented by having long (about 30 cm) discharge tubes (4 mm internal diam).

Half of each sample (4 half-heads) was examined after 6, 13, or 20 days at 2.5 or 5°C and the other half after an addi-

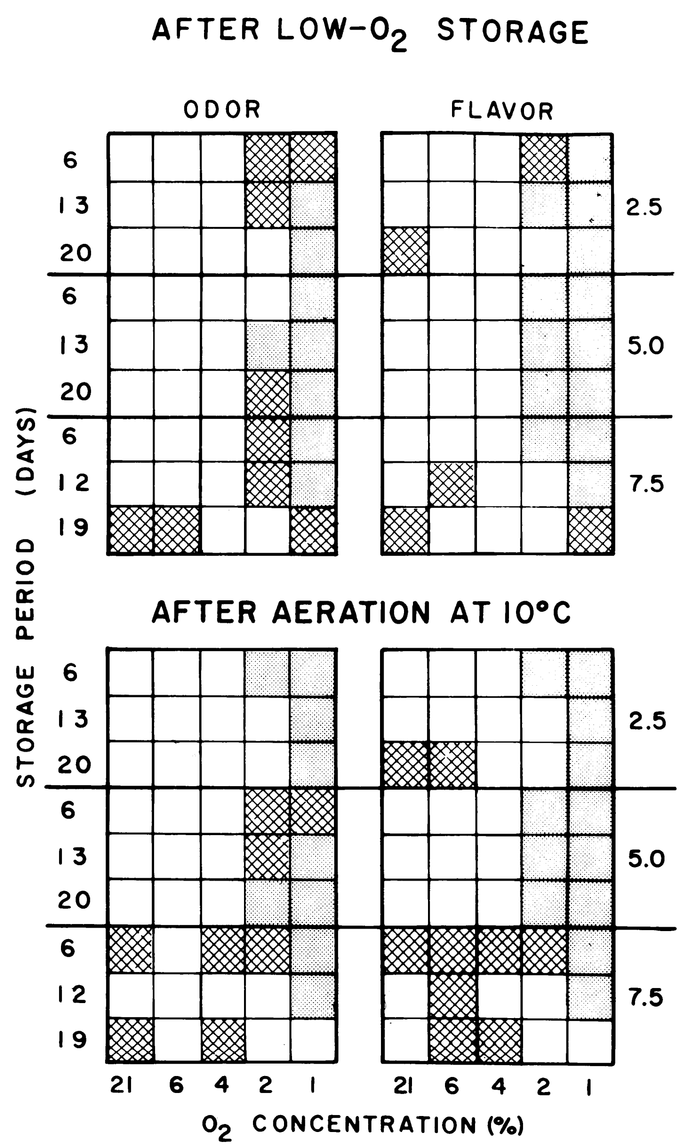

Fig. 1. Storage conditions that induced no (blank), slight (cross-hatched) or severe (dotted) off-odors or off-flavors in cauliflower (evaluated when cooked). Sample categorized according to its most objectionable curd. Aeration was 3 days following storage at 2.5 or 5°, and 2 days following storage at 7.5°C.

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[3]Mention of commercial products is for information only and does not imply endorsement by the U.S. Department of Agriculture.

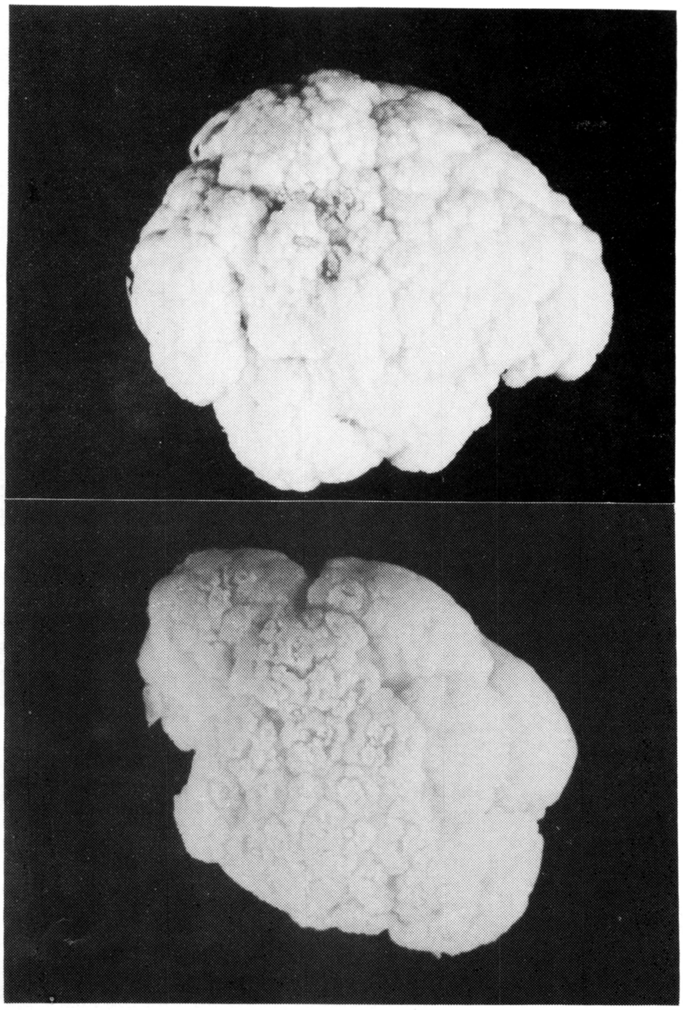

Fig. 2. Cauliflower florets showing low–O_2 injury: Top, raw head held 20 days at 2.5°C in 1% O_2 plus 3 days in air at 10°; bottom, cooked section from head held 13 days at 2.5° in 1% O_2.

tional 3 days in air at 10°. For cauliflower stored at 7.5°, where deterioration is relatively rapid, the respective holding periods were 6, 12 or 19, and 2 days. During subsequent storage in air, the jars were vented but had no positive air flow.

Cooking. All stubs of leaves around the curds were removed prior to cooking. If necessary, the stem of each of the 4 half-heads was trimmed to bring the total weight per sample to 1000 ± 50 g. Cooking procedures were the same as those used for broccoli (7).

Evaluation of quality. The color of each half-head was evaluated when raw and later when cooked, by measuring the values of L, a, and b on a Hunterlab Color/Difference Meter (Model D25D2) equipped with a 5 cm diam (2-inch) viewing port. Standardization was with a white tile (L = 91.9, a = –1.4, and b = –0.5). We also kept records of objectionably gray or yellow curds.

Tenderness and pH of cooked tissue were measured as for broccoli (7). We also evaluated the incidence and extent of visible low–O_2 injury, soft rot, and curd spots other than soft rot on a scale of 1 (none) to 9 (extreme). We judged and described odors of the raw and cooked product and flavor of the latter. Statistical treatment of these observations was not feasible.

Statistical treatment. We evaluated each atmosphere in 2 tests at each temp and for each storage period. Data were subjected to analysis of variance for split-split plots. Means were

Table 1. Incidence of bacterial soft rot and curd spotting of cauliflower stored in various O_2 concn.[z]

Storage temp (°C)	O_2 concn (%) 21	6	4	2	1
	Bacterial soft rot (% heads affected)[y]				
2.5	20	14	10	16	25
5.0	31	27	25	23	41
7.5	16	18	17	14	48
Mean	22	20	17	18	38
	Curd spotting (% heads affected)[x]				
2.5	6	8	0	4	4
5.0	37	41	37	33	12
7.5	27	31	20	25	8
Mean	23	27	19	21	8

[z]The data are means of 2 tests for all storage periods and both examinations at each storage period. The relatively low incidence of BSR and CS at 7.5° likely is due to initial differences in susceptibility among tests.

[y]Includes all heads with any amount of soft rot.

[x]Includes heads rated 7 (not normally salable) or 9 (not normally usable).

tested by Duncan's multiple range test, but using Harter's tables of critical values for the .05% level (3).

Results

Odor and flavor. Cauliflower stored in 1% O_2 developed a relatively mild, sour off-odor. The odor developed at all temp tested, but not in all heads in each test, and it almost always disappeared during aeration at 10°C.

In cooked samples, however, highly objectionable off-odors and off-flavors characterized most heads previously held in 1% O_2 and many of those held in 2% O_2 (Fig. 1). When one-half of a head was held in 1% O_2 and the other half in 2% O_2, the objectionable odor and flavor were occasionally absent in the half held in 2% O_2. These defects were still present in curds cooked after aeration, and the off-odors were sometimes most intense at that time. Unlike broccoli (7), all parts of the florets were about equally affected whenever off-flavors occurred. However, within a given sample of 4 half-heads, some were inedible, whereas others had normal flavor.

Off-odors or off-flavors that developed at 4, 6, or 21% O_2 (Fig. 1) were due to aging and were characterized as "flat" in some heads or "sulfurous" in others.

Visible low–O_2 injury. Visible injury occurred only in cauliflower held in 1% O_2 in the tests of Jan. (2.5°C), Feb. (5°C), and March (7.5°C), 1974. The injury tended to become more serious as holding time increased, but subsequent aeration usually did not aggravate the symptoms.

Affected tissue was depressed below the normal level of the curd and became light tan. This pattern lent an appearance of dryness (Fig. 2), even though individual primordia, though less plump than normal, were not dry. The injury tended to be more prominent in cooked than in raw curds, and in mild cases, the depression and the illusion of dryness were noticeable only in cooked curds.

The stubs of leaves never showed any symptom of low–O_2 injury.

Decay. Soft rot (SR) was common in all tests, but its occurrence was independent of O_2 levels from 2 to 21%. SR invariably was most serious on cauliflower held in 1% O_2, regardless of storage temp (Table 1). Thus, soft rot is a symptom of low–O_2 injury in cauliflower, as it is with radishes (5) and broccoli (7). Mold growth was infrequent and not related to O_2 concn.

Curd spotting (CS), which was associated with *Pseudomonas* spp. and characterized by brown to black spots of various sizes, was a common defect in most of our tests and resembled

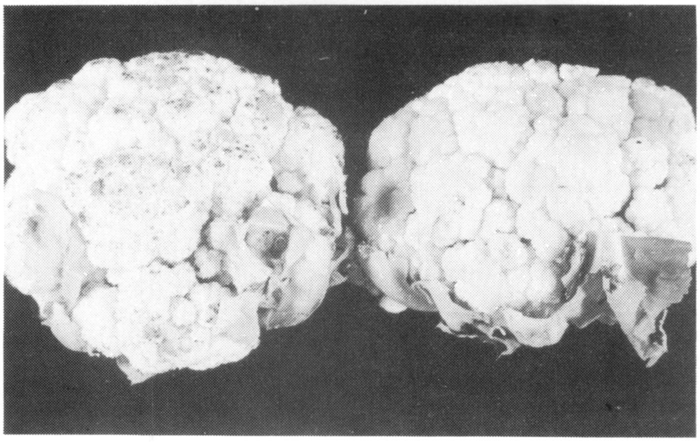

Fig. 3. Halves of same head after 20 days of storage at 5°C in 6% O_2 (left) or 1% O_2 (right) plus 3 days in air at 10°. Note that half from 6% O_2 shows severe curd spotting and little bacterial soft rot (smooth grayish areas), whereas the reverse is true for the half from 1% O_2.

that described by Coleno et al. (2) and the symptoms of bacterial leaf spot on the curd noted by Ramsey and Smith (10). The incidence of CS was not diminished by non-injurious levels of O_2, but was reduced by 1% O_2 (Table 1). In 1% O_2, where curd spotting was minimal, soft rot was abundant (Fig. 3).

The data for SR and CS were not statistically analyzed because, upon inspection, it was obvious that none of the O_2 concn tested provided any practical control of the disorders.

Color of curd. None of the O_2 concn that we used had any consistent effect on the Hunter values of L (lightness), a (degree of greenness), b (degree of yellowness), or on the a/b ratio, whether the curds were evaluated raw or cooked.

Even though O_2 concn had no significant effect on color, certain trends did emerge. Generally, curds held in 1% O_2 were 1 to 2 units darker and 0.1 to 0.4 units less green than any others, whether sampled raw or cooked and regardless of storage temp. Curds from 2 or 4% O_2 tended to be yellower than the others. Since curds from 2 or 4% O_2 also were relatively high in green components, and thus distant from gray, their color tended to be more pleasing even when lightness (L) was no greater than in relatively gray curds from other atmospheres.

Duration of storage did not materially affect any color factor of curds stored at 2.5 or 5°C. However, for curds stored at 7.5°, L values had decreased from the initial 79.8 to 78.5 after 6 days and to 77.8 after 19 days; the latter difference was significant at P = 5%. For cooked curds, the respective values were 70.1, 69.2 and 68.6, with no significance between the means.

Objectionable gray or yellow discoloration of cooked curds was not related to any of our experimental variables. However, we did find some relationships between Hunter values and visual evaluation of curd color. When L was below 66.0, the curds generally were objectionably dark; the darkening tended to be decidedly gray when b was below 20.0 and decidedly yellow when b was above 22.5. When b was between these values, the dark discoloration was not readily definable. Hunter a values and objectionable darkening were not related.

Identification of raw curds that will darken when cooked would be desirable, to eliminate such cauliflower before it is marketed or processed. Unfortunately, we were unable to find any useful predictor for such a separation among the following criteria: L, a, b, L/b, L/a, a/b or $|a+b|$.

Firmness. None of the treatment variables significantly influenced the firmness of cooked curds, whether comparisons were expressed as actual values (kg) at the time of examination or as a percentage of the values of similar samples tested prior to storage. However, at the end of all storage periods, and regardless of temp, shear resistance was about double that before storage, when it ranged from 16 to 36 kg and averaged 23 kg.

pH. None of the experimental variables influenced pH. Prior to storage, pH of the cooked tissue ranged from 6.0 to 7.3. As with broccoli (7), low pH values tended to be associated with firm curds and high values with relatively soft curds, but the relation was much less distinct than with broccoli.

Discussion

Two main points emerge from our current evaluation of the response of cauliflower to storage in low–O_2 atmospheres and from our earlier tests with high CO_2 (8): 1) The storage life of cauliflower was not extended by either low O_2 or high CO_2 at 2.5, 5, or 7.5°C, and 2) cauliflower curds were injured by low O_2 (2% or less) or by high CO_2 (5% or more).

Stoll (12) did extend the storage life of cauliflower by about 2 weeks by holding it in 2 to 3% O_2 and O to 3% CO_2 at 0°C. We did not evaluate the effect of CA on cauliflower at 0°C, because in commercial practice, this temperature cannot be maintained during transit without danger of some freezing in the load.

Even though cauliflower is highly sensitive to low O_2 and to high CO_2, the defects induced by these atmospheres differ in their response to subsequent aeration. The off-odors and off-flavors induced by low O_2 were evident even after the curds had been aerated several days prior to being cooked, whereas defects induced by CO_2 (off-odors, off-flavors, discoloration, softening) were no longer evident in curds cooked after aeration (8). The changes induced by high CO_2 were clearly related to, even if not caused by, reversible changes in tissue pH, whereas low O_2 atmospheres had virtually no effect on pH.

A comparison of our current and earlier (8) results on CA storage of cauliflower with those on broccoli (7) shows that these vegetables, even though they are closely related (6), differ markedly in sensitivity to low O_2 and high CO_2. Cauliflower can be injured by 2% O_2 or 5% CO_2, whereas broccoli not only tolerates low O_2 (½%) and high CO_2 (at least 10%), but its useful storage life is substantially lengthened in such atmospheres. We do not know the reason for this difference in response, but we suggest the following hypothesis.

Green tissue of some plants apparently is more tolerant of low O_2 or high CO_2 than essentially white tissue, regardless of maturity of the tissues involved. This difference in response is illustrated by the white and green curds of cauliflower and broccoli, respectively. However, the hypothesis is supported by other circumstantial evidence. The stubs of leaves of cauliflower showed no visible evidence of injury from low O_2 or from high CO_2, and in white cabbage, the green outer leaves remained in good condition during long-term storage in 21% CO_2, whereas the inner, presumably white, leaves were injured (13). As another example, in head lettuce, CO_2 injury (brown stain) shows up first and most severely on the white midrib, even at only 1 to 2% CO_2 (9). By contrast, the green portions of the lamina of the same leaves appeared normal even in 10% CO_2 (11). The pattern for low–O_2 injury of head lettuce is similar – achlorophyllous tissue was severely injured by storage in ¼ to ½% O_2, whereas the green wrapper leaves were only slightly injured in ¼% O_2 (4). Finally, romaine, an upright cultivar of lettuce, in which all leaves and even some midribs are green, was not injured even by 12% CO_2 (1).

These examples of greater sensitivity of white than of green tissue to injury by low O_2, and especially by high CO_2, do not prove that chlorophyll is the primary factor involved in this difference. However, the ratio of the rates of photosynthesis to photorespiration appears to provide a reasonable basis for the hypothesis. The importance of this ratio in respect to yield of crops has been emphasized by Zelitch (14), and it may be important in determining crop quality. Since white tissue depends on translocated material for metabolic substrate, a relatively high rate of photorespiration for the crops in question, added to normal dark respiration, may deprive non-photosynthetic tissue of substrate during growth and thus make white tissue more susceptible than green to deleterious effects of low O_2 or high CO_2 during storage. This presumed disadvantage would be enhanced when the proportion of white tissue is relatively large, as in cauliflower or head lettuce, or would be diminished when the proportion is small, or when the white and green tissues are in direct contact, as in the leaves of romaine lettuce or in the wrapper leaves of head lettuce.

This hypothesis also would be consistent with the finding that the midrib of head lettuce is very susceptible to various disorders not connected to CA storage, such as russet spotting, pink rib, rib discoloration, and internal rib necrosis (9).

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Effects of Applied Growth Substances on Growth of Shoot Apices Excised from Onions in Rest[1]

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Abstract. **Both 6-furfurylaminopurine (kinetin) and sucrose substituted for exposure to 10°C in promoting growth of excised shoots of onion (*Allium Cepa* L.), but no additive effect of these substances and exposure to 10°C was observed. Ammonium (5-hydroxycarvacryl) trimethyl chloride piperidine carboxylate (ACPC) nullified the promotive effect of 10°C treatment when applied prior to temperature treatment but was without effect when applied after temperature treatment. Sucrose and kinetin partially overcame the effect of ACPC. Abscisic acid (ABA) inhibited growth of onion shoots and nullified growth promoted by exposure to 10°C regardless of time of application of ABA. Kinetin reduced the effect of ABA but sucrose did not.**

Chemicals have been tested as a means of controlling rest in onion bulbs. The use of chemicals for prolonging rest has been more successful than for shortening it. For example, maleic hydrazide applied before harvest retards sprouting of onion bulbs very effectively (12) and ABA injected into onion bulbs has been reported to delay sprouting (2). Other chemicals such as ether and ethylene chlorhydrin (15) or applications of gibberellic acid (GA_3), a mixture of gibberellins 4 and 7 ($GA_{4/7}$), and napthaleneacetic acid (NAA) have not been successful in breaking rest in onions (22). However, the application of exogenous GA_3 induced bud break in various woody species (23) and its effectiveness in shortening rest in potato tubers is well documented (14, 18). The possible role of hormones in onion rest deserves more study if the phenomenon is to be understood and eventually controlled.

Excised shoot apices can be used as tools to study onion rest (17). Our object was to obtain information on the effects of temperature and growth substance treatments on growth of onion shoots excised from onion bulbs still in rest.

Materials and Methods

Bulbs of 'Spartan Banner', a good storage onion, were grown at the M.S.U. Muck Farm. After harvesting and curing, the scales were removed from the dormant bulbs to expose the shoot apices which were then washed with distilled water. For some experiments 'Abundance' and 'Downing Yellow Globe' were obtained from commercial growers after they were harvested and cured. All bulbs were held at 20°C until used and all experiments were begun within one month of harvest.

To test the effects of chemicals on growth of the excised shoots, the following substances were used either alone or in combination with a 10°C temperature treatment: sucrose (10%), (2 chloroethyl)phosphonic acid (ethephon) (100 ppm), kinetin (100 ppm), GA_3 or $GA_{4/7}$ (100 ppm), ABA (1 ppm),

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