Relationship between the Nutritional Value and the Head Structure of Lettuce

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Abstract

Crisphead lettuce has much lower vitamin A, vitamin C, calcium, and iron contents than leaf or romaine lettuce. This experiment was conducted to determine whether the low nutritional value is associated with the head structure. Heads of a crisphead lettuce cultivar Salinas grown in the field were kept open by hand, while leaves of a romaine lettuce cultivar Lobjoits were closed by tying with wire. These plants as well as the normal controls were analyzed for their nutritional contents. The content of β-carotene (provitamin A), Ca, and Fe was higher in the outer leaves than in the inner leaves of a normal lettuce head, while there was little difference in vitamin C content between the two classes of leaves. Artificially opening the lettuce head greatly increased its nutrient content to a level comparable to leaf or romaine lettuce. After the romaine lettuce leaves were closed, the levels of β-carotene and vitamin C dropped to a minimum and the contents of Ca and Fe were also largely reduced. These results suggest that the lower nutritional value of crisphead lettuce is due to the enclosure of its leaves in the head structure. The physiological basis of these findings and their implications for genetic improvement of the nutritional value of lettuce are discussed.

INTRODUCTION

The major product from agricultural production is food that is fundamental to human life and health. Consumers have become more demanding for safe and nutritious food that improve physical performance, reduce risks of diseases, and increase the life span. One of the major missions of the USDA-ARS National Program for the Plant, Microbial, and Insect Genetic Resources, Genomics and Genetic Improvement is to utilize genetic tools, information, and materials to ensure such a high quality, safe, and abundant supply of food for the United States and other nations.

Vegetables play an important role in human diet and nutrition. Lettuce is the most important vegetable crop produced for fresh market in the United States in terms of acreage, production, and market value (Ryder, 1986). Most lettuce production and consumption in U.S. is of the crisphead type. Compared to leaf or romaine types, crisphead lettuce has much lower vitamin A, vitamin C, calcium, and iron content (Table 1). To improve the nutritional value of lettuce, one must first understand why such a large difference exists. The most obvious difference between crisphead lettuce and leaf or romaine lettuce is that crisphead type forms a head. This experiment was conducted to determine if the lower nutritional value in crisphead lettuce is due to head formation.

MATERIALS AND METHODS

Seeds of a crisphead lettuce cultivar Salinas and a romaine lettuce cultivar Lobjoits were planted in double-row raised beds on one-meter centers at the Spence field site of the USDA Research Farm in Salinas, Calif. on March 1, 2001. After thinning, plants were spaced 35 cm between rows and 30 cm between plants within rows. From the time the crisphead lettuce started to form heads, leaves of selected plants were kept open by hand so they could not form heads. About 45 days after planting, leaves of randomly selected romaine lettuce plants were closed by tying with wires. When plants reached

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maturity at 82 days after planting, these plants and normal controls were harvested. Leaves of normal 'Salinas' control plants were then divided into outer leaves and inner leaves. The outer leaves include the first six leaves from the outside of the head, not including the frame and wrapper leaves. The remaining inside leaves of the head constituted the inner leaves. Similar numbers of leaves from the opened lettuce heads were also divided into outer and inner leaves.

Leaf samples from two plants of each treatment and normal control were sent to a commercial analytical lab (Medallion Laboratories, Minneapolis, Minn.) for nutritional analyses. β-Carotene (provitamin A) content was determined using High Performance Liquid Chromatography (HPLC). Vitamin C (ascorbic acid) was analyzed by using AOAC fluorescence method (Deutsch and Weeks, 1965). Calcium and iron analyses were done by Inductively Coupled Plasma (ICP) assay.

RESULTS AND DISCUSSION

In a normal closed lettuce head, β-carotene content was higher in the outer leaves than in the inner leaves (Fig. 1). When the head was opened up, β-carotene content was greatly elevated to a level comparable to leaf or romaine lettuce. There was little difference in vitamin C content between outer leaves and inner leaves of a closed head (Fig. 2). Nevertheless, vitamin C content also increased to a level similar to leaf or romaine lettuce when the head was opened. Calcium and iron contents were both higher in the outer leaves than in the inner leaves of a closed head (Fig. 3 and 4). When we opened the lettuce heads, however, the contents of both elements increased to the level of leaf or romaine lettuce. These results suggest that the lower nutritional value of head lettuce is due to the enclosure of its leaves in the head structure.

To demonstrate this point further, we did a reverse experiment. We closed the normally open romaine lettuce leaves and analyzed the nutrient content. Compared to open romaine lettuce leaves, β-carotene and vitamin C contents dropped to a minimum and Ca and Fe contents were also largely reduced in closed romaine lettuce leaves (Fig. 5). These results again demonstrate that closing lettuce leaves can have a pronounced adverse effect on nutritional value.

The biogenesis of β-carotene takes place in chloroplasts where the carotene exists in photosynthetic membranes as chlorophyll-carotenoid-protein complexes. β-Carotene plays a role in photosynthesis as an accessory pigment that absorbs at different wavelengths from the chlorophylls and transfers the absorbed light energy to the chlorophylls. Besides their function as light-harvesting pigments, carotenoids also protect the cells by directly quenching the excess energy of excited chlorophyll or quenching the highly reactive singlet oxygen (Gross, 1991). Fe in plant leaves is stored largely as a ferric phosphoprotein called phytoferritin. Barton (1970) observed large quantities of phytoferritin in chloroplasts and confirmed earlier evidence that chloroplasts are rich in Fe, containing as much as 80% of the total Fe in plants (Neish, 1939). Iron also exists in chloroplasts as Fe-S proteins in which each of four iron atoms is bound to two sulfur atoms. The Fe-S proteins are primary electron acceptors for the photosystem I (PS I) and the electron transport pathway between PS I and PS II (Salisbury and Ross, 1985). In green plants there is often a good correlation between the level of Fe supply and the chlorophyll content, plants well supplied with Fe being high in chlorophyll (Jacobson and Oertli, 1956; Dekock et al., 1960). Applying radioactive Fe-59 to tomato plants suffering from Fe chlorosis, Machold and Scholz (1969) observed that the distribution of Fe-59 in the leaves corresponded exactly to the areas in which regreening occurred. As we opened the lettuce heads, the normally light green to yellow inner leaves turned green, signaling an increase of chloroplasts with the penetration of light. Because of the close association of β-carotene and iron with the photosynthetic apparatus, it is not surprising to see the higher β-carotene and Fe content in the greener outer leaves of a lettuce head and opened heads. In contrast, the inside leaves of closed romaine lettuce turned yellow as compared to the green leaves of normal control plants, which probably led to the lower values of both nutrients in the closed leaves.

The leaf tissues are mainly supplied with Ca by the transpiration stream in the xylem that translocates Ca directly from the soil solution. Inadequate levels of Ca may exist in young leaves of developing heads when they are enclosed by outer leaves and do not freely transpire. Brown melanin compounds from polyphenol oxidation are associated with the deficient tissues at the apex and margin of leaves, resulting in a Ca-related physiological disorder of lettuce, tipburn (Collier and Tibbitts, 1982). Barta and Tibbitts (1986) found that enclosure of young lettuce leaves in aluminized polyethylene sheaths for four days reduced leaf Ca concentration by 57% and induced tipburn in 53% of the enclosed leaves. Therefore, higher transpiration rate probably accounts for the higher Ca content in the outer leaves and opened leaves of lettuce head in our experiment. We also observed tipburn in some of the closed romaine lettuce leaves, consistent with the reduced Ca content.

Ascorbic acid is a sugar acid and a positive correlation between ascorbic acid and sugar content (r = 0.81) in lettuce has been reported by Shinohara and Suzuki (1981). Ascorbic acid content in lettuce leaves increases under strong light conditions and decreases under weak light or shaded conditions (Hulewicz and Kalbarczyk, 1976; Shinohara and Suzuki, 1981). The increased photosynthetic area and sugar supply might have contributed to the higher vitamin C content in our opened lettuce head, whereas closing romaine lettuce leaves might have the opposite effects.

Butterhead lettuce also has lower nutritional value than leaf or romaine lettuces, but has higher nutrient contents than crisphead lettuce except iron (Table 1). The head of the butterhead lettuce is often partially open on the top, allowing light to penetrate deeper into the head. The head of butterhead type is also generally much smaller and thus has proportionally more outer green leaves than the head of crisphead type. These factors may explain the nutritional status of butterhead lettuce in relation to other lettuce types.

Despite the efforts from public health organizations and produce industry, increasing the consumption of fruits and vegetables is often hard to achieve due to dietary habits and cultural reasons. Enhancing the nutritional levels of vegetables would improve the nutrient intake without requiring an increase in consumption. The improvement of nutritional value for head lettuce is probably limited to a large extent by the fact that its leaves are enclosed in a head structure. Open-headed variants naturally occur in crisphead lettuce populations, but may not be accepted by consumers as they resemble leaf lettuce. Genetic engineering has the potential to markedly increase the nutritional value of head lettuce, which also awaits the increased public acceptance. We plan to screen our germplasm collection to identify sources that would be useful in a breeding program for improved nutritional value in lettuce.

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Literature Cited

Barta, D.J. and Tibbitts, T.W. 1986. Effects of artificial enclosure of young lettuce leaves on tipburn incidence and leaf calcium concentration. J. Amer. Soc. Hort. Sci. 111(3): 413-416.

Barton, R. 1970. The production and behavior of phytoferritin particles during senescence of *Phaseolus* leaves. Planta 94:73-77.

Collier, G.F. and Tibbitts, T.W. 1982. Tipburn of lettuce. Hort. Rev. 4:49-65.

Dekock, P.C., Commisiong, K., Farmer, V.C. and Inkson, R.H.E. 1960. Interrelationships of catalase, peroxidase, hematin and chlorophyll. Plant Physiol. 35:599-604.

Deutsch, M.J. and Weeks, C.E. 1965. AOAC 967.22 (Vitamin C (Total) in Vitamin Preparations). J. Assoc. Official Agric. Chem. 48(6):1248-1256.

Gross, J. 1991. Pigments in Vegetables: Chlorophylls and Carotenoids. p. 121-122. AVI Publishing Company, Inc., Westport, CT, USA.

Hulewicz, D. and Kalbarczyk, M. 1976. The influence of light on the yield of lettuce and its nutrient content. Archiv fur Gartenbau. 24(1):113-120.
Jacobson, L. and Oertli, J.J. 1956. The relation between iron and chlorophyll contents in chlorotic sunflower leaves. Plant Physiol. 31:199-204.
Machold, O. and Scholz, G. 1969. Iron status and chlorophyll synthesis in higher plants. Naturwiss. 56:447-452.
Neish, A.C. 1939. Studies on chloroplasts. Biochem. J. 33:300-308.
Ryder, E.J. 1986. Lettuce breeding. p. 433-474. In: Breeding Vegetable Crops, M.J. Bassett (eds.). AVI Publishing Company, Inc., Westport, CT, USA.
Salisbury, F.B. and Ross, C.W. 1985. Plant Physiology. p. 186-187. Wadsworth Publishing Company, Belmont, CA, USA.
Shinohara, Y. and Suzuki, Y. 1981. Effects of light and nutritional conditions on the ascorbic acid content of lettuce. J. Japan Soc. Hort. Sci. 50(2): 239-246.
U.S. Department of Agriculture, Agricultural Research Service. 2001. USDA Nutrient Database for Standard Reference, Release 14. Nutrient Data laboratory Home Page, http://www.nal.usda.gov/fnic/foodcomp

Tables

Table 1. Nutrient content of the four major lettuce types. Source: U.S. Department of Agriculture, Agricultural Research Service. 2001.

Nutrients	Crisphead	Leaf	Romaine	Butterhead
Vitamin A (IU/100 g)	330.0	1,900.0	2,600.0	970.0
Vitamin C (mg/100 g)	3.9	18.0	24.0	8.0
Calcium (mg/100 g)	19.0	68.0	36.0	32.0
Iron (mg/100 g)	0.5	1.4	1.1	0.3

Figures

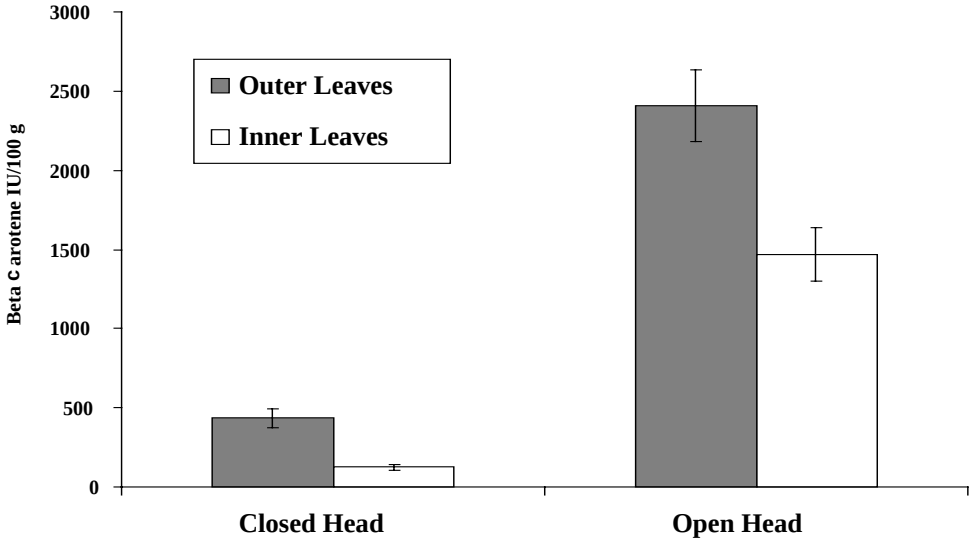

Fig. 1. Mean and standard error of β-carotene content (in International Units per 100 g fresh leaves) of normal closed head and manually opened head of 'Salinas' head lettuce.

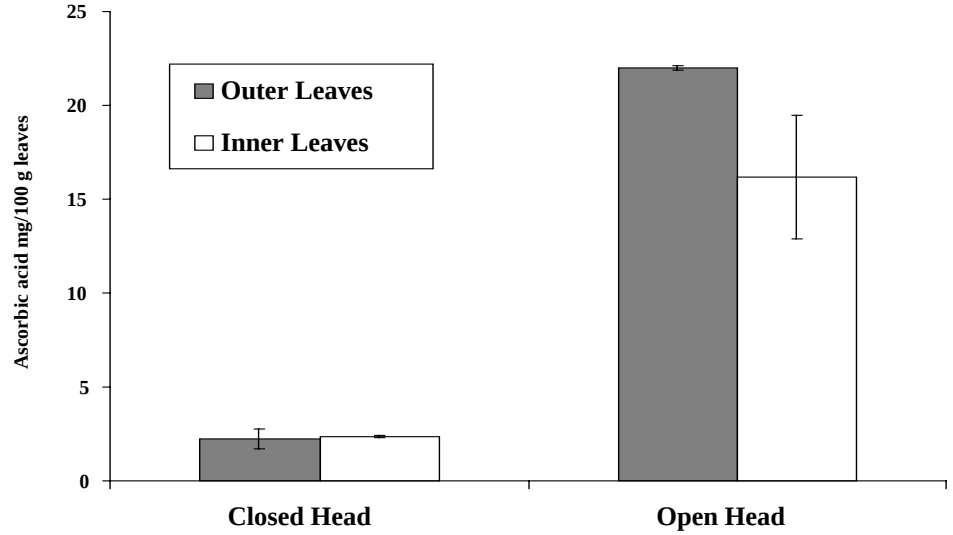

Fig. 2. Mean and standard error of vitamin C content of closed head and opened head of 'Salinas' head lettuce.

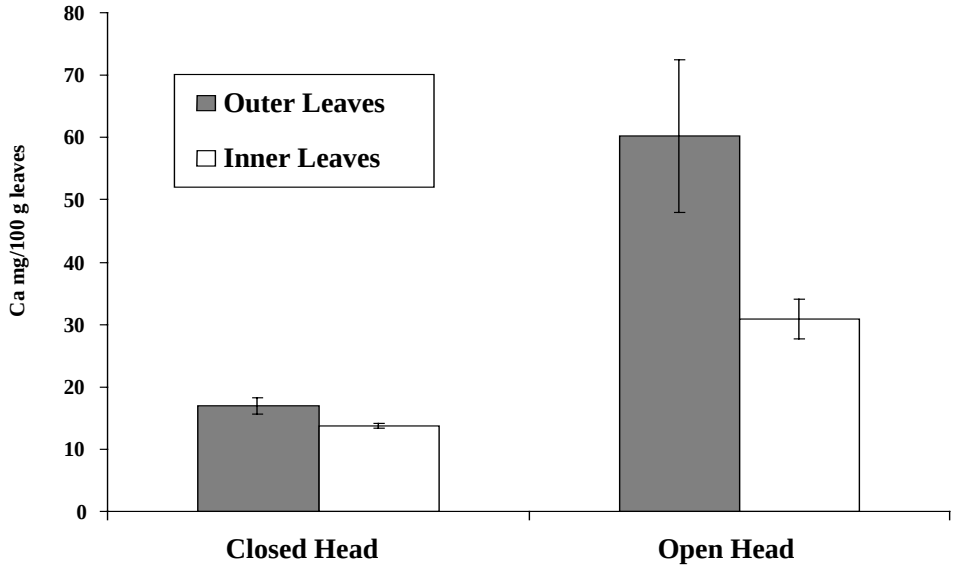

Fig. 3. Mean and standard error of calcium content of closed head and opened head 'Salinas' head lettuce.

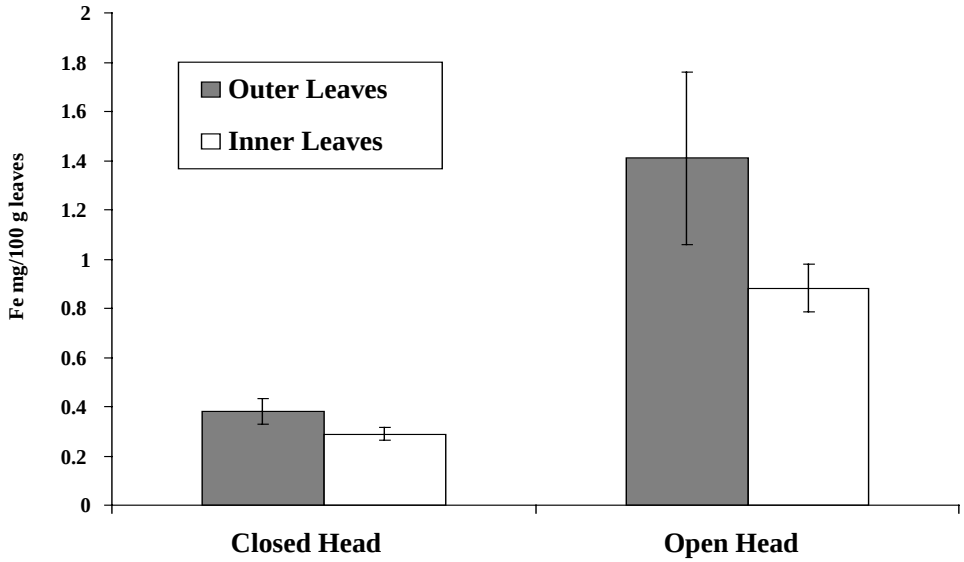

Fig. 4. Mean and standard error of iron content of closed head and opened head of 'Salinas' head lettuce.

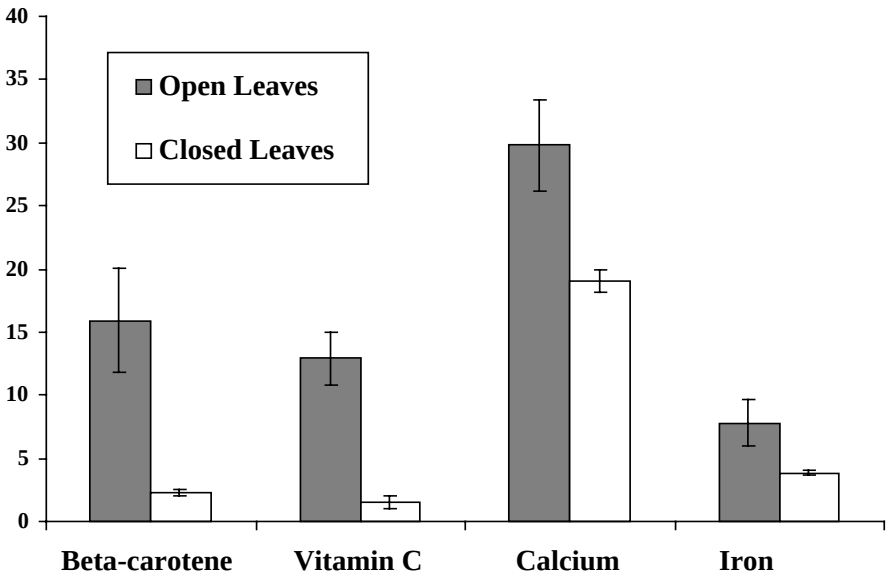

Fig. 5. Mean and standard error of β-carotene (International Unit/g leaves), vitamin C (mg/100 g leaves), Ca (mg/100 g leaves), and Fe (mg/kg leaves) content of normal open leaves and closed leaves of 'Lobjoits' romaine lettuce.