# キャベツの収量および遊離糖含量に及ぼす培養液中の窒素,リンおよびカリウムの影響


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| 誌名 | 園藝學會雜誌 |
| ISSN | 00137626 |
| 著者 | 原, 徹夫 |
| 巻/号 | 58巻3号 |
| 掲載ページ | p. 595-599 |
| 発行年月 | 1989年12月 |



農林水産省 農林水産技術会議事務局筑波産学連携支援センター
Tsukuba Business-Academia Cooperation Support Center, Agriculture, Forestry and Fisheries Research Council Secretariat

J. Japan. Soc. Hort. Sci. 58(3) : 595-599. 1989.

# Effects of Nitrogen, Phosphorus and Potassium in Culture Solution on the Head Yield and Free Sugar Composition of Cabbage

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**Summary**

Cabbage plants were grown for about 2 months in a culture solution containing 3 levels of nitrogen (5, 50, 500 ppm), phosphorus (2, 20, 200 ppm) and potassium (5, 50, 500 ppm), and effects of the supply on head yield and free sugar composition of the plants were studied.

Plant dry weight and head yield increased with the increase of N (5~50 ppm), P (2~20 ppm) and K (5~50 ppm) in the culture solution, and decreased at the highest level of each element. Nitrogen, phosphorus and potassium contents in plants increased greatly with the increase of levels of each element. Fructose, glucose and sucrose contents of plants decreased with the increase of nitrogen levels, and the decrease of sucrose was great. In the phosphorus and potassium treatment, fructose and glucose contents did not change remarkably but sucrose content was the highest at 20 ppm of P and at 50 ppm of K. Fructose content was higher in head leaves than in outer leaves. There was close correlation between head yield and sucrose content in the outer leaves in all treatments with the exception that 5 ppm N. Nitrogen deficiency caused an increase of free sugar content, especially of sucrose.

## Introduction

Cabbage plants produce large heads when suitable amounts of mineral nutrients are supplied. When phosphorus and potassium are deficient, head yield and sugar content decrease, but the sugar content increases in the many cases of nitrogen deficiency. Under ordinary conditions, ratios of nitrogen content to other nutrient contents and to carbohydrate contents are a main factor in determining the head production of cabbage plants(4). Normal cabbage heads contain a large amount of minerals, sugars and vitamins, and thus have good qualities and high commercial value as a vegetable.

Sweet taste is one of the important factors in estimating the quality of cabbage heads. Free sugars are responsible for the sweet taste, because they are the largest part of carbohydrates of the head. The main free sugars in cabbage plants are glucose, fructose and sucrose, and proportions of these sugars are influenced by cultural conditions(6). If the proportions vary with the nutritional conditions, the quality and taste of cabbage heads may change to some extent. Therefore, we studied how nutrient status of cabbage plants affects the proportions of the free sugars. We investigated relationships between three major elements (N, P and K) and the concentration of free sugars, because these elements greatly influence the sugar production(5).

Received for publication October 26, 1987.

## Materials and Methods

Seeds of cabbage (*Brassica oleracea* L. var. *capitata* L. CV. Fuji) were sown in vermiculite with a complete culture solution on 16 October, 1983. Uniform seedlings were transplanted to 4 liter pots set in a green house on 12 November. The constituents of the culture solution were 50 ppm N, 20 ppm P, 50 ppm K, 100 ppm Ca and 25 ppm Mg. These nutrients were added in form of $NaNO_3$, $Na_2HPO_4$, $K_2SO_4$, $CaCl_2$ and $MgSO_4$, respectively. All micronutrients were also added to the culture solution(2). The plats were thinned to one per pot until 26 November, when the nutrient treatment was made with the same chemicals

as described above. In the culture solution up to harvest three levels of nitrogen (5, 50 and 500 ppm), phosphorus (2, 20 and 200 ppm) and potassium (5, 50 and 500 ppm) were established in three replications. These solutions were aerated occasionally and renewed every 7 days. All the plants were harvested simultaneously on 22 January, 1984, and separated into the head leaves (composing each head), outer leaves, stems and roots. All the four parts of the plants were dried at 70°C, weighed and milled for chemical analysis.

In the chemical analysis nitrogen was determined by Gunning's method, phosphorus by the colorimetric ammonium vanadomolybdate method, and potassium by the flamephotometric method. Free sugars were extracted with 70% ethanol and the extract passed through a column of Amberlite IR-120 ($H^+$ form) and then through a column of Amberlite IRA-410 ($OH^-$ form). The sugar extract was concentrated to 2 ml ond filtered with a millipore (0.45 $\mu$m) filter, and the filtrate was injected into a high performance liquid chromatograph (Shimadzu HPLC LC-6 A) with a stainless steel column (4×250 mm) packed with Shimpack $PNH_2$. Elution was carried out with acetonitrile-water (70 : 30, v/v) at a flow rate of 1.2 ml/min, and the sugars were detected with a differential refractometer (Shimadzu RID-2 A).

## Results

*Plant growth and nutrient contents in plants*

Total dry weights of plants increased with the increase of N (from 5 to 50 ppm), P (from 2 to 20 ppm) and K (from 5 to 50 ppm) in culture solution, and decreased at the highest level of each element (Table 1). Similar tendencies were found in the results of head dry weights. During the head development stage, symptoms of nitrogen, phosphorus and potassium deficiencies were observed at 5 ppm of N, 2 ppm of P and 5 ppm of K, respectively. When growth decreased with the deficiency. or excess of these elements, the head yield decreased to a greater extent than the total dry weight. Thus the ratio of head/whole plant was the highest at the second level of each element.

Nitrogen, phosphorus and potassium contents in plants increased greatly with the increase of levels of each element in culture solution, and each content showed no change or a slight decrease with the increase of levels of the other two elements (Table 2). These contents were higher in head leaves than in outer leaves.

**Table 1.** Effects of different concentrations of N, P and K in culture solution on plant growth.

| Conc. of nutrients in culture solution (mg/l) | Dry weight (g/plant) | | Head/whole plant |
|---|---|---|---|
| | Whole plant | Head | |
| N 5 | 20.5 | 2.7 | 0.13 |
| N 50 | 99.0 | 50.1 | 0.51 |
| N 500 | 72.5 | 26.5 | 0.37 |
| P 2 | 54.8 | 22.1 | 0.40 |
| P 20 | 99.0 | 50.1 | 0.51 |
| P 200 | 70.8 | 30.4 | 0.43 |
| K 5 | 56.4 | 17.0 | 0.30 |
| K 50 | 99.0 | 50.1 | 0.51 |
| K 500 | 82.1 | 41.0 | 0.50 |

**Table 2.** Effects of different concentrations of N, P and K in culture solution on the content of each element in the plants.

| Conc. of nutrients in culture solution (mg/l) | Content of major elements in plant (% on dry weight basis) | | | | | |
|---|---|---|---|---|---|---|
| | Outer leaves | | | Head leaves | | |
| | N | P | K | N | P | K |
| N 5 | 0.68 | 0.39 | 1.89 | 2.03 | 0.55 | 2.44 |
| N 50 | 1.69 | 0.29 | 1.13 | 2.28 | 0.39 | 2.07 |
| N 500 | 3.70 | 0.21 | 0.84 | 4.31 | 0.40 | 1.63 |
| P 2 | 2.13 | 0.06 | 1.31 | 1.65 | 0.17 | 2.16 |
| P 20 | 1.69 | 0.29 | 1.13 | 2.28 | 0.39 | 2.07 |
| P 200 | 1.65 | 0.57 | 1.28 | 2.08 | 0.52 | 1.71 |
| K 5 | 2.03 | 0.46 | 0.18 | 2.81 | 0.42 | 0.47 |
| K 50 | 1.69 | 0.29 | 1.13 | 2.28 | 0.39 | 2.07 |
| K 500 | 1.60 | 0.26 | 4.54 | 2.02 | 0.42 | 4.49 |

*Free sugar contents in plants*

The elution pattern of free sugars in the head leaves grown in culture solution containing 50 ppm N is shown in Fig. 1, as an example in the HPLC analysis. Fructose, glucose, sucrose and maltose were eluted in turn within 8 minutes after injection. The results on maltose were omitted, because its amount was too small to interpret the fluctuation. Fructose, glucose and sucrose contents in outer leaves and head leaves decreased with the increase of leaves of nitrogen in culture solution, and the decrease in the sucrose

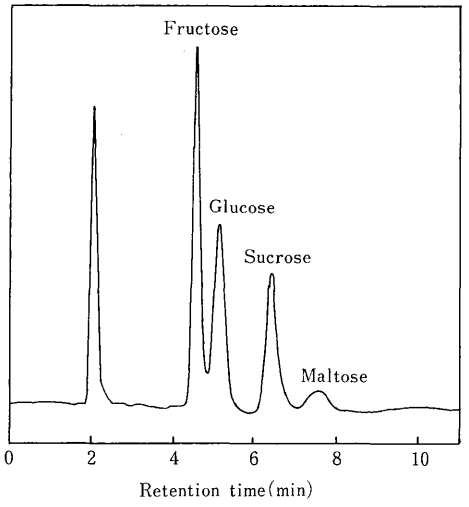


**Fig. 1.** High performance liquid chromatogram of free sugars in head leaves of plants grown in culture solution containing 50 ppm N.

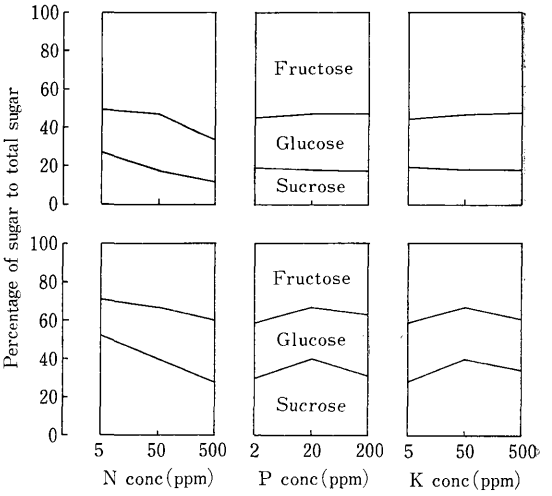


**Fig. 2.** Effects of different concentrations of N, P and K in culture solution on the percentage of each free sugar to total sugar in plants. Upper figures; head leaves. Lower figures; outer leaves.

content was remarkable (Table 3). The sucrose content in outer leaves was higher than fructose or glucose contents at 5 ppm of N, whereas at 500 ppm of N, it was the lowest. Fructose content was higher in head leaves than in outer leaves at all nitrogen levels. Percentage of the sucrose to total sugar (fructose+glucose+sucrose) decreased greatly with the increase of levels of nitrogen in culture solution (Fig. 2). The percentage of fructose was higher in head leaves than in outer leaves.

In the case of phosphorus treatment, fructose and glucose contents in outer leaves did not change greatly, but sucrose content was the highest at 20 ppm of P (Table 3). All the contents of the free sugars in head leaves were higher at 20 ppm of P than at 2 or 200 ppm of P. Fluctuations caused by the phosphorus treatment were smaller than that by the nitrogen treatment: especially, sucrose content in head leaves was comparatively low and almost the same in each plot. The percentage of sucrose/total sugar was high at 20 ppm of P in outer leaves but in head leaves that of sucrose, glucose and fructose did not change much (Fig. 2).

**Table 3.** Effects of different concentraitons of N, P ad K in culture solution on the contents of free sugars in the plants.

| Conc. of nutrients in culture solution (mg/l) | Free sugar contents in plant (% on dry weight basis) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Fructose | | Glucose | | Sucrose | | Total | |
| | OL | HL | OL | HL | OL | HL | OL | HL |
| N 5 | 6.7 | 15.4 | 4.5 | 6.6 | 12.1 | 8.3 | 23.3 | 30.3 |
| N 50 | 5.1 | 11.5 | 4.1 | 6.5 | 6.2 | 3.9 | 15.4 | 21.9 |
| N 500 | 3.8 | 8.3 | 3.1 | 2.6 | 2.7 | 1.7 | 9.6 | 12.6 |
| P 2 | 5.4 | 9.3 | 3.8 | 4.4 | 3.7 | 3.2 | 12.9 | 16.9 |
| P 20 | 5.1 | 11.5 | 4.1 | 6.5 | 6.2 | 3.9 | 15.4 | 21.9 |
| P 200 | 4.7 | 9.2 | 4.1 | 5.3 | 4.0 | 3.0 | 12.8 | 17.5 |
| K 5 | 4.9 | 8.8 | 3.7 | 3.9 | 3.4 | 3.0 | 12.0 | 15.7 |
| K 50 | 5.1 | 11.5 | 4.1 | 6.5 | 6.2 | 3.9 | 15.4 | 21.9 |
| K 500 | 5.8 | 11.1 | 4.1 | 6.3 | 5.1 | 3.8 | 15.0 | 21.2 |

OL: Outer leaves, HL: Head leaves

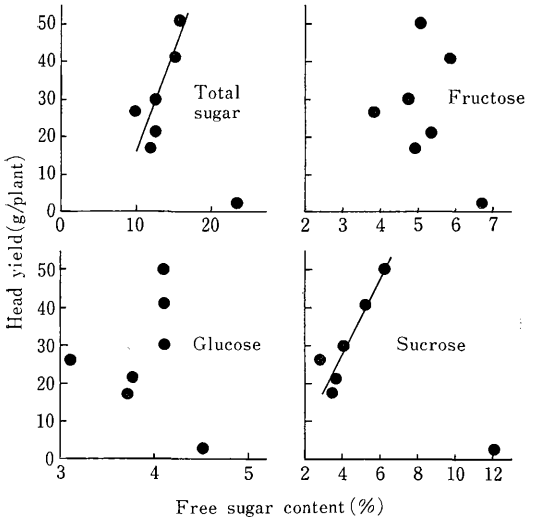


**Fig. 3.** Relationship between head yield and free sugar content in outer leaves.

Only the treatment of 5 ppm K decreased free sugar contents in both outer leaves and head leaves (Table 3). No great difference in the free sugar contents existed between the treatments of 50 ppm K and 500 ppm K. The percentage of sucrose/total sugar did not vary in head leaves, but was high at 50 ppm of K in outer leaves (Fig. 2).

*Relationship between head yield and free sugar content*

There was a positive correlation between head yield and total sugar content or sucrose content in outer leaves in all treatments, with the exception of the 5 ppm N (Fig. 3). Although free sugar contents in 5 ppm N treatment were very high, head yield was markedly low. There was no clear relationship between head yield and fructose or glucose content.

## Discussion

The critical contents of nitrogen, phosphorus and potassium deficiency which result in a 50% decrease in the head yield of cabbage plants were previously reported to be 1.3, 0.1 and 0.3%, respectively(3). In the present experiment, nitrogen, phosphorus and potassium contents (Table 2) in the outer leaves grown by treatments of 5 ppm N, 2 ppm P and 5 ppm K were lower than the critical contents mentioned above. It was obvious that these plants were affected by the severe deficiency of each element. Free sugars did not accumulate in the case of phosphorus and potassium deficiency but accumulated abundantly in the case of nitrogen deficiency (Table 3). Free sugars synthesized in outer leaves in nitrogen deficiency can be transported into other plant parts, but they are not converted to amino acids or other high molecular compounds because of nitrogen shortage. The free sugars accumulated in cabbage plants in nitrogen deficiency are partly changed to starch(3). Free sugar contents in the outer leaves and head leaves decreased distinctly with a treatment of 500 ppm N. When nitrogen is absorbed abundantly by cabbage plants, free sugars are utilized rapidly in all plant organs, resulting in a decrease in the concentration of free sugars in the head leaves.

The small decreases in free sugar contents with deficiency or excess of phosphorus or potassium (Table 3) are attributed to the decrease of sugar production of outer leaves. The photosynthetic rate of these leaves is considered to be low because the phosphorus and potassium in these leaves are lower or much higher than the critical nutrient levels leading to a decrease in the photosynthetic rate of other leaves(1). Sugars produced in these leaves are transferred smoothly to head leaves, based on the fact that the concentration of free sugars in head leaves produced with 2 ppm P, 5 ppm K, 200 ppm P and 500 ppm K was comparatively high.

Under nitrogen deficiency, free sugars of outer leaves accumulate mainly as sucrose, because sucrose has a lower effect on osmotic pressure than fructose and glucose at the same concentration in plant tissues. In cabbage plants, sucrose may be an active sugar and a main material for transportation of photosynthates. In outer leaves, high photosynthetic rates make the sucrose content high. This partly explains the positive correlation between head yield and sucrose content in outer leaves.

Sugars transported into the head leaves are converted to fructose, which contributes highly to the sweet taste of the head leaves, because D-fructose is generally recognized to be sweeter than sucrose and D-glucose. Although this

result may be derived from the genetic character of cabbage plants, it is desirable to consumers weo like to eat sweet cabbage heads.

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## キャベツの収量および遊離糖含量に及ぼす培養液中の窒素，リンおよびカリウムの影響


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### 摘　要

濃度を3段階（低，中，高）とした窒素（5，50，500 ppm N），リン（2，20，200 ppm P）およびカリウム（5，50，500 ppm K）を含む培養液でキャベツを約2か月間水耕栽培し，これら要素の供給量が結球収量と遊離糖含量に及ぼす影響について調査した．

全植物重および結球重ともに培養液中の各要素濃度の増加により低濃度区から中濃度区まで上昇し，高濃度区で低下した．植物体中の窒素，リンおよびカリウム含量は培養液中の各要素濃度の増加により著しく上昇した．

植物体中のフラクトース，グルコース，シュクロース含量は培養液中の窒素濃度の増加により低下し，その低下はシュクロースにおいて大きかった．リンおよびカリウム処理の場合は，フラクトース，グルコース含量はあまり変化せず，シュクロース含量は中濃度区で高かった．窒素低濃度区の結果を除外すると，結球重と外葉のシュクロース含量との間に正の相関が認められた．窒素低濃度区の場合にはシュクロースの集積が認められた．