A STUDY OF CAULIFLOWER

Brassica Oleracea Linn, var. *botrytis* D.C.

by
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degree of Doctor of Philosophy

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INTRODUCTION

Monographs and farmers bulletins on the culture of cauliflower plants emphasize the difficulties and the hazards involved in the culture of the plant. The factors upon which the successful culture of the plants depends are listed as ample nutrition, abundance of precipitation, and relatively low temperature during the growing season. However, a review of the literature on cauliflower production shows that most technical papers deal with minor-element nutrition and also manurial studies and that the effects of the environment on the development of the plant have been neglected. It was the purpose of this study to find out more about the growth and development of cauliflower as influenced by variety and environment in order to eliminate some of the hazards involved in the culture of the plant. Certain other phases were included to supply essential information for such a study.

SECTION I

A STUDY OF THE MORPHOLOGY OF THE CAULIFLOWER

Introduction

One of the ways that plants respond to the environment is by changes in their morphological features. Differences in such features also make up part of the distinctions among varieties. The purpose of this study is to describe the morphological development of the cauliflower plant from germination of the seed to preanthesis, in order to serve as a guide in a study of morphological differences among varieties,[1] and the effect of environment on the morphology of the plants.[2] Of secondary importance is the evaluation of the morphological descriptions given by other authors, and also the description of certain morphological abnormalities encountered in the physiological experiments.

Review of Literature

The peculiar organization of the cauliflower inflorescence has attracted the attention of botanists and horticulturists for centuries, but only three technical papers relating to this subject have been found. These three papers disagree with the commonly accepted botanical and horticultural concept which appears to have been introduced by DeCandolle. He gave cauliflower its scientific subspecies name, botrytis, and described it in French and English in his "Memoir of the genus *Brassica*" (16). His

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[1] Section III.

[2] Section IV, V, VI.

description of the cauliflower was not very technical, and can be summarized in three points: (1) The flowers were not spread as a panicle, but held tightly together and formed a corymb; (2)the pedicels grew fleshy and lost their shape from being held tightly together; (3) nothing but rudiments of abortive flowers were produced.

Master (36) used more technical terms. He stated that cauliflower and broccoli afforded familiar illustrations of hypertrophy of flower stalks accompanied by a corresponding defective development of the flowers. Henslow (28) wrote about the globular masses of the hypertrophied inflorescence with the flowers being in bud and the name implying flowers of the stem.

Bailey (4) seemed to have translated the botanical term hypertrophy into common English. He used the words condensed and consolidated fleshy flower stems and thickened malformed flowers, and he referred to the "stem-flower" interpretation of the name cauliflower.

The morphology of the cauliflower was clarified by Lund and Kiesrschou (35). They said that the cauliflower was characterized by an excessive branching brought about by the suppression of the flower-axis of the inflorescence and promotion of the development and growth of the branches. These second order branches, after a period of active development, in turn were suppressed, and a new order of branches developed, - until the apexes of some of the last developed branches ultimately produced normal and functioning flowers, while the rest of the branches remained as naked apical meristems.

Lund et al (35) said further, that the development was brought a little farther in the defective "Ricy" cauliflowers and also in the broccolis, where initiation of the sepal whorl of the flowers and some elongation of the pedicel took place. They also mentioned that some displacement of the peduncles took place because of crowding, and that the peduncles became fleshy.

The first of the English authors to question the malformed and abortive flower theory was Dark (15). He studied broccoli, and his description of the development confirmed Lund and Kiaerschou. Rao (48) studied the cauliflower. He agreed with Dark, and compared the cauliflower curd to the condition evident among the cereals, viz. the formation of a tillering node. Oldham (41) in one of the latest non technical publications on the culture of Brassica oleracea and related cruciferous crops, adopted Dark's definition of the curd.

Materials and Methods

The cauliflower plants sampled for morphological study were the summer cauliflower varieties Snowball M and The Forbes. They were raised in the greenhouse at the U.S.D.A. Plant Industry Station, Beltsville, Maryland, during the winter of 1950-51. Plants were harvested at four different stages of development, shortly after germination, at the 10-node stage, at the 20-node stage, and at the time of initiation of the inflorescence. Some cauliflower plants were left intact and permitted to go to seed. Branches of the inflorescence, in all stages of development, were collected from the same plants the same day. The material was killed and fixed in F.A.A. solution for later examination under the binocular microscope and photomicrography. Some cauliflowers of both winter and summer varieties were also bought in the market and studied for morphological differences.

The materials used for photography were stained for a few seconds with fast green, and pictures were taken with a Bausch and Lomb camera equipped with Micro Tessar lens at an enlargement of 5-20x depending on size of the specimen. The specimen was submerged in glycerin during exposure. A carbon-arc lamp lighted one side of the specimen while a tungsten-filament lamp of lower intensity was used on the other side. Photomicrographs are not presented for all stages of development described in the text because of difficulties involved in photographing of the most transparent and smallest structures.

Results

Seeds soaked for 24 hours and dissected under the binocular microscope had a well developed hypocotyl with a primary root apex and two heart-shaped cotyledons folded over each other. No structures were present on the plumule. However, initiation of true leaves started very soon after the soaking of the seeds had taken place, and several structures were present at the time the cotyledons appeared above ground. These structures were normal leaf primordia with primordia of stipules (Figure 1).

The cauliflower plants had two kinds of leaves. The first 14 - 17 leaves were petiolate, while the remaining leaves on the main stem were sessile. Between the petiolate and sessile leaves were two to five leaves of a divided to cleft type, with lobes of the leaf blade on both sides of the petiole.

The stipules located on each side of the petiole were rudimentary on the petiolate leaves. They increased in size and made up the lower lobe on the intermediate leaves, and merged with the leaf blade on the sessile

Figure 1. Cauliflower morphology.
Young vegetative apical meristems with primordia of leaves, rudimentary stipules, and scars after dissected leaves.

leaves. No buds were distinguishable in the axils of the leaves although it may be assumed that meristems were there.

The sequence of stages in the change of the vegetative apical meristem into an inflorescence was shown in Figure 2, where A and B represented vegetative growing points with primordia of leaves, and C and D represented transition stages. The latter was characterized by enlargement and rounding of the apex, and by initiation of several whorls of bracts. These bracts could not be distinguished from leaf primordia until structures were initiated in their axils. The part of the stem immediately below the bracts elongated somewhat during this phase so that the inflorescence stood up as a small tower on the top of the stem.

Initiation of primary peduncles of the inflorescence in the axils of the bracts were the next step in the development. (Figure 2 M). These primary peduncles served as secondary apical meristems, initiated bracts and yielded secondary peduncles. (Figure 2 F). It is not known how much branching occurred before the first of these meristems began to initiate flowers, but branches of fifth order were observed on cauliflower of marketable size. The number of apexes in the curd of the above cauliflower were estimated to be five million by counting the number of primary branches, the number of secondary branches on the first primary, the number of tertiary on the first secondary etc. Each apex had one or two whorls of structure surrounding it that were either bracts in the axils of which a new order of peduncles would appear, or primordia of flowers. Only a few of the apexes developed flowers, fruit and seed during the subsequent phases of the life cycle. (See Figure 3 A, B, C, for development of the curd.) The suppressed parts did not abscise, but remained alive and some of them started to grow after the seed crop on

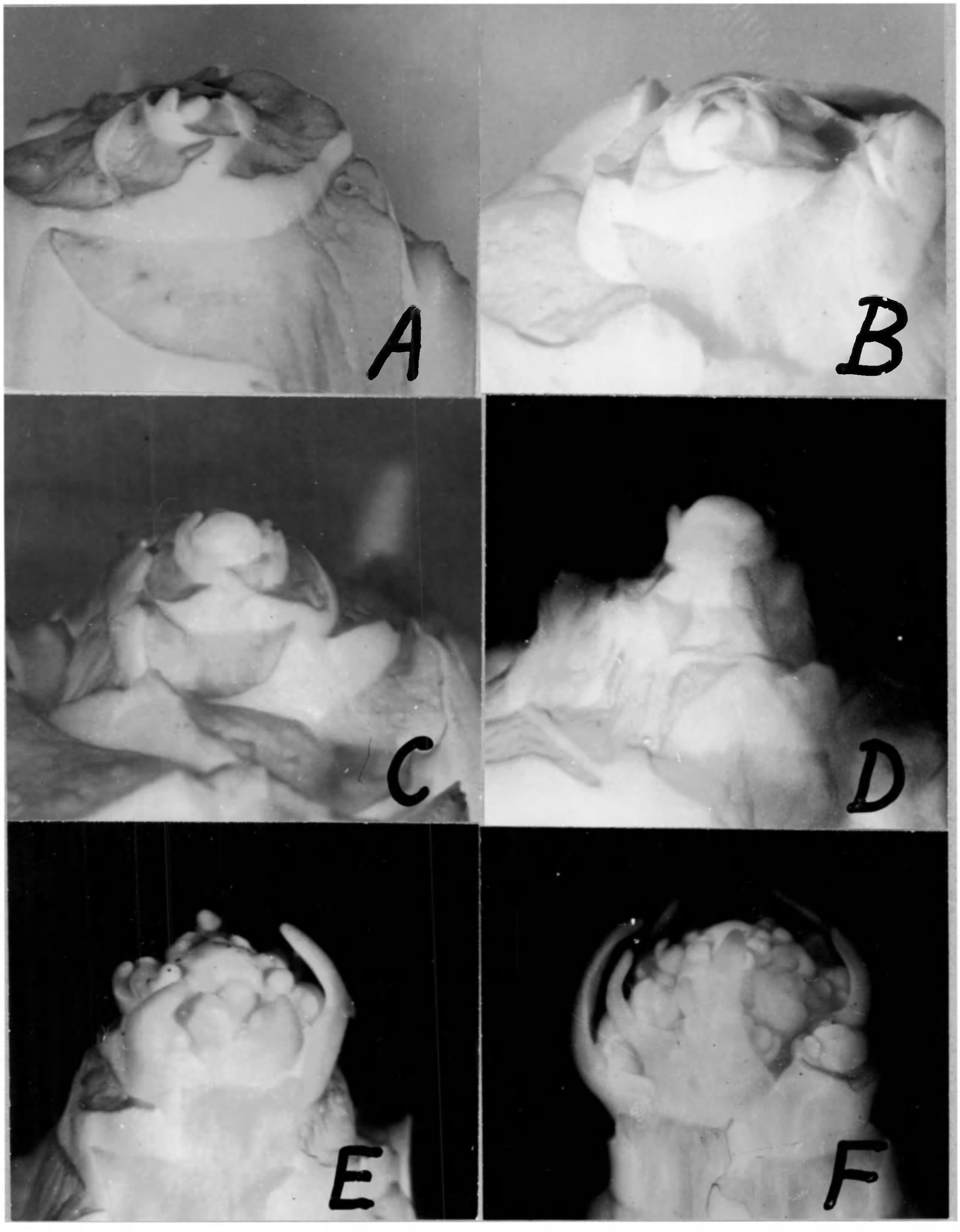

Figure 2. Cauliflower morphology.
Different stages in the development of the apical meristem.
A. and B. Vegestative meristems with primordia of leaves.
C. and D. Transition stages with rounded apexes surrounded by whirl of bracts and slight elongation of stem just below the apex.
E. Initiation of first order peduncles in the axile of the bracts.
F. Initiation of bracts by second order apexes.

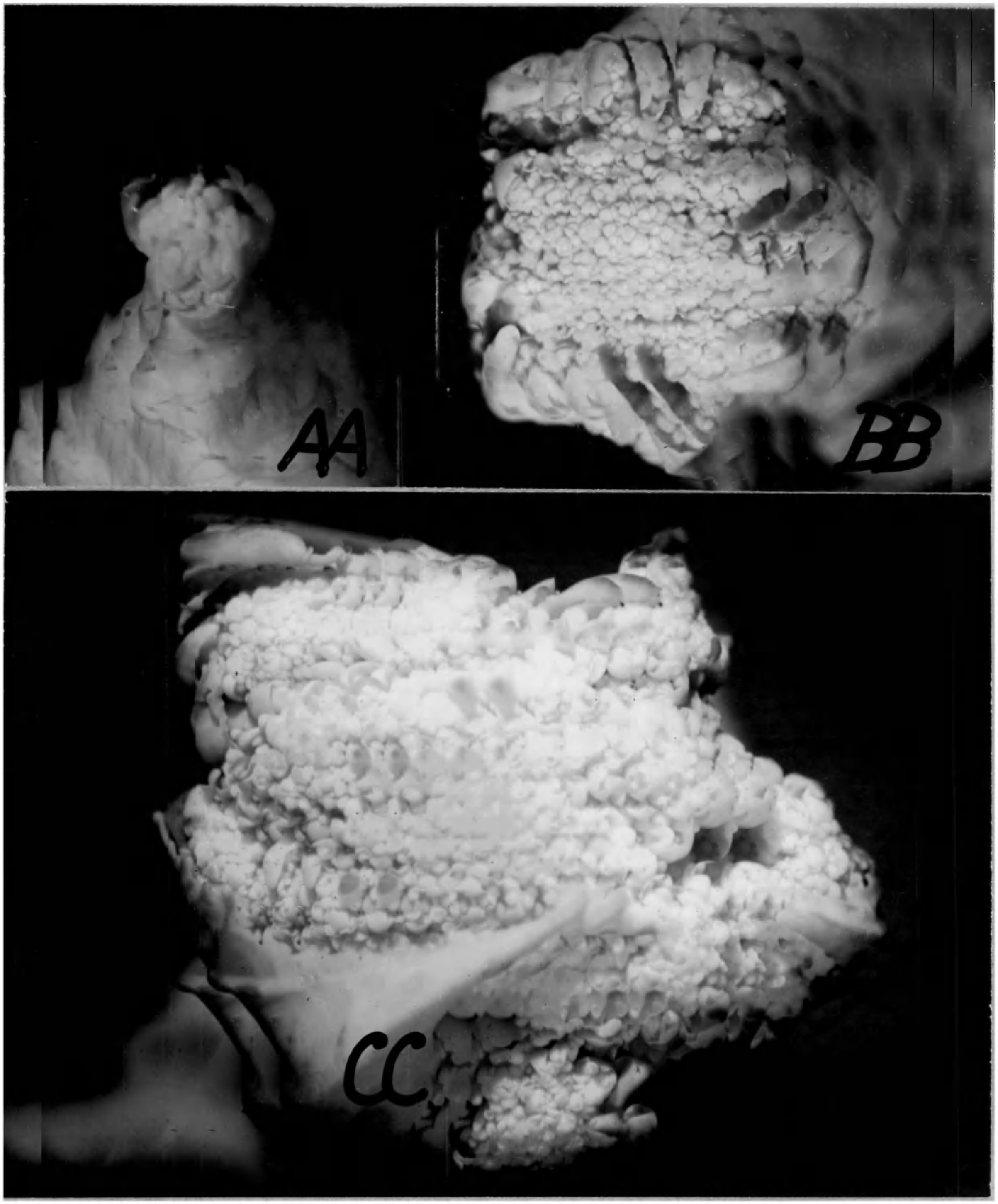

Figure 3. Cauliflower morphology.
Different stages in the development of the curd.
A. Initiation of first order peduncles.
B. Initiation of bracts and peduncles of later orders.
C. Mature curd.
Note similarity of structures in all stages of development.
They are also all the same, namely naked apexes and bracts.

the first panicles to develop, reached maturity. Parts of the curd were still intact and alive 6 months after the first panicles had developed. The suppressed branches deteriorated most commonly from attack of micro-organisms however.

The peduncles did not elongate during the branching period, but the primary tissue, pith and cortex increased in size, and secondary growth started, so that the peduncles became thick and succulent. A detailed description of the anatomy of the stem and the inflorescence was given elsewhere.[1]

The development of the inflorescence (Figure 4) after the heading stage began with the elongation of the peduncles at the same time as the sepals were initiated on the flower primordia. The flower apexes enlarged, and the primordia of the androecia were initiated at their bases. The sepals grew rapidly to cover the apexes and the androecia, and the pedicels started to elongate. These steps were all completed before the young flower buds appeared above the surface of the curd. The enlarged flower apexes developed into gynoecia, and the petals were finally initiated between the whorls of the androescia and the sepals. At the time of anthesis only rudimentary petals were present on the first flower of the panicle under certain environmental conditions.

A normal panicle, (Figure 5 A), was dissected under the binocular microscope, and three racemes were removed. These racemes alternated with flowers in an unorderly manner on the panicle. Thirty-three flower buds were counted on the main raceme of the panicle while the apex was still initiating more flower buds. Many abnormal flowers were also found

[1] Section 2

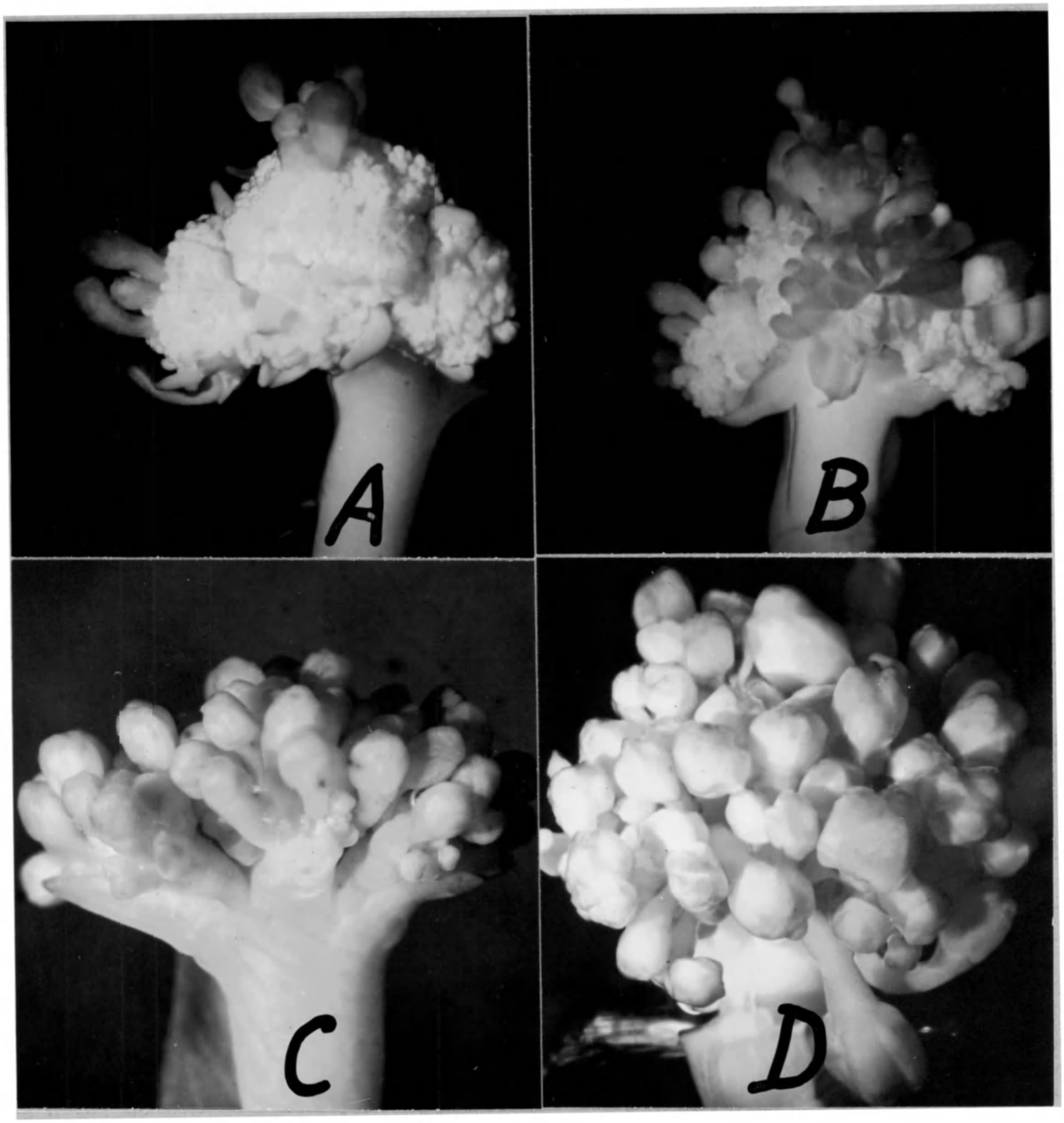

Figure 4. Cauliflower morphology.
Different stages in the development of the raceme.
A and B. Flowers just emerging from the curd.
Apexes of the flowers covered by sepals. Androecia also initiated, but not seen.
C and D. Later stages in the development of the racemes.

Figure 5. Cauliflower morphology.
A. Normal panicle before anthesis of lower flower.
B. Abnormal panicle. Lower flower with raceme developed within the flower.

in the region where flowers and racemes alternate. This may have been due to their photoperiodic exposures reported elsewhere.[1] These abnormal flowers were one sided, the side facing away from the floral axis being normal, while the side facing the floral axis had developed flowers within the flower. Even whole racemes were found within flowers. These abnormalitities could be traced back to the earliest stages in the development of the individual flowers, the initiation of the sepals and the androecia, and coincides with the main change of initiation of structures viz. the change from initiation of peduncles to flowers.

Another abnormality was encountered in the low temperature experiments with cauliflower. The growing points died on about 40 per cent of the plants, and the first or second leaf developed into a funnel-shaped structure. The plants were raised under controlled conditions and no insects were present that could have injured the plants.

Discussion

The popular name for the Brassica oleracea botrytis is cavolfiore in Italy, coliflor in Spain, couve flor in Portugal and cauliflower in England. All these popular names are derived from the Latin "caulis" and "floris," (stem and flower). The two Latin words put together have been give a distinct botanical morphological meaning: "Cauliflory: the production of flowers from the old wood, as in the redbud, chocolate tree, and many tropical trees," (Webster's Dictionary). Authors have not been found who stated directly that the cauliflower curd was a stem flower, but both Bailey(4) and Henslow (28) among others said that

[1]Section 5 pp (37)

the name implied "flower of the stem," or "stemflower," and their reference to the meaning of the two Latin words could have only one implication, and have undoubtedly misled the authors to the incorrect definition of a cauliflower curd consisting of thickened malformed abortive flowers.

It is interesting to note that no author from the North European countries mentions that the cauliflower consists of malformed and abortive flowers. The reason may be found in their popular name of the plant. The Germans name it "blumenkohl," the Dutch call it "bloemkool" and the Scandinavians say "blomkaal." The English translation of this name of German origin is "flowering Kale" or flowering cabbage depending on which English word is preferred as a name for the Brassica oleracea tribe. The German name does not imply any abnormal development of the inflorescence as does the name cauliflower, but the origin of the German name can also be traced back to Latin, since caulis was used as a generic name for the Brassicas by the ancient writers, (Sturtevant (53). Thus it appears that the Latin linguistic group adopted the botanical morphological meaning of caulis (stem), while the German linguistic group used the generic meaning of caulis((kale). The latter is undoubtedly the correct interpretation since the four technical papers including this one, reject the theory of abortive flowers which is the sole foundation for the "cauliflory" theory.

The extensive work of Lund and Kioerschou (35)[1] has been confirmed on all points except one. The question disagreed on is the cause of the excessive branching of the inflorescence. Lund et al. said that the suppression of the main apex followed by the development and the later

[1]Lund and Kioerschou's paper received a Danish national award. It is published in Danish, and no reference has been found to it in English literature.

suppression of the lateral apexes and so forth caused the excessive branching. The view expressed in this paper is that the excessive branching is brought about by the absence of apical dominance of any of the apexes of the inflorescence during the curd developing phase. Dominance is later acquired by the first apexes to develop normal and functioning flowers and the rest of the curd remains as naked apical meristems. Additional evidence for the latter view, is the corymb-like development of the curd. The inflorescence would have been cymose-paniculate if the view of Lund et al was correct.

Rao (48) compared development of the cauliflower curd to the condition evident among the cereals, viz. the formation of a tillering node. This may be questioned since the spike initiated by the tillering node consists of a fairly definite number of flowers, while the racemes of the panicle of the cauliflower are indeterminate and continue to initiate new flowers until the developing seeds have exhausted the supply of nutrients and plant food.

Floral abnormalities have been found in several crucifers and Summers (54) gave them an atavistic interpretation, while Arber (2) doubted the possibility of tracing the ancestry this way. The cauliflower abnormality was followed back to the earliest stages in the development of the raceme which coincided with the change from initiation of peduncles to flowers. This coincidence must be considered as evidence for its physiological cause.

The symptoms, dieback of the apical meristem of the young cauliflower plants followed by the development of a funnel-shaped leaf, were also encountered by Dr. R. Lamm and the author on a truck farm in southern Sweden. (Unpublished). DeCandolle (16) reported that another subspecies of the oleracea namely, costata, frequently developed funnel-shaped structures from the primary ribs of the leaves. He disclaimed every pretention to rank it even as a subspecies and considered it only as an accidental defect. The same phenomenon has also been described by Goebel (23). Only one of three varieties exhibited the symptoms in the experiments reported here, and the symptoms were not seen on plants of the same variety exposed to normal temperature. This phenomenon was, therefore, thought to be a hereditary characteristic which required a specific environment for its expression.

Summary

The literature on the subject of cauliflower morphology was surveyed and two different thoughts on the morphology of the curd compared. The morphology of the developing cauliflower plants from germination of the seeds to pre-anthesis was described and five main points brought out.

1. Rudimentary stipules were present at the base of the petiolate leaves. They enlarged on the intermediate types of leaves and merged with the leaf blade on the sessile leaves.
2. The curd of the cauliflower consisted of naked apexes of peduncles surrounded by a whorl or two of indeterminate structures which developed either into apexes of a new order of peduncles or to flowers.
3. The excessive branching was brought about by the absence of apical dominance by any of the apexes of the inflorescence during the curd developing phase.

4. Dominance was acquired by the first branches of the inflorescence to develop racemes, and they suppressed the other apexes of the curd, which remained as naked apical meristems. The suppressed apexes did not abscise, but deteriorated most commonly from attack of micro-organisms.
5. The apexes of the racemes were indeterminate, i.e. initiation of new flowers took place until the developing seeds had exhausted the plant nutrients and the plant food.

Two morphological abnormalities, viz. the development of a raceme within a flower, and dieback of the apical meristem followed by the development of a funnel-shaped leaf, was described and defects of economic importance were associated with these abnormalities.

SECTION II

A STUDY OF THE ANATOMY OF THE CAULIFLOWER

Introduction

The abnormal inflorescence or "curd" is the edible part of the cauliflower.[1] It has been referred to as hypertrophic by Master (36), Henslow (28) and others, as being composed of condensed and consolidated fleshy flower stems and thickened malformed flowers by Bailey (4), and as being monstrous by Metzger (38), Pedersen (47) and Nilsson (40).[2] The anatomy of this abnormal cauliflower inflorescence is not well known. A study was undertaken to disclose the anatomical structure, to describe the nature of the anatomical abnormality if any, and to study the maturation (lignification) of tissue with the aim of finding a possible connection between the anatomy of the curd and quality.

Review of Literature

The anatomy of the cauliflower has not attracted much attention, and only two papers dealing with the subject have been found. Lund and Kiærschou (35) described all the tissues and tissue systems of the _Brassica oleracea_, but their detailed description of the cauliflower was mainly confined to the morphology of the curd. Winton and Winton (61) were also concerned with the morphology, and seem to adhere to an in-

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[1] Leaves of young cauliflower plants are also eaten in some countries.

[2] The morphology of the cauliflower is described in Section I

correct definition of the curd, viz. the malformed and abortive flower theory. They also studied the different tissues, but did not describe any abnormality in the anatomy of the peduncles, nor did they describe the maturation or lignification of tissues. Both Lund and Kiaerschou (35) and Winton and Winton (61) used drawings for illustrations, while photomicrographs were used in this study.

Materials and Methods

The cauliflowers sampled for anatomical study[1] were raised in the greenhouse at the Plant Industry Station, Beltsville, Maryland, during the winter 1950-51. The plants and the points at which samples were taken are shown in Figure 1. These points on the plants were designated as follows:

A. Lower stem.

B. Middle stem.

C. Upper stem.

D. First order branch of the inflorescence.

E. Second order branch of the inflorescence.

F. Upper stem from plant in bloom.

G. First order branch from plant in bloom.

H. Second order branch from plant in bloom.

I. Small branch of the curd.

Samples were also taken from the stems of some younger plants.

The material was killed and fixed in F.A.A. solution, dehydrated in ethyl-butyl alcohol series, embedded in paraffin, cut on the microtome to 10μ, and stained with safranin and fast green. Standard procedures were

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[1]See Section V.

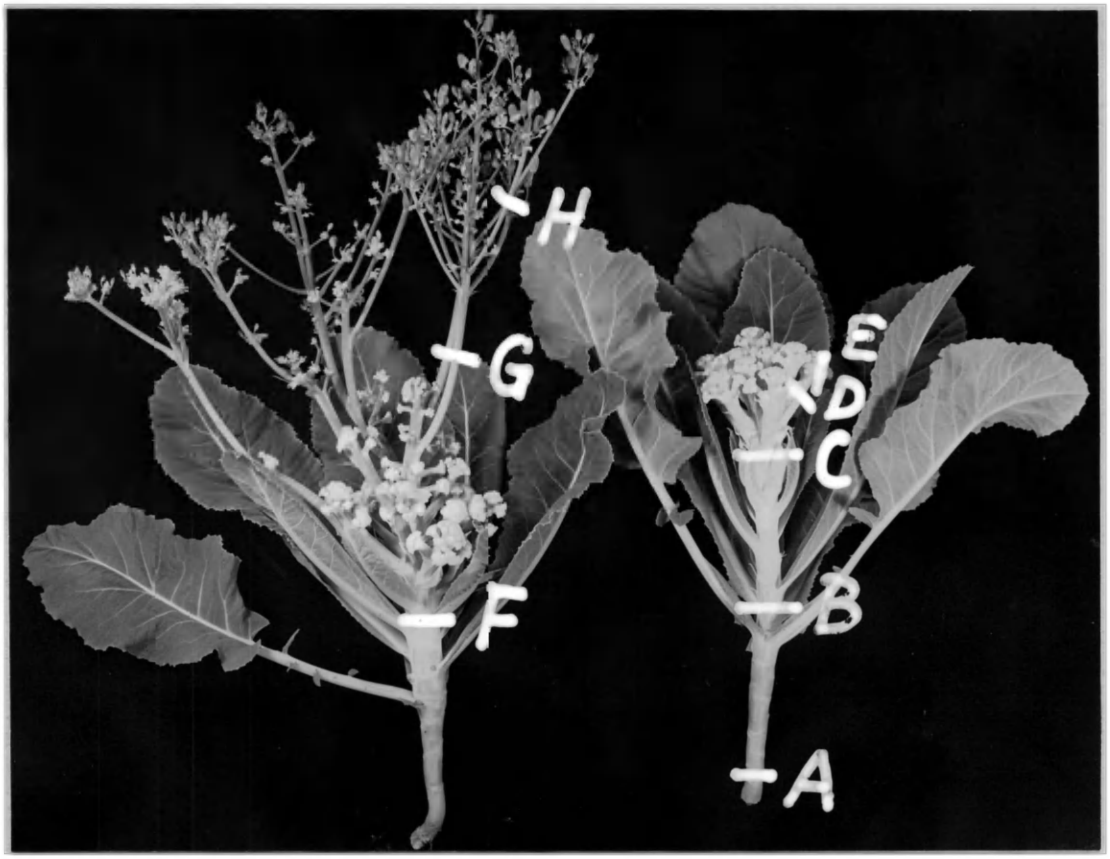


Figure 1. Cauliflower plants and locations sampled for anatomical study. Locations designated as follows:

A. Lower stem. B. Middle stem. C. Upper stem.
D. First order branch of inflorescence.
E. Second order branch of inflorescence.
F. Upper stem from plant to bloom.
G. First order branch of inflorescence from plant in bloom.
H. Second order branch of inflorescence from plant in bloom.

used at all times. Photomicrographs were taken with a Bausch and Lomb camera using contrast process ortho film.

Results

The young immature cauliflower stem had a dictyostele or dissected siphonostele (Figure 2). Interfascicular cambium developed during secondary growth so that the old mature stem had the appearance of a siphonostele (Figure 3).

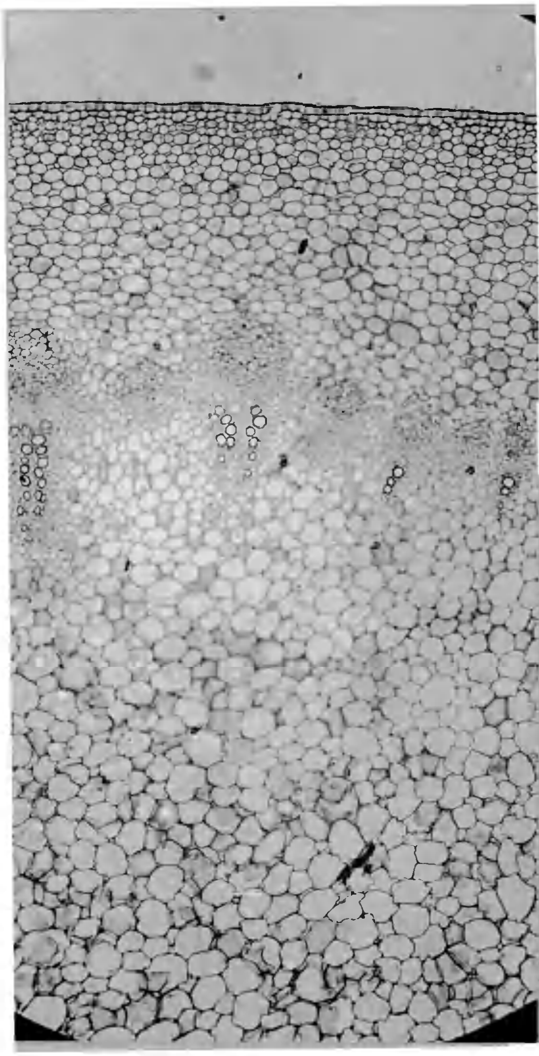
The vascular bundles (Figures 4 and 5) were collateral and varied in size. The primary phloem was capped by an arc of pericyclic fibers which formed a discontinuous cylinder of sclerenchyma tissue. Adjacent bundles were separated by phloem-xylem rays of parenchyma. The primary xylem (Figure 6, A and B), consisted of annular and spiral elements which were surrounded by Xylem fiber elements. The large secondary xylem vessels (Figure 6, C) were reticulate or pitted and were also surrounded by xylem fibers.

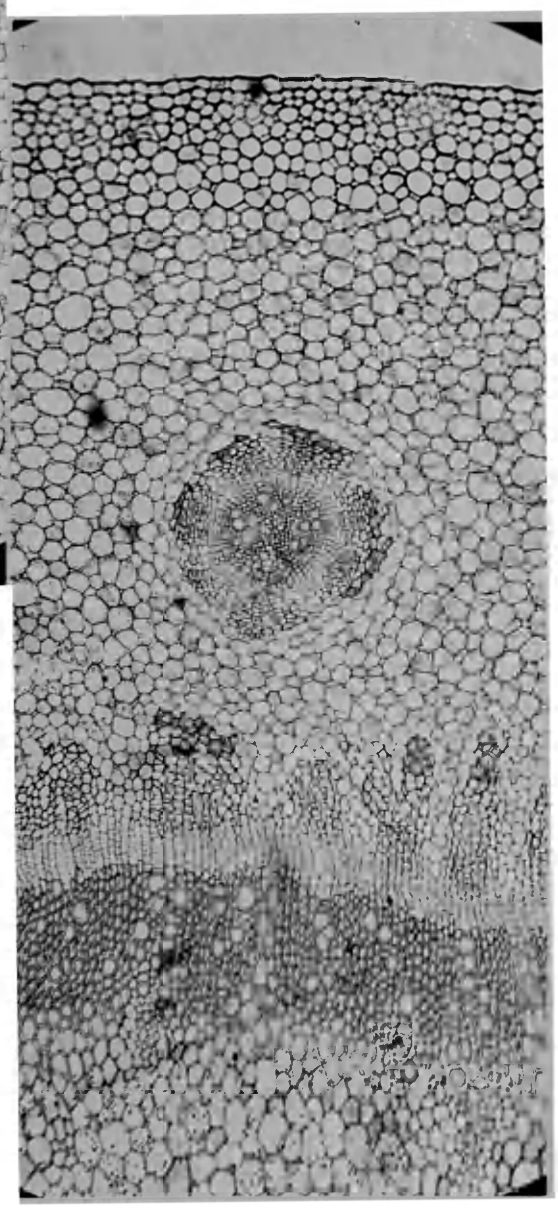
The immature epidermis, cortex, and pith (Figure 7, A and B) continued to grow for some time after cell division ceased. This gave the cells a large zig-zag shaped surface which enabled them to expand greatly without rupture. The cells then became spherical (Figure 7, C and D) during subsequent expansion. Longitudinal sections of cortex and pith before and after expansion of the peduncles are shown in Figure 7, E, F, G, and H. The epidermis, cortex and pith remained intact, and no periderm was formed.

All tissues and tissue systems were developed at the time of harvest of the cauliflower for the market (Figure 8, D), but the stems were not mature, i.e. the cells of the peduncles were capable of expansion

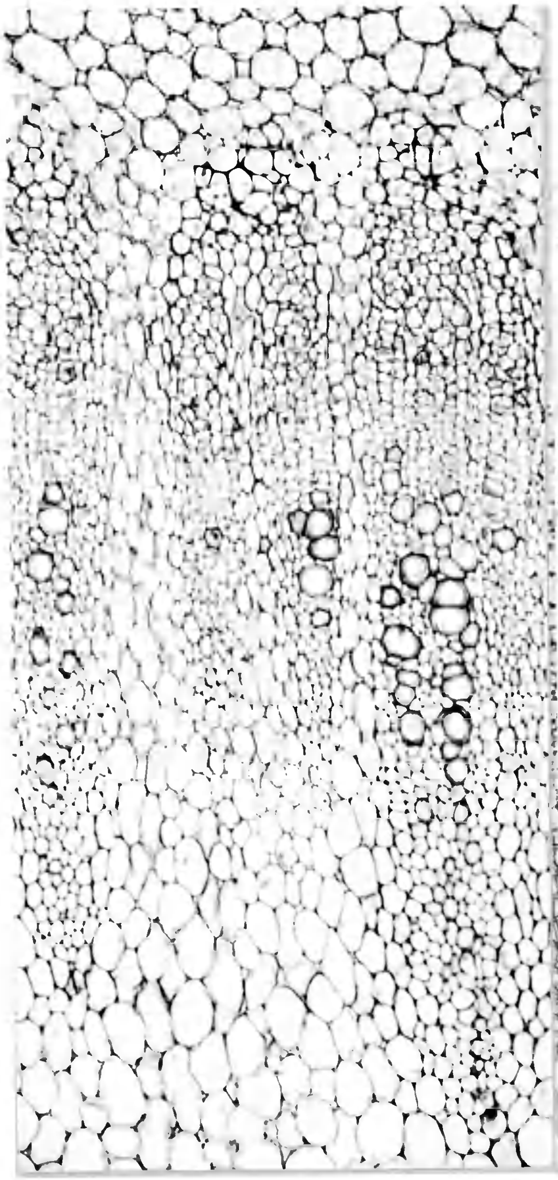
Left Figure 2.

Cauliflower anatomy. Cross section of first order branch of inflorescence showing dictyostele.



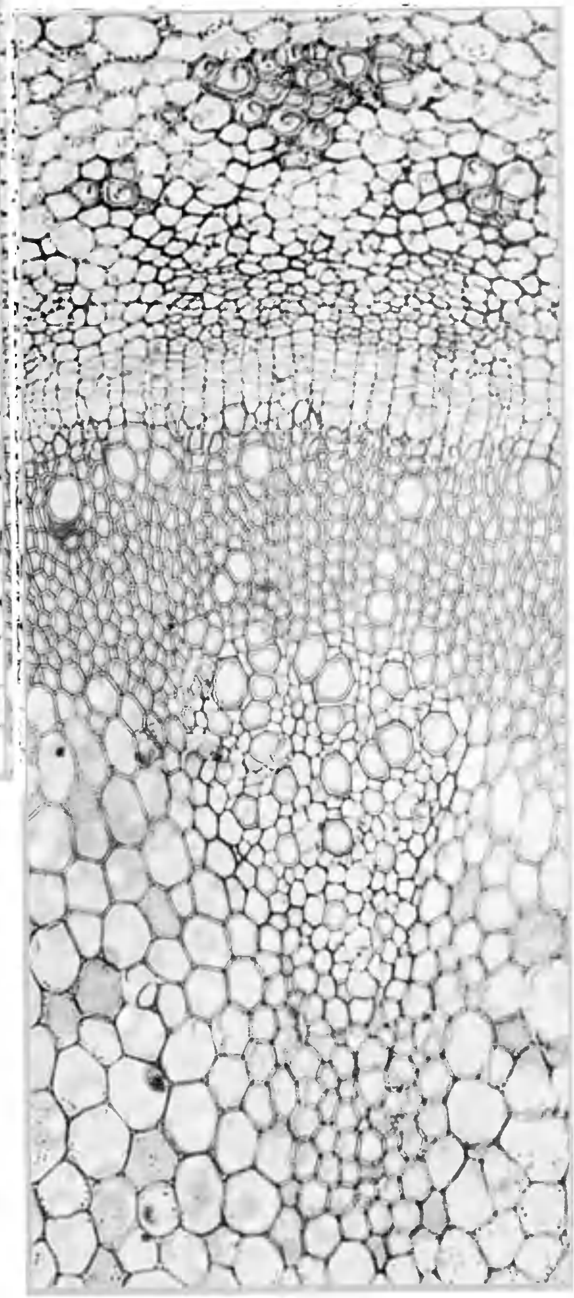


Right Figure 3. Cauliflower anatomy. Cross section of middle stem. Interfasicular cambium have changed the stem to siphonostele. Leaf trace also seen.



Left Figure 4.

Cauliflower anatomy.
Cross section of vascular bundles of upper stem (immature). Only primary xylem and secondary xylem vessels lignified.



Right Figure 5.

Cauliflower anatomy.
Cross section of vascular bundles of middle stem (mature). Primary xylem, secondary xylem, and phloem fibers lignified.

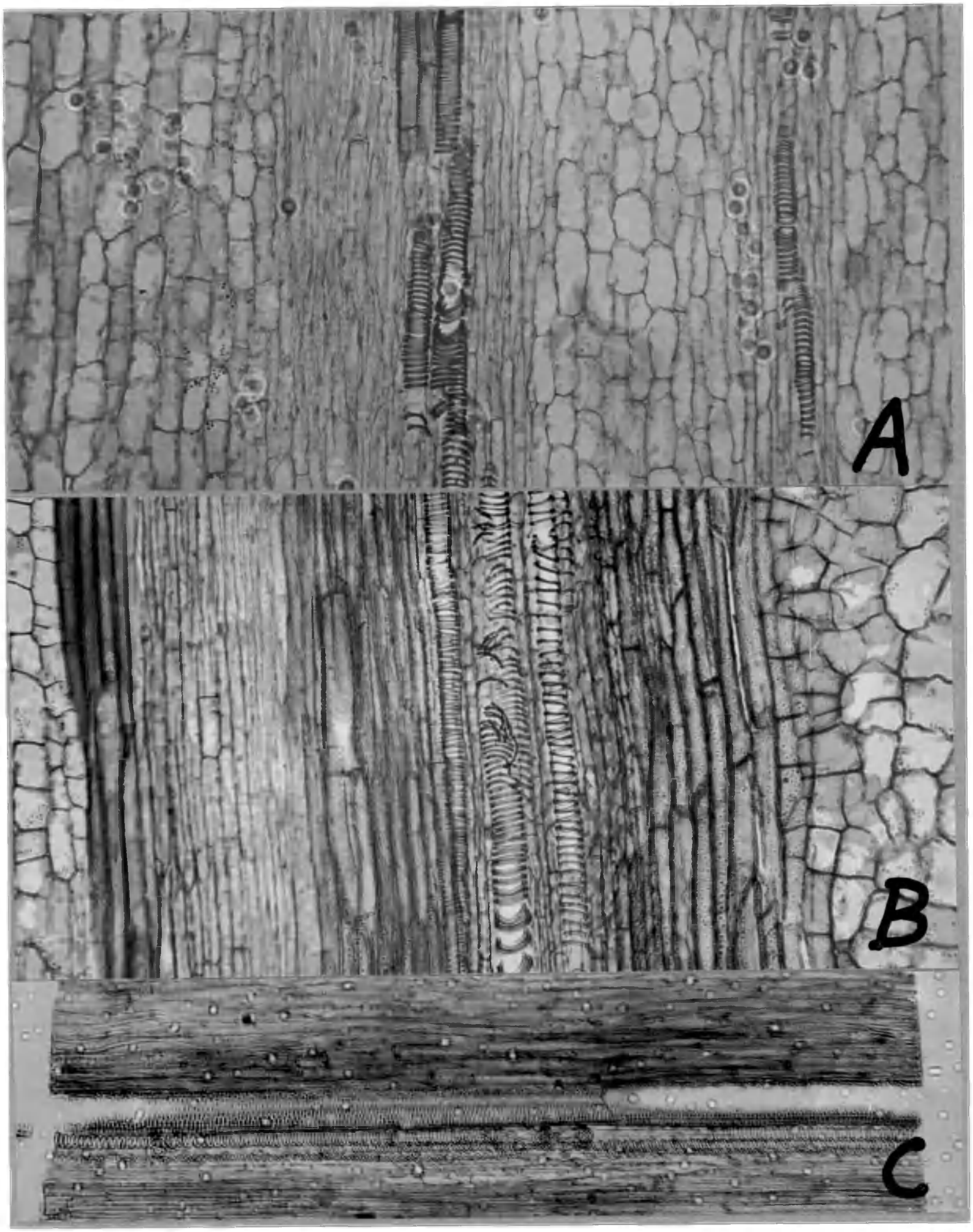


Figure 6. Cauliflower anatomy.

A. Longitudinal sections of first order branch of inflorescence (immature). Only primary xylem and secondary xylem vessels lignified.

B. Longitudinal section of middle stem (mature). Primary and secondary xylem, and phloem fibers lignified.

C. Detail of reticulate vessel (mature).

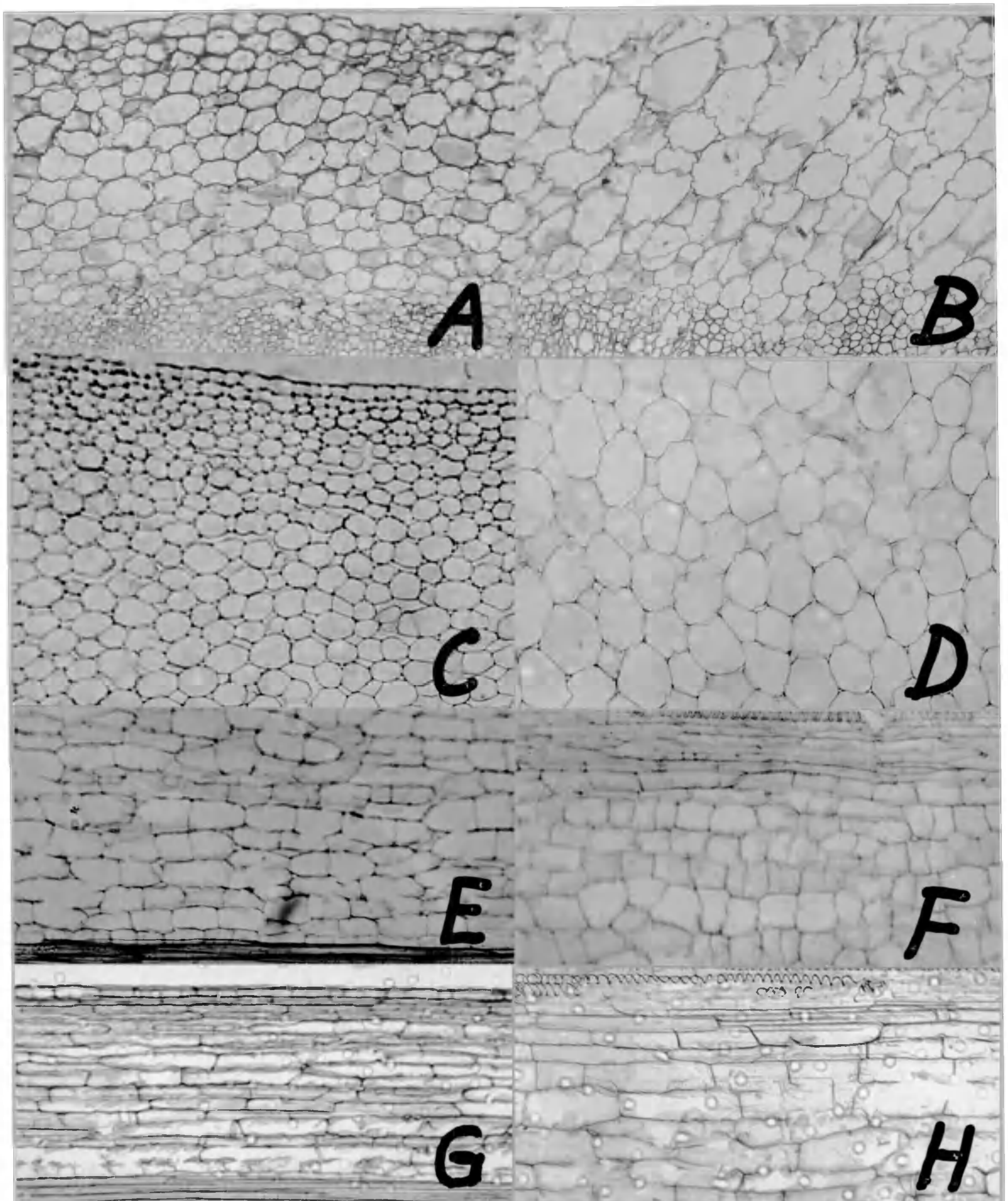


Figure 7. Cauliflower anatomy.
A. Cross section of cortex with epidermis and B. pith of young stem. No intercellular spaces, cell walls wrinkled or zig-zag shaped.
C. Cross section of cortex with epidermis and D. pith of mature stem. Intercellular spaces present, cell walls smooth.
E. Longitudinal section of cortex with epidermis and F. pith of young stem. Cells not elongated.
G. Longitudinal section of cortex with epidermis and H. pith of elongated stem. Note stretching of cells.

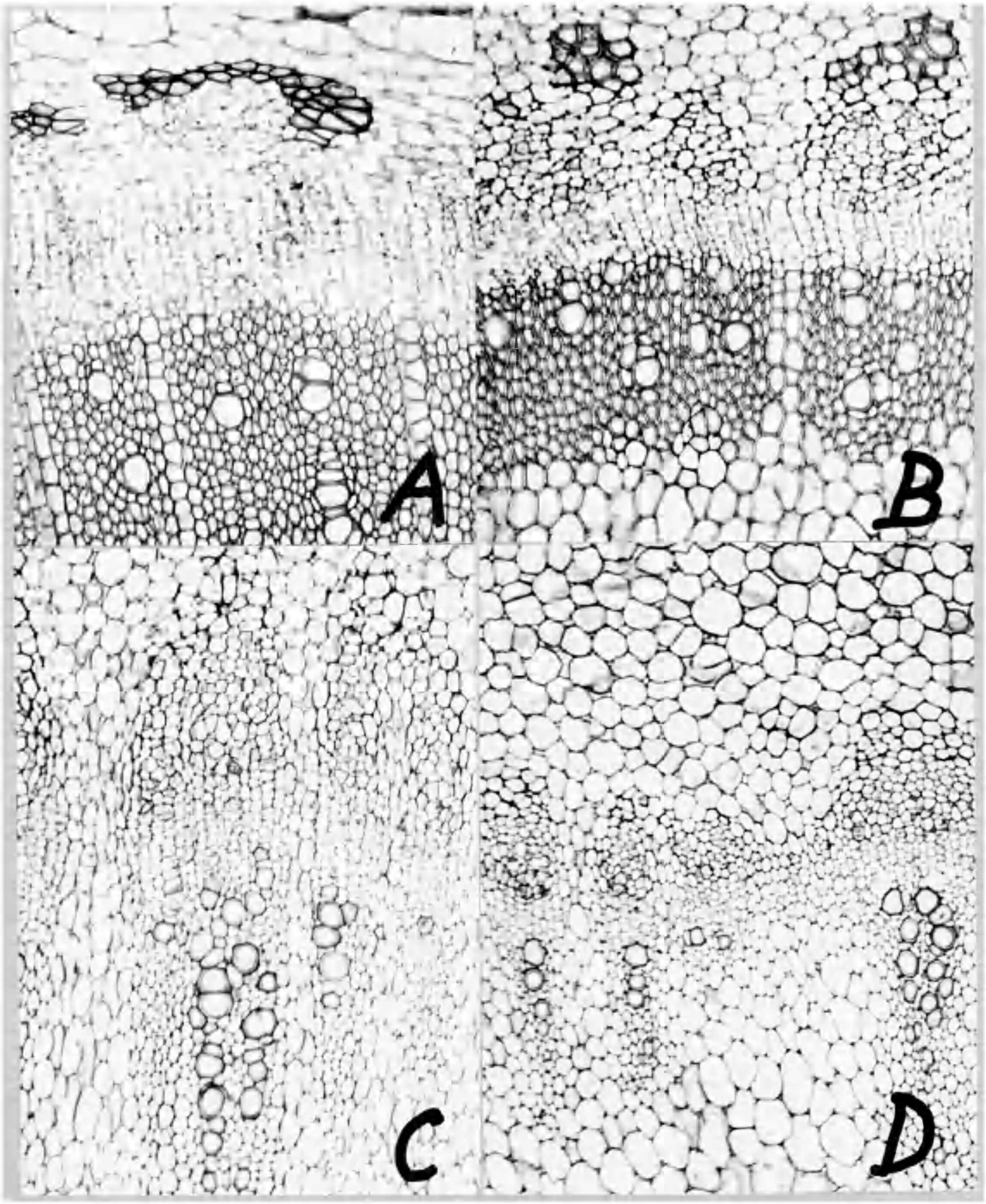


Figure 8. Cauliflower anatomy.
A. Cross sections of lower stem. B. Cross section of middle stem. C. Cross section of upper stem.
D. First order branch of inflorescence showing ontogeny of tissue maturation before elongation of branches of the inflorescence. Maturation proceeds upward from older to younger tissue.

during the subsequent flowering phase, and the scerenchma tissues were not lignified. The only tissues of the curd to be slightly lignified at the time of harvest for the market were annular and spiral primary xylem and secondary xylem vessels. However, lignification of pericyclic- and xylem fibers and of xylem rays were prominent in the lower and middle part of the main stem (Figure 8, A and B), while the upper part of the main stem was not lignified as the peduncles (Figure 8, C).

The expansion of the peduncles during the flowering phase was followed by lignification of the tissue. Lignification seemed to start in the lower part of the primary peduncles (Figure 9, C) and proceeded upward as the peduncles grew (Figure 9, D). Lignification also seemed to proceed downward from the expanding peduncles to the not previously lignified part of the upper stem (Figure 9, A and B). The upper part of the main stem was thus first lignified on the side supporting expending branches of the inflorescence.

No flower organs could be distinguished on the longitudinal section of a small branch of the curd (Figure 10), but bracts and apical meristems could be seen easily.

Discussion

The terms used by the different authors to describe the cauliflower curd are defined by Jackson (29) as follows:

Hypertrophy: an abnormal enlargement of an organ, presumably by excess of nourishment.

Consolidated: (Consolide, I make firm)

1. when unlike parts are coherent.
2. Crozier adds, having a small surface in proportion to bulk, as many cacti.

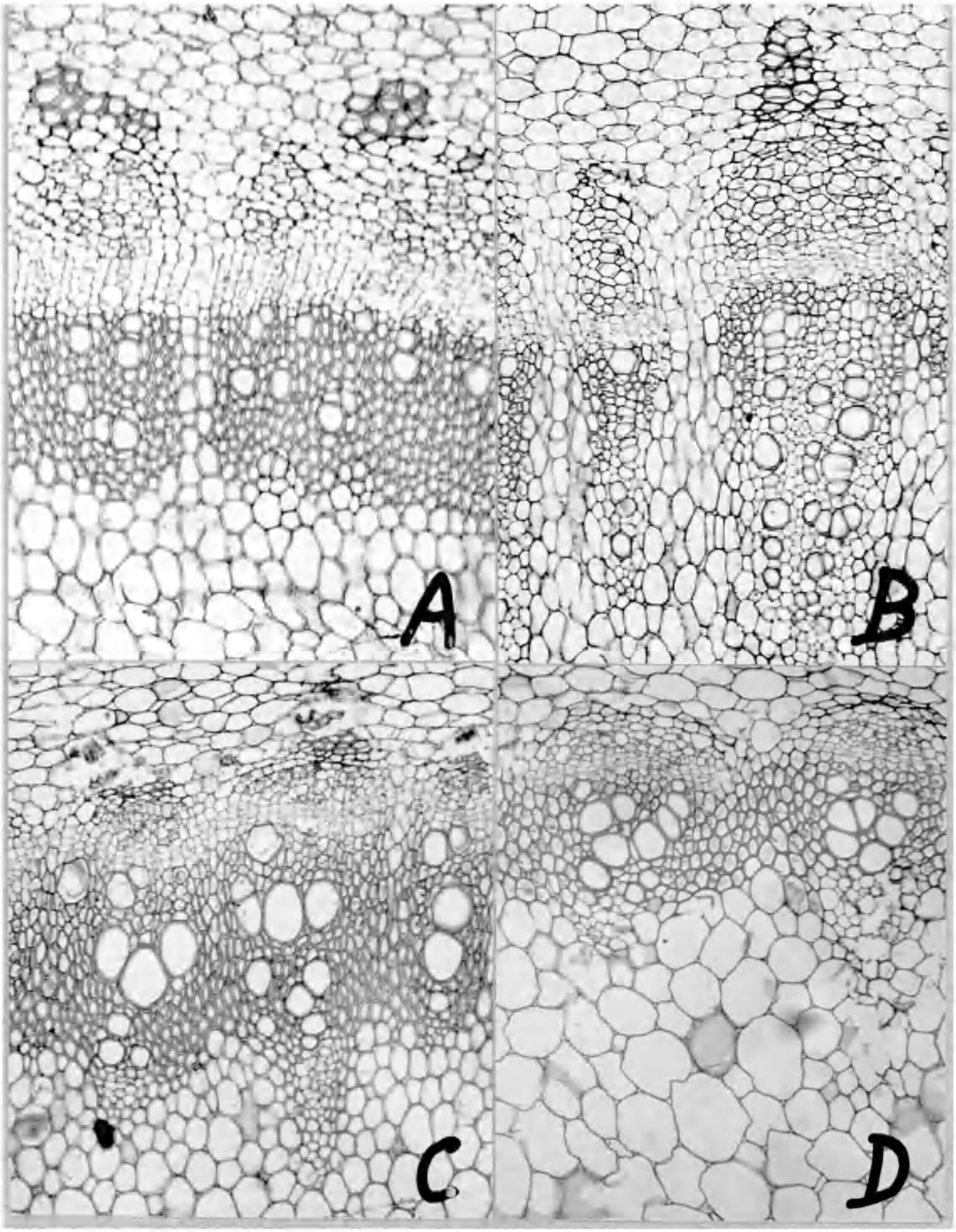


Figure 9. Cauliflower anatomy.
A. Cross section of middle stem. B. Cross section of upper stem from plant in bloom. C. First order branches of plant in bloom. D. Second order branches of plant in bloom showing ontogeny of tissue maturation after elongation of branches of the inflorescence. Maturation proceeds upward from first order branches of inflorescence and also downward until it encounters already lignified tissue in the main stem.

Figure 10. Cauliflower anatomy.
Longitudinal section of a small branch of the curd.
No floral parts can be distinguished.

Condensation: (*Condensatio*, making dense) = Concentration.

Compacted: (*Compactus*) closely joined or pressed together.

Monstrosity: (*Monstrositas*) some conformation deviating from the usual and natural structure. adj. monstrous.

Two facts are apparent concerning the usage of these terms in the description of the cauliflower inflorescence: (1) the words seem to be correctly applied by the different authors, although (2) none of the terms describe specifically the nature of the abnormality of the curd.

The morphological abnormality was described elsewhere[1] as an excessive branching of the inflorescence caused by the absence of apical dominance of the primary, secondary and later order apical meristems during the curd developing phase. This was followed by absence of elongation of the peduncles, and a small length-width ratio which made the peduncles appear hypertrophic.

A study of the anatomy of the cauliflower inflorescence disclosed only one abnormality, namely the absence of lignification of the sclerenchyma tissue during the curd developing phase. This is the general distinction between ancestral types of vegetables and the hypertrophically developed edible forms. However, the hypertrophy is frequently associated with the development of secondary and tertiary cambiums which by their activity greatly increase the bulk of edible tissue. No such development was found in the normal cauliflower although another subspecies of the *Brassica oleracea*, namely *gongyloides*, possesses such features.

An interesting abnormality was encountered in the winter cauliflower

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[1]Section I.

variety "January" planted in spring and exposed to the warm weather conditions in College Park, Maryland during the summer 1950. The upper stem enlarged and developed into a Kohlrabi-like structure instead of initiating an inflorescence. The anatomy of the greatly enlarged upper part of the stem was not studied, and it is not known whether secondary cambium had developed or not, but the growth habit of the plants was that of cauliflower, not kohlrabi except for the enlarged apical part. Plants were found in different stages of such development, so it is unlikely that it was due to seed admixture.

The fibrous nature of the prominent bundle sheath should be pointed out. It is easily overlooked by observing cross sections of peduncles during the curd developing phase only, but longitudinal sections of peduncles before and after elongation disclosed that the bundle sheath consisted of potential fibers which became lignified following elongation of the peduncles.

There is no reason to believe that quality might be impaired by the premature lignification of the sclerenchyma of the peduncles. Lignification of sclerenchyma tissue was limited to elongated peduncles and to the upper part of the main stem supporting flowering branches. This lignification occurred relatively long after the edible state of maturity.

Summary

The cauliflower curd consisted of peduncles, bracts and naked apical meristems.

The main tissues present at the time of harvest for the market were thin-walled parenchyma (epidermis, cortex, phloem-xylem rays, pith, and apical meristems).

The collateral vascular bundles contained both pericyclic and xylem fiber elements, but these elements did not seem to impair the quality of the cauliflower since they were not lignified at the time of harvest for the market.

Anatomically abnormal tissues were not found, and the abnormality of the cauliflower seems to be the absence of apical dominance of the inflorescance, absence of elongation of peduncles during the curd developing phase, and absence of lignification of the schlerenchyma tissue.

NOTE CONCERNING SECTION III AND IV.

The experimental work reported in section III and the three first experiments of section IV were carried out at Lewiston, Idaho, and reported previously in a thesis written in partial fullfilment of the requirements for the degree Master of Science and presented to the graduate school at the University of Idaho in 1949.

The survey of literature, discussion, and summary were rewritten after the library facilities of the U. S. D. A., Library became available to the author. Sections III and IV were included in this thesis because the author consider the material an integral part of the study, which will be submitted for publication sectionwise in the order given in this thesis. Section III and IV are found in the appendix.

SECTION V

A STUDY OF THE EFFECTS OF ENVIRONMENT ON GROWTH AND DEVELOPMENT OF CAULIFLOWER, (B) STUDIES IN THE GREENHOUSE

Introduction

It was concluded in Section IV that premature heading occurred in cauliflower since mean number of leaves within a variety varied tremendously with the environment. However, the variation in leaf number occurred between experiments, not within experiments where the environmental factor responsibel for it could have been identified. The experiments reported in Section IV were limited to treatments of transplants and measurements of the effects of treatments after transplanting to the field. None of the environmental factors could, therefore, be excluded as possible cause of premature heading in cauliflower. A study of the effects of photoperiodism, nutrition, temperature and their interactions was conducted under greenhouse conditions where environmental factors other than the variable under study could be kept under more rigid control than under field conditions.

Review of Literature

The survey of literature given in Section IV covers the papers dealing with growth and development in cauliflower. No attempt will be made to survey the literature concerning the effects of photoperiodism and nutrition on development of plants in general, but the survey will be limited to some papers concerning the quantitative measurements of development as a consequence of the environment.

Murneek and Gomez (39b) appear to be the first to study the histological effects of photoperiodism. They worked with the Biloxi soybean. Borthwick and Parker (10) described the histology and the morphology of the Biloxi soybean and used node counts and number of flower primordia initiated as quantitative measurements of the effects of photoperiodic stimuli by which the following problems were investigated, namely, identification of the organ of perception of photoperiodic stimuli in Biloxi soybean (11), interaction of photoperiod with temperature for control of flowering in Biloxi soybean (42), interaction of photosynthesis with photoperiod for the control of flowering in Biloxi soybean (43), and Scully, Parker and Borthwick (53), interaction of photoperiod and nutrition for control of flowering inBiloxi soybean, while Parker, Hendricks, Borthwick and Scully (44) worked out action spectrum for photoperiodic control of flowering in Biloxi soybean.

Borthwick, Parker and Heinze (12) also applied node counts to a study of the effects of photoperiodism and temperature on development of barley and action spectrum for the control of floral initiation in barley were worked out by Borthwick, Hendricks and Parker (13). The same authors described the morphology of the Hyoscyamus niger (45) and worked out the action spectrum for the photoperiodic control of flowering.

Blaauw and co-workers, as reported by Went (60), used histological studies in their extensive work on the effects of temperature on initiation and development of flower primordia in tulip and hyacinth bulbs. Gregory and Purvis (18, 19, 20) applied node counts to their study of effects of vernalization in rye, while Heath and Matur (27) studied leaf and scale numbers in onion sets. These studies demonstrate the usefulness of histological and morphological examination of the plants in a study of the effects of environment on development.

Materials and Methods

The experiments were carried out in a greenhouse of the U.S.D.A., Plant Industry Station, Beltsville, Maryland, during the winter of 1950-51. The greenhouse was divided into three sections in which the night temperature was controlled by thermostats while the day temperature was controlled manually. Two of the sections of this greenhouse were held at a night temperature of 55-60° F., and the third section was held at a night temperature of 65-70° F. during the winter of 1950-51.

Information relative to the size of experiment needed to test differences of importance at given levels of significance was available from the experiments reported in Section III and IV. The mean, the standard deviation, and the L.S.D. required to test a difference between two means at the 5% level using 10 replications of the varieties Snowball M or The Forbes are given in Table 1.

The range in variation among means was 31.6 leaves for the variety Snowball M, while the variety The Forbes had a range of 35.6 leaves. It was assumed that these varieties would exhibit a similar variability in the greenhouse tests, and that 10 replications would be adequate to test differences between means within varieties resulting from particular treatments. A number of replications of ten was, therefore, used in all the greenhouse experiments and also in the experiments in controlled cabinets reported in the next section.

Method of planting, and number of plants to the pot or crock, were also the same in all experiments. Eight corks of size 3 were nailed

Table 1. Mean number of leaves per plant, their standard deviation and L.S.D. calculated assuming a number of replications (N) of 10 for the cauliflower varieties Snowball M and The Forbes raised under different environmental conditions.

Variety and treatment	Mean No. of leaves	Standard deviation	L.S.D. at 5% level N = 10
<u>Snowball M</u>			
In variety test, Lewiston, Idaho, 1948	50.8	5.15	5.1
Not exposed to cold treatment during seedling stage, Md. 1950	35.7	3.90	3.9
Exposed to cold treatment during seedling stage, Maryland 1950	34.4	3.90	3.9
Planted directly in the field, Maryland, 1950	67.0	13.4	13.4
<u>The Forbes</u>			
In variety test, Lewiston, Idaho, 1948	37.4	3.94	4.0
Not exposed to cold treatment during seedling stage, Md. 1950	31.7	3.00	3.0
Exposed to cold treatment during seedling stage, Maryland, 1950	31.7	3.00	3.0
Planted directly in the field Maryland, 1950	58.0	10.60	10.7

into a wooden disk which fitted the pots and crocks. The corks were pressed down in the soil or sand and two seeds were planted in each hole. The holes were later filled with sterilized soil or sand depending on the experiment. The plants were thinned out to 8 plants after germination and seven of these were sampled at successive dates of harvest, while the last plant in each crock was harvested at the termination of the experiment. Sampling was done at random although crowding of adjacent plants was avoided as much as possible.

Experiment I was a photoperiodic experiment for testing the effects of an 8-hour photoperiod for a given duration of development on the subsequent growth and development under 16-hour photoperiod. The actual treatments were as follows:

(a) 16-hour photoperiod continuously.

(b) 8-hour photoperiod until 9.1 nodes, followed by 16-hour photoperiod.

(c) 8-hour photoperiod until 18.1 nodes, followed by 16-hour photoperiod.

(d) 8-hour photoperiod continuously.

(e) 8-hour photoperiod continuously

Treatment (d) was to have been changed to 16-hour photoperiods when 30 nodes were initiated. Differentiation of the inflorescence occurred at that stage however. The change was not made and the treatment was kept on 8-hour photoperiod until termination of the experiment, while treatment (e) was changed to 16-hour photoperiod and permitted to go to seed. Some of the material of treatment (e) was later used in a study of the morphology[1] and the anatomy[2] of the cauliflower curd.

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[1]Reported in Section I.

[2]Reported in Section II.

Planting date for the experiment was October 18, 1950. The seed was sown in sterilized soil in 3" clay pots. The plants were repotted into 8" pots November 8 and watered weekly with nutrient solution beginning November 11. The 8-hour photoperiod was accomplished by covering the plants with a double layer of black sateen cloth at 4 P.M. and uncovering at 8 A.M. daily. The 16-hour photoperiod was accomplished by addition of light of relatively low intensity from incandescent-filament lamps. The incandescent light was controlled by an electric time switch.

Experiments II, III, IV, and V were all performed as sand culture experiments in which the manual watering technique was used. Glazed earthenware crocks with straight sides, rounded inside bottoms and side drainage holes were employed. Their inside diameter was 4" and their greatest depth was 7½". The drainage holes were covered with sheets of glass wool which retained the sand. A preliminary test with fine and coarse sand did not result in any significant differences, so that fine sand was used in the subsequent experiments because of its greater water holding capacity. The plants were watered every day with one pint of nutrient solution.

Excellent growth was obtained in a preliminary test with a four salt nutrient solution recommended for soybeans by Dr. M. W. Parker, U.S.D.A., Plant Industry Station, Beltsville, Maryland. The four salts were calcium nitrate, magnesium sulphate, potassium sulphate, and mono potassium phosphate. Hoagland's minor element solution A and B were used in addition. Dr. Parker's solution (solution 1 in these experiments) was used as a reference solution and variations were made to give the desired levels of the different elements. Calcium sulphate, calcium chloride and mono sodium phosphate were used as substituting salts to balance the solutions. Calcium was not completely balanced in the nitrogen nutrition series since it would have raised the chlorine and sulphur concentration excessively. The pH values for the various solutions were all between 5 and 5.2 due to the buffering action of the mono potassium phosphate and mono sodium phosphate.

Experiment II was a factorially designed experiment for testing the effects of two temperatures and five levels of nitrogen nutrition on the fresh weight, length of stem, and number of nodes initiated in the cauliflower variety Snowball M, planted November 28, 1950. The night temperature treatments were 65-70° and 55-60° F. The components of the nutrient solutions are given in Table 2.

Table 2. Components of nutrient solutions for Experiment II.

Solution number	Parts per million of elements						
	N	P	K	Ca	Mg	S	Cl
1	112	18	86	160	56	100	-
2	61	"	"	87	"	"	-
3	33	"	"	"	"	131	-
4	18	"	"	"	"	"	39
5	10	"	"	"	"	"	60

Experiment III was a factorially designed experiment for testing the effects of temperature and deficiency of nitrogen during indicated periods of time on fresh weight, length of stem and number of nodes initiated in the cauliflower variety Snowball M planted November 28, 1950. The night temperatures were 65-70° and 55-60° F., respectively. The nutrient treatments were as follows:

(a) Full nutrient solution continuously.

(b) -N from 1/4 to 1/20.

(c) -N from 1/31 to 2/18.

(d) -N from 2/18 to 3/9.

(e) -N from 3/9 to termination of the experiment.

The components of the full nutrient solution and the -N solution are given in Table 3.

Table 3. Components of nutrient solutions for Experiment III.

Solution number	Parts per million of elements						
	N	P	K	Ca	Mg	S	Cl
1	112	18	86	160	56	100	-
7	0	"	"	87	"	131	85

Experiment IV was a non orthogonal nitrogen, phosphorous and potassium nutrition experiment for studying the effects of the particular elements on the fresh weight, length of stem and number of nodes of cauliflower. Seed of the early variety, The Forbes, was planted February 17, 1951 and the experiment was performed in the 55-60° F. night temperature section of the greenhouse. The components of the nutrient solutions are given in Table 4.

Experiment V was a nitrogen nutrition (2) x photoperiod (2) x temperature (2) factorially designed experiment for testing the effects of the different environmental combinations on the fresh weight, length of stem and number of nodes of cauliflower. The Forbes was the variety used and the seed was planted February 17, 1951. The actual treatments were as follows:

(a) Nitrogen nutrition, 112 p.p.m. vs. 10 p.p.m.

(b) Photoperiods, 16-hours vs. 8-hour.

(c) Temperatures, (night) 65-70° vs. 55-60° F.

Table 4. Components of nutrient solutions for Experiment IV.

Solution number	Parts per million of elements							
	N	P	K	Ca	Mg	S	Cl	Na
Nitrogen series								
6	205	18	86	293	56	100	-	-
1	112	"	"	160	"	"	-	-
2	61	"	"	87	"	"	-	-
3	32	"	"	"	"	131	-	-
4	18	"	"	"	"	"	39	-
5	10	"	"	"	"	"	60	-
Phosphorus series								
1	112	18	86	160	56	100	-	-
8	"	5	"	"	"	107	-	-
9	"	2.5	"	"	"	108	-	-
10	"	1	"	"	"	109	-	-
Potassium series								
1	112	18	86	160	56	100	-	-
11	"	"	20	"	"	74	-	3
12	"	"	10	"	"	"	-	15
13	"	"	5	"	"	"	-	21

This provided eight factorial combinations. The nutrient solutions were the same as number 1 and 5 of the other nutrition experiments. The different photoperiods were accomplished in the same manner as in the photoperiodic experiment (experiment I).

All plants were cut at the cotyledonary node when harvested. They were weighed individually and the number of nodes was counted on each. Primordia of leaves too small to be detected by the naked eye were identified under the binocular microscope and counted. Measurements of length of stem were also made.

The data were subjected to analysis of variance. No method of stratification was used, but the plants were moved around on the greenhouse bench in order to eliminate possible localized climatic differences.

Results

Experiment I, Greenhouse

Exposures of cauliflower plants to 8-hour photoperiods throughout the experiment or until initiation of 18.1 nodes resulted in decreased fresh weight compared to continuous 16-hour photoperiods. However, plants exposed to 8-hour photoperiods until differentiation of 9.1 nodes commenced to grow very rapidly following the change to 16-hour photoperiods and soon reached the size of the latter. They were later again surpassed by the ones given continuous 16-hour photoperiod possibly because of the earlier initiation and start of growth of the curd.

Length of stem was also suppressed under the 8-hour photoperiod (Table 5, Figure 1 and 2) and none of the plants exposed to 8-hour photoperiods reached the stem length of those exposed to 16-hour photoperiod continuously.

Table 5. Experiment I, Greenhouse. The effect of 8-hour photoperiods for a definite duration of development followed by 16-hour photoperiods during the remaining time of the experiment on the fresh weight, length of stem, and the number of nodes initiated on cauliflower plants at successive dates of harvest, (pot grown in soil, in the greenhouse, planted October 18, 1950).

Date of harvest	8-hour photoperiod until					L.S.D. 5% level	Mean	Coefficient of variability
	0 nodes	9.1 nodes	18.1 nodes	all the time	all the time*			
	Fresh weight, grams per plant							
Nov. 18, '50	1.13	1.09	1.09	1.09	1.09	N.S.	1.11	36.04
Dec. 5, '50	5.65	4.69	4.51	4.51	4.51	N.S.	4.95	33.74
Dec. 20, '50	12.40	11.76	10.65	10.30	10.28	N.S.	11.08	35.21
Dec. 28, '50	18.40	18.55	14.10	14.89	15.05	N.S.	16.20	32.84
Jan. 4, '51	23.3	23.4	18.0	16.3	15.9	6.3	19.4	36.31
Feb. 10, '51	107.5	80.4	78.9	63.1	--	14.4	84.2	17.85
	Length of stem, cm. per plant							
Dec. 5, '50	6.67	5.73	3.20	3.20	3.20	0.78	5.27	16.13
Dec. 20, '50	11.05	9.42	4.96	5.04	5.13	0.81	7.12	12.64
Dec. 28, '50	13.44	11.77	6.50	5.80	5.87	0.83	8.66	10.60
Jan. 4, '51	15.30	13.05	7.59	6.48	6.45	1.17	9.77	13.41
Feb. 10, '51	26.9	21.2	17.5	10.9	--	1.66	19.71	9.49
	Number of nodes per plant							
Nov. 8, '50	7.4	7.0	7.0	7.0	7.0			
Nov. 18, '50	9.3	9.1	9.1	9.1	9.1			
Dec. 5, '50	14.1	13.1	13.0	13.0	13.0	0.8	13.4	6.72
Dec. 20, '50	19.9	18.7	18.3	18.0	18.2	N.S.	18.6	11.82
Dec. 28, '50	25.2	24.6	21.7	21.5	21.6	2.9	22.9	14.47
Jan. 4, '51	27.4	26.4	24.3	23.7	23.9	2.9	25.1	12.74
Feb. 10, '51	30.7	32.7	30.3	29.9		2.2	31.0	7.42

*This treatment was exposed to long day and permitted to bloom and the plants were sampled for a study of the morphology and the anatomy of the cauliflower curd, (Aamlid, part I, pp and part II, pp).

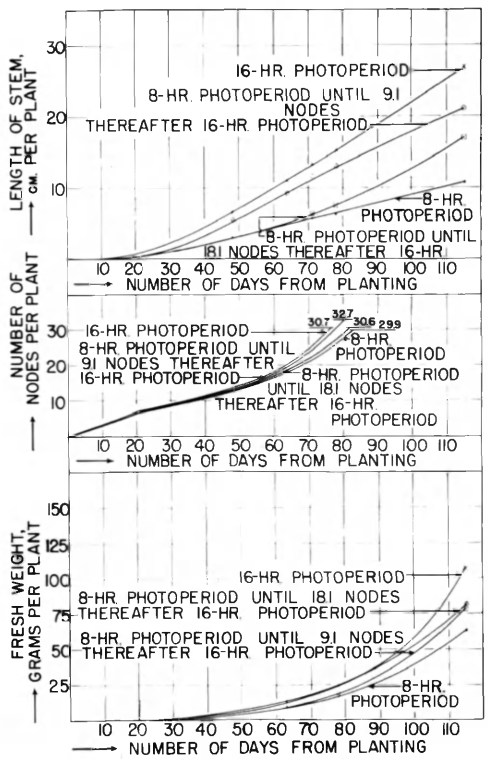


Figure 1. Experiment I, Greenhouse
Growth curves (fresh weight and length of stem), rate of initiation of nodes and mean number of nodes initiated before initiation of the inflorescence in cauliflower variety The Forbes raised under 8-hour photoperiod for a given duration of development followed by 16-hour photoperiod until termination of the experiment.

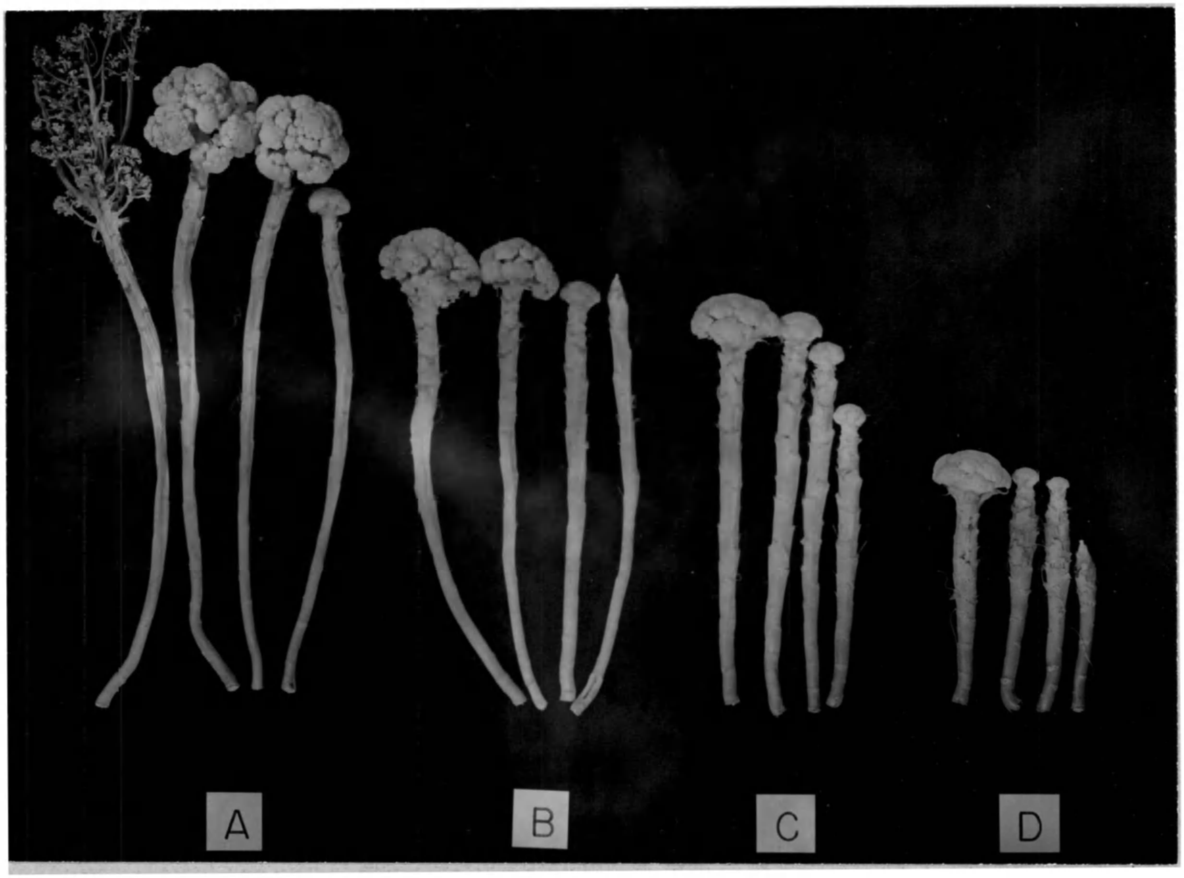


Figure 2. Experiment I, Greenhouse.
Length of stems of cauliflower plants variety The Forbes raised under 8-hour photoperiod for a given duration of development followed by 16-hour photoperiod until termination of the experiment.
(A) 16-hour photoperiod all the time.
(B) 8-hour photoperiod until 9.1 nodes.
(C) 8-hour photoperiod until 12.1 nodes.
(D) 8-hour photoperiod all the time.

Only plants receiving continuous 8-hour photoperiods had significantly slower rate of initiation of nodes and plants exposed to 8-hour photoperiods during initiation of the first 9.1 nodes showed an increase in mean number of nodes initiated before differentiation of the inflorescence. However, the effects of photoperiods on the rate of initiation and mean number of nodes initiated before differentiation of the inflorescence primordia were both very small.

Experiment II, Greenhouse

None of the interactions of nitrogen nutrition and temperature were significant. Nitrogen and temperature data were, therefore, presented in separate tables.

Significant decrease in fresh weight, which resulted from low levels of nitrogen, were encountered as soon as 7 weeks after planting of the seed when the plants were of the size of transplants (Table 6, Figures 3, 5, 6, 7, 9). These effects were more pronounced as the plants advanced in growth.

Lower rates of initiation of nodes were also encountered under low nitrogen nutrition (Table 6, Figure 3) but no significant differences in total number of nodes, formed before initiation of the inflorescence primordia, were found.

Temperature did not influence fresh weight under the conditions of this experiment (Table 7, Figures 4, 8) but the higher temperatures resulted in longer stems (Table 7, Figures 5, 9) than were found in lots of 55-60 degrees F. The 65-70° F. temperature caused a highly significant increase in the total number of nodes initiated before differentiation of inflorescence primordia (Table 7, Figure 4) and had also a slight effect on the rate of initiation of nodes.

Table 6. Experiment II, Greenhouse. The effects of five levels of nitrogen nutrition on the fresh weight, length of stem, and number of nodes initiated in cauliflower plants at successive dates of harvest. (sand culture in the greenhouse, planted November 28, 1950).

Date of harvest	Parts per million of nitrogen					L.S.D.	Mean	Coefficient of variability
	112	61	33	18	10	5% level		
	Fresh weight, grams per plant							
Dec. 19, '50	0.14	0.11	0.11	0.10	0.10		0.11	
Dec. 29, '50	0.58	0.47	0.38	0.35	0.35		0.42	
Jan. 6, '51	1.48	1.21	0.95	1.01	0.84		1.10	
Jan. 13, '51	3.47	2.38	2.26	1.83	1.52		2.29	
Jan. 20, '51	6.57	4.49	4.23	3.80	2.96	1.15	4.44	34.69
Jan. 29, '51	14.32	9.88	9.18	8.08	4.59	3.09	9.21	35.12
Feb. 9, '51	28.6	20.8	19.0	16.2	10.1	3.6	18.9	30.17
Mar. 11, '51	157	113	113	83	48	31	103	33.01
Maturity	528	402	313	208	115	50	313	17.57
	Length of stem, cm. per plant							
Dec. 29, '50	2.05	1.80	1.56	1.35	1.33	0.28	1.62	24.69
Jan. 6, '51	4.74	3.88	3.50	3.47	3.14	0.54	3.75	
Jan. 13, '51	7.70	6.41	6.39	5.23	4.96	0.72	6.14	19.28
Jan. 20, '51	11.35	9.25	8.78	8.30	6.92	0.82	8.92	14.56
Jan. 29, '51	16.06	13.42	12.75	11.59	9.08	1.00	12.58	12.70
Feb. 9, '51	20.4	18.2	16.4	15.2	12.2	0.98	16.4	9.39
Mar. 11, '51	31.3	28.7	27.1	22.9	19.1	2.0	25.8	8.72
Maturity	39.8	36.6	32.3	29.7	22.5	2.3	32.1	8.14
	Number of nodes per plant							
Dec. 19, '50	5.8	5.7	5.7	5.6	5.5	N.S.	5.7	8.77
Dec. 29, '50	8.3	8.2	7.9	7.7	7.7	0.3	7.9	6.42
Jan. 6, '51	10.5	10.2	9.9	9.6	9.5	0.5	9.9	7.85
Jan. 13, '51	13.1	12.3	12.2	11.6	11.4	1.4	12.1	12.44
Jan. 20, '51	15.3	14.1	14.3	13.7	13.6	0.9	14.2	10.23
Jan. 29, '51	19.8	18.5	18.4	18.4	17.1	1.4	18.4	
Feb. 9, '51	29.4	25.2	25.7	24.2	23.2	2.6	25.5	16.17
Mar. 11, '51	49.6	48.5	51.8	51.6	51.0	N.S.	50.6	12.09
Maturity	53.2	51.2	50.2	49.8	54.0	N.S.	51.7	

Table 7 . Experiment II, Greenhouse. The effect of two temperature levels on the fresh weight, length of stem, and number of nodes initiated in cauliflower plants at successive dates of harvest, (sand culture in the greenhouse, planted November 28, 1950).

Date of harvest	Temperature 65-75° F.	Temperature 55-60° F.	L. S. D. 5% level	Mean	Coefficient of variability
	Fresh weight, grams per plant				
Dec. 19, '50	0.11	0.11		0.11	
Dec. 29, '50	0.45	0.39		0.42	
Jan. 6, '51	1.17	1.03		1.10	
Jan. 13, '31	2.58	2.00		2.29	
Jan. 20, '51	4.52	4.26	N.S.	4.44	34.69
Jan. 29, '51	9.23	9.18	N.S.	9.21	35.18
Feb. 9, '51	19.1	18.7	N.S.	18.9	30.17
Mar. 11, '51	100	105	N.S.	103	33.01
Maturity	323	302	N.S.	313	17.57
	Length of stem, cm. per plant				
Dec. 29, '50	1.96	1.27	0.16	1.62	24.69
Jan. 6, '51	4.48	3.01	0.34	3.75	22.93
Jan. 13, '51	7.38	4.89	0.48	6.14	19.38
Jan. 20, '51	10.39	7.46	0.52	8.92	14.56
Jan. 29, '51	14.13	11.03	0.64	12.58	12.70
Feb. 9, '51	18.6	14.3	0.62	16.4	9.39
Mar. 11, '51	27.8	23.8	1.3	25.8	8.72
Maturity	35.3	29.0	1.5	32.1	8.14
	Number of nodes per plant				
Dec. 19, '50	5.7	5.6	N.S.	5.7	8.77
Dec. 29, '50	8.0	7.8	0.2	7.9	6.42
Jan. 6, '51	10.0	9.8	N.S.	9.9	7.85
Jan. 13, '51	12.4	11.8	N.S.	12.1	12.44
Jan. 20, '51	14.2	14.2	N.S.	14.2	10.23
Jan. 29, '51	18.8	18.0	N.S.	18.4	12.44
Feb. 9, '51	26.3	24.7	1.6	25.5	16.17
Mar. 11, '51	57.4	43.8	3.5	50.6	12.09
Maturity	58.2	45.2	2.9	51.7	9.90

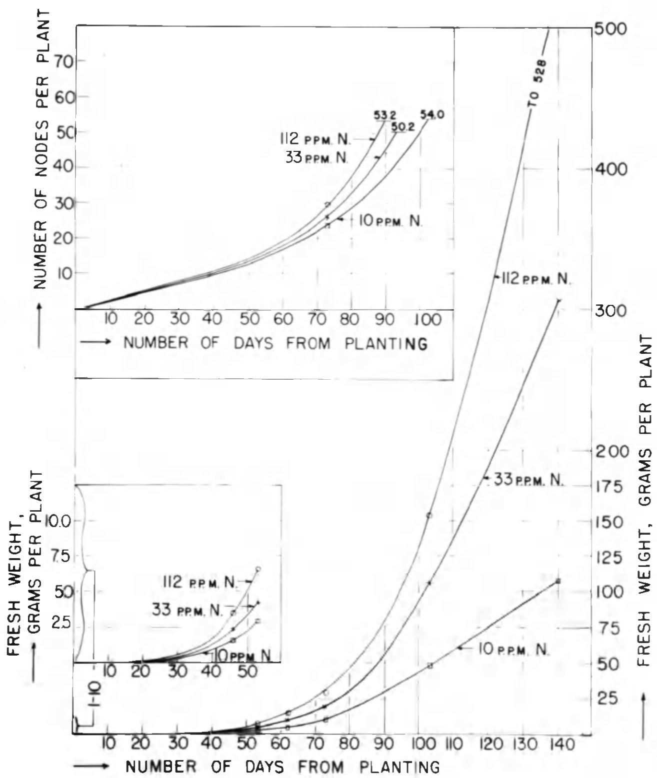


Figure 3. Experiment II, Greenhouse. Growth curves (fresh weight), rate of initiation of nodes and mean number of nodes initiated before initiation of inflorescence primordia in cauliflower variety Snowball M in the nitrogen nutrition series 112- 33- and 10 p.p.m-N.

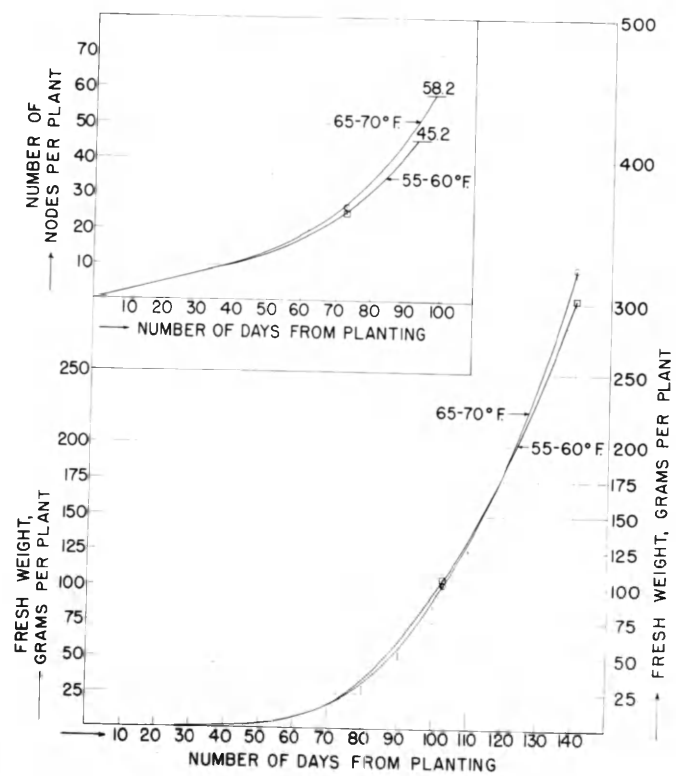


Figure 4. Experiment II, Greenhouse. Growth curves (fresh weight), rate of initiation of nodes and mean number of nodes initiated before initiation of inflorescence primordia in cauliflower variety Snowball M at the 65-70° and 55-60°F. night temperatures.

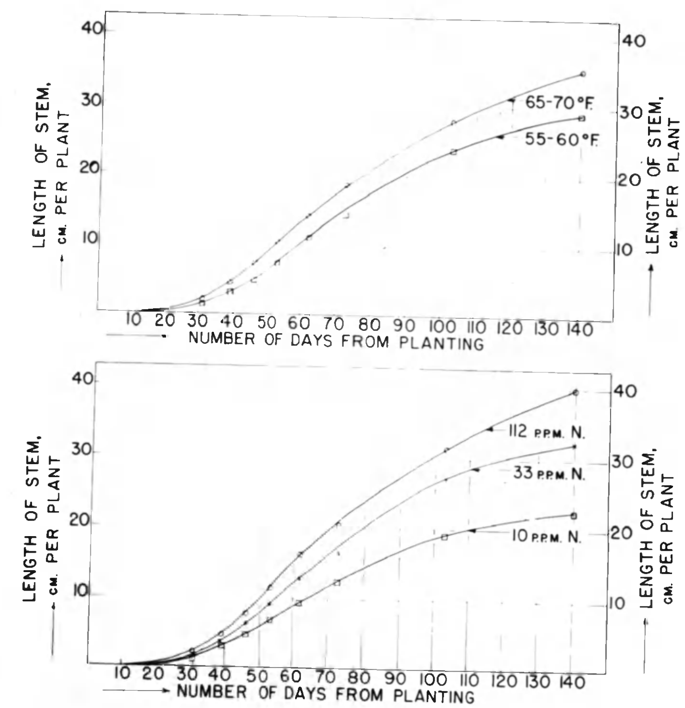


Figure 5. Experiment II, Greenhouse. Growth curves (length of stem) for the cauliflower variety Snowball M in the nitrogen nutrition series 112- 33- and 10 p.p.m-N. and for the night temperatures 65-70° and 55-60°F.

Figure 6. Experiment II, Greenhouse
Representative plants of cauliflower variety
Snowball M of Nitrogen nutrition series 112-
61- 33- 18- and 10 p.p.m. N. raised under 65-70 °F.
night temperature.

Figure 7. Experiment II, Greenhouse.
Representative plants of cauliflower variety Snowball M of Nitrogen nutrition series 112- 61- 33- 18- and 10 p.p.m. N. raised under 55-60° F. night temperature.

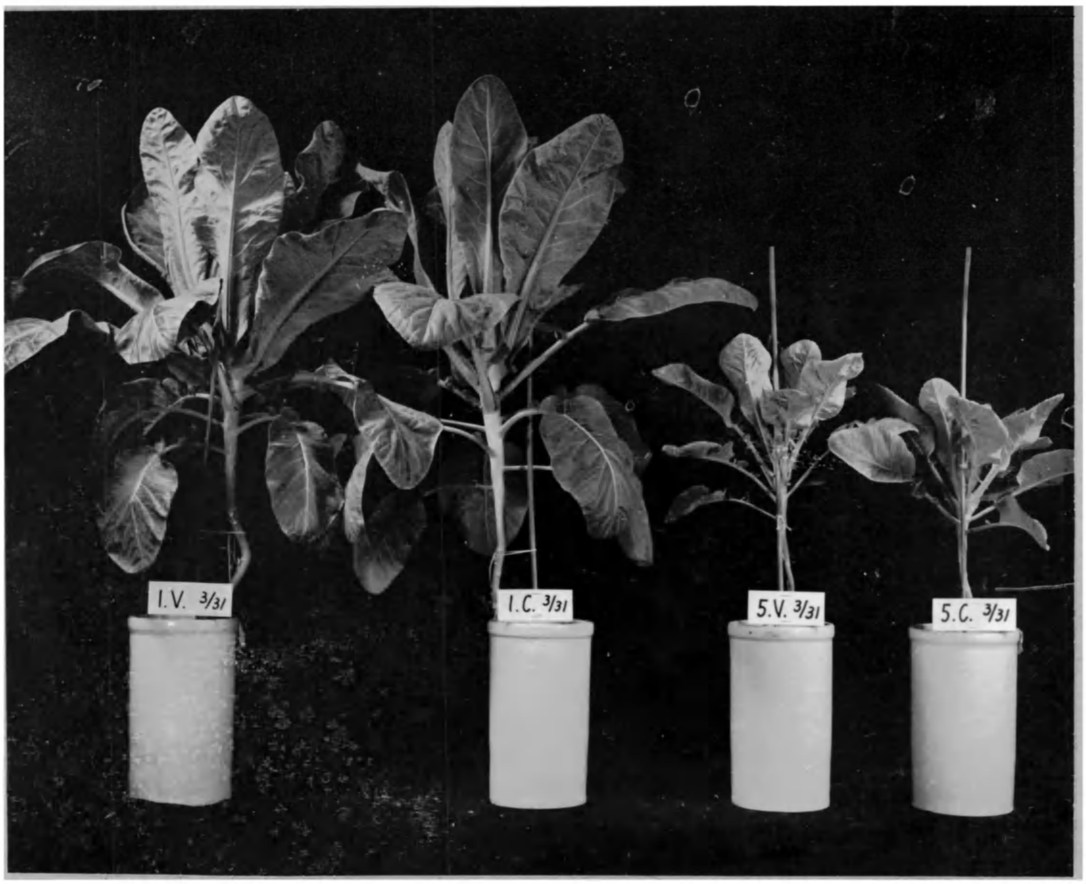


Figure 8. Experiment II, Greenhouse.
Representative plants of cauliflower variety Snowball M of 112- and 10 p.p.m. nitrogen nutrition series raised under 65-70° and 55-60° F. night temperature.

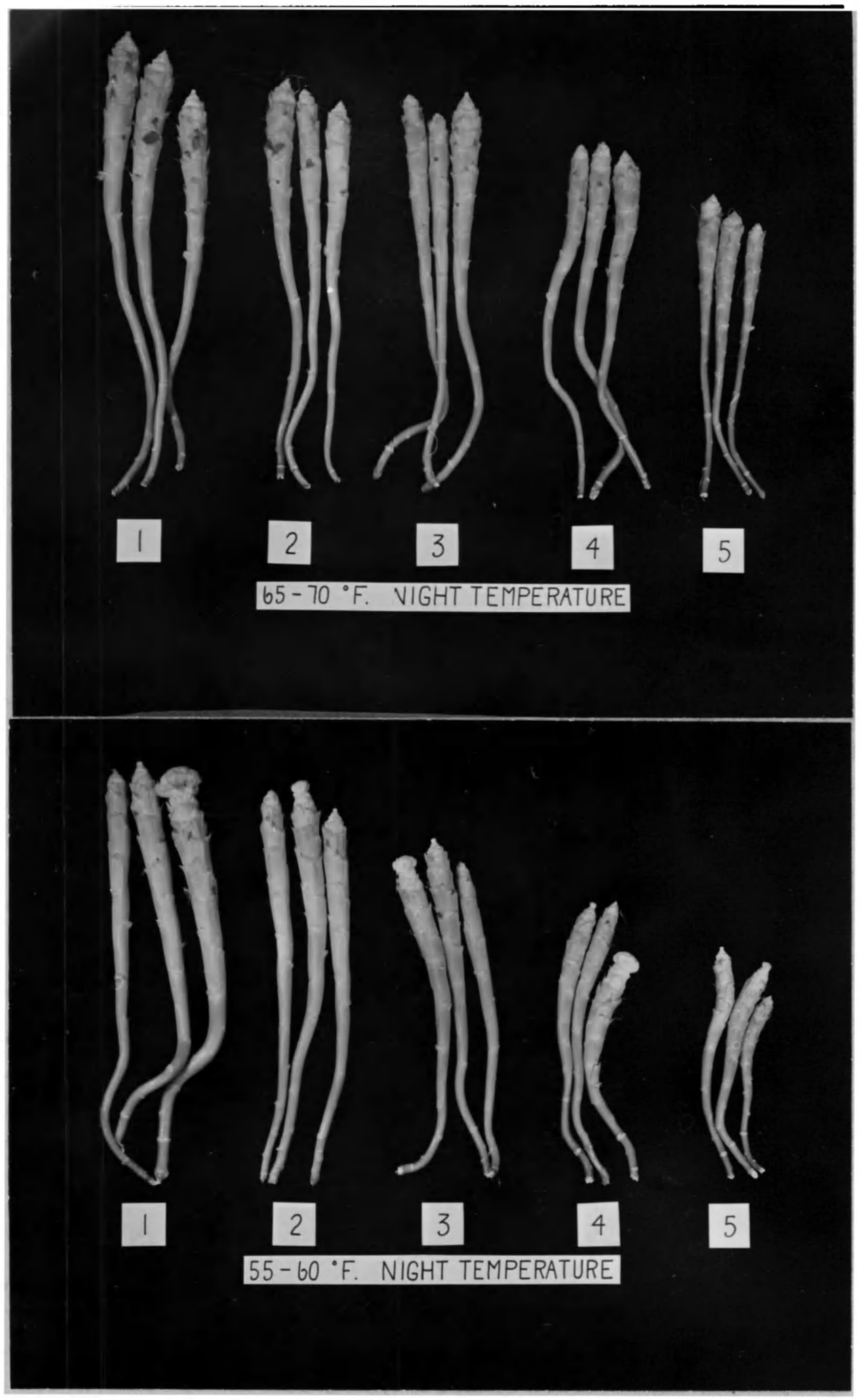


Figure 9. Experiment II, Greenhouse.
Length of stems of cauliflower plants variety Snowball M of nitrogen nutrition series 112- 61- 33- 18- and 10 p.p.m. N. raised under 65-70° and 55-60° F. night temperatures.

Experiment III, Greenhouse

None of the interactions of nitrogen deficiency and temperature were significant and the nutrition and temperature data were presented in separate tables.

The fresh weight of cauliflower plants in treatment -N, from 1/4 to 1/20 (about 6 to 8 weeks old) equaled those given the continuouse full nutrient solution at the termination of the experiment (Table 8, Figures 10, 13, 14). The deficiency of nitrogen during later periods of growth resulted in decreases in fresh weight and these decreases were more pronounced the later in the growth period the deficiency occurred. The effects of nitrogen deficiency on length of stem were similar to the effects on fresh weight (Table 8, Figures 12, 16).

No significant differences among mean number of nodes initiated before initiation of the inflorescence were found but nitrogen deficiency during the early stages of growth (1/4 to 1/20 or 6 to 8 weeks old) resulted in temporary reduction in the rate of initiation of nodes (Table 8, Figure 10).

Differences in fresh weight were not found between 65-70° and 55-60° F. night temperatures (Table 9, Figures 11, 15), but the stems were significantly longer for the 65-70° F. temperature (Table 9, Figures 12, 16). Rate of initiation of nodes was not markedly influenced by the temperature under the conditions of this experiment, but the mean number of nodes initiated before initiation of inflorescence primordia was 9.1 nodes greater for the higher temperature.

Experiment IV, Greenhouse

The similarity of the response of the plants to variations in nitrogen, phosphorus and potassium nutrition was demonstrated in Tables 10, 11,

Table 8. Experiment III, Greenhouse. The effects of nutrient solutions deficient in nitrogen for indicated periods of time on fresh weight, length of stem, and number of nodes initiated in cauliflower plants at successive dates of harvest, (sand culture in the greenhouse, planted November 28, 1950).

Date of harvest	Without N for period indicated					L.S.D. 5% level	Mean	Coefficient of variability
	N all the time	Jan. 4 – 20	Jan. 31 – Feb. 18	Feb. 19 – Mar. 9	Mar. 9			
	Fresh weight, grams per plant							
Jan. 4, '51	1.22	1.24	1.21	1.27	1.31		1.24	
Jan. 13, '51	3.21	2.32	3.30	3.36	3.56		3.15	
Jan. 20, '51	6.3	3.5	6.3	6.2	6.1	1.3	5.6	36.42
Jan. 31, '51	15.1	6.5	14.9	14.9	15.3	2.9	13.3	33.83
Feb. 18, '51	53.8	28.2	33.6	51.7	48.7	10.0	43.2	36.98
Mar. 11, '51	149	78	112	109	147	32	119	29.41
Maturity	567	573	448	361	289	101	452	24.78
	Length of stem, cm. per plant							
Jan. 4, '51	4.31	4.45	4.38	4.35	4.44	N.S.	4.38	20.55
Jan. 13, '51	7.94	7.20	8.15	8.13	8.29	N.S.	7.94	18.39
Jan. 20, '51	11.1	9.4	11.6	11.1	11.2	1.0	10.9	14.08
Jan. 31, '51	17.0	10.9	17.2	16.8	16.8	1.0	15.7	10.45
Feb. 18, '51	25.2	18.1	23.2	23.9	24.6	1.0	23.0	6.99
Mar. 11, '51	32.0	24.8	30.2	29.9	31.4	2.3	29.7	8.75
Maturity	41.1	39.6	37.6	36.0	36.2	3.4	38.1	10.00
	Number of nodes per plant							
Jan. 4, '51	9.8	9.9	9.8	9.9	10.0	N.S.	9.9	8.02
Jan. 13, '51	12.6	12.5	12.5	12.7	12.8	N.S.	12.6	9.84
Jan. 20, '51	15.5	15.3	15.4	15.2	15.3	N.S.	15.3	11.63
Jan. 31, '51	21.1	18.4	21.2	21.0	21.1	1.9	20.5	14.63
Feb. 18, '51	38.1	29.8	38.6	39.0	38.4	4.8	36.7	20.98
Mar. 11, '51	50.8	51.8	50.8	48.8	55.7	N.S.	51.6	11.24
Maturity	54.5	58.1	57.7	53.7	52.0	N.S.	55.2	13.95

Table 9. Experiment III, Greenhouse. Effects of two temperature levels on the fresh weight, length of stem, and number of nodes initiated in cauliflower plants at successive dates of harvest. (sand culture in the greenhouse, planted November 28, 1950).

Date of harvest	Temperature 65-70° F.	Temperature 55-60° F.	L. S. D. 5% level	Mean	Coefficient of variability
	Fresh weight, grams per plant				
Jan. 4, '51	1.35	1.15		1.24	
Jan. 13, '51	3.36	2.93		3.15	
Jan. 20, '51	5.8	5.5	N.S.	5.6	36.42
Jan. 31, '51	13.1	13.6	N.S.	13.3	33.83
Feb. 18, '51	43.6	42.8	N.S.	43.2	36.98
Mar. 11, '51	115	122	N.S.	119	29.41
Maturity	470	433	N.S.	452	24.78
	Length of stem, cm. per plant				
Jan. 4, '51	5.32	3.45	0.36	4.39	20.55
Jan. 13, '51	9.36	6.52	0.58	7.94	18.39
Jan. 20, '51	12.6	9.1	0.6	10.9	14.08
Jan. 31, '51	17.6	13.8	0.7	15.7	10.45
Feb. 18, '51	25.1	20.8	0.7	23.0	6.99
Mar. 11, '51	31.6	27.7	1.5	29.7	8.75
Maturity	41.1	35.0	2.2	38.1	10.00
	Number of nodes per plant				
Jan. 4, '51	10.0	9.7	0.3	9.9	8.02
Jan. 13, '51	12.7	12.5	N.S.	12.6	9.84
Jan. 20, '51	15.5	15.1	N.S.	15.3	11.63
Jan. 31, '51	20.8	20.3	N.S.	20.5	14.63
Feb. 18, '51	37.7	35.8	N.S.	36.7	20.98
Mar. 11, '51	56.4	46.7	3.3	51.6	11.24
Maturity	59.8	50.7	4.4	55.2	13.98

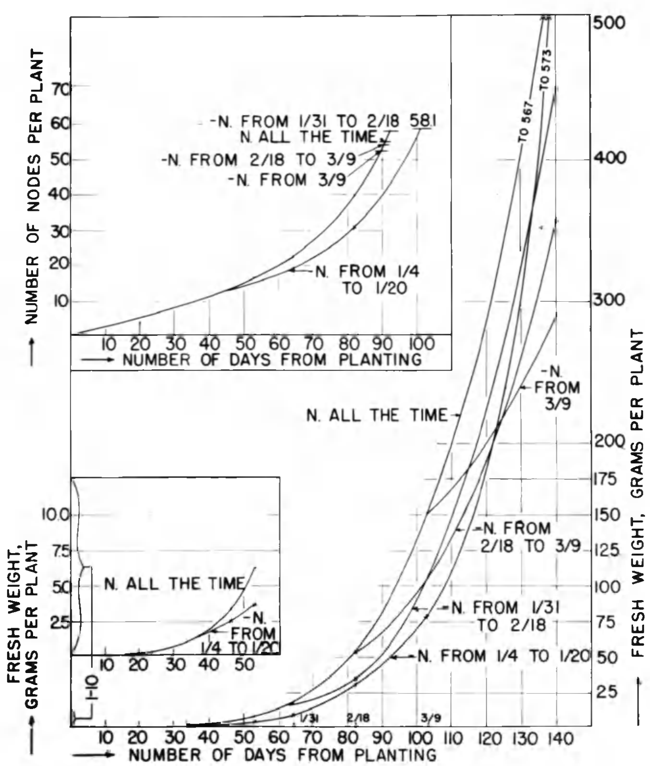


Figure 10. Experiment III, Greenhouse. Growth curves (fresh weight), rate of initiation of nodes and mean number of nodes initiated before initiation of inflorescence primordia in the cauliflower variety Snowball M in the nitrogen deficiency experiment. (Seed planted 11/28)

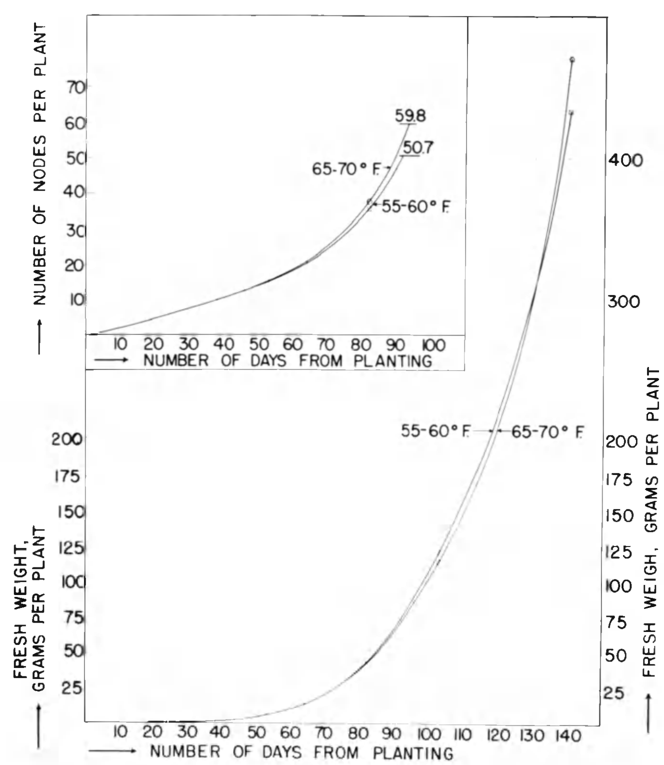


Figure 11. Experiment III, Greenhouse. Growth curves (fresh weight), rate of initiation of nodes and mean number of nodes initiated before initiation of inflorescence primordia in the cauliflower variety Snowball M at 65-70° and 55-60°F. night temperatures. (Seed planted 11/28)

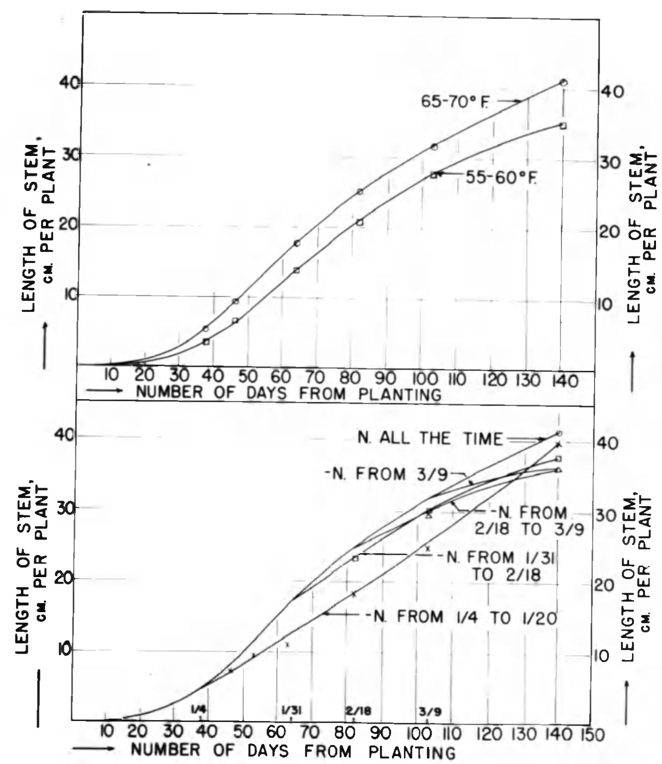


Figure 12. Experiment III, Greenhouse. Growth curves (length of stem) for the cauliflower variety Snowball M in the nitrogen deficiency experiment and at the 65-70° and 55-60°F. night temperatures

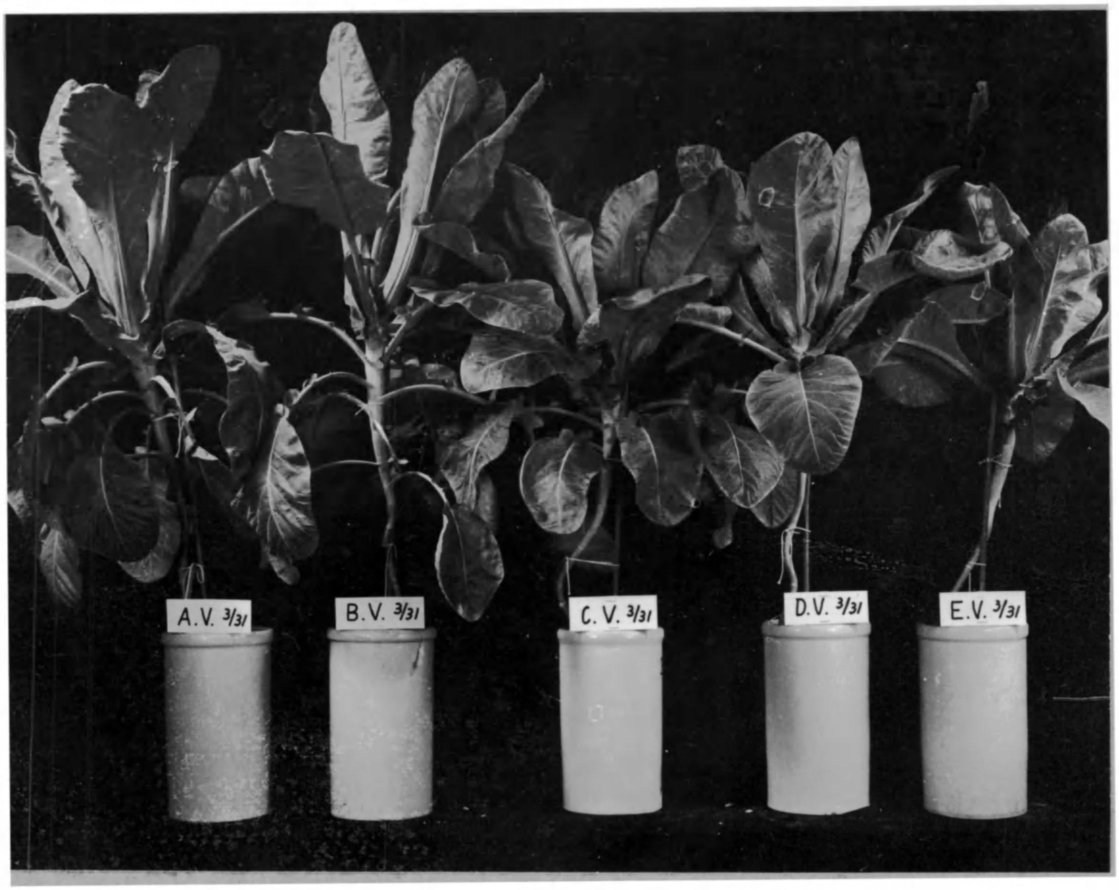
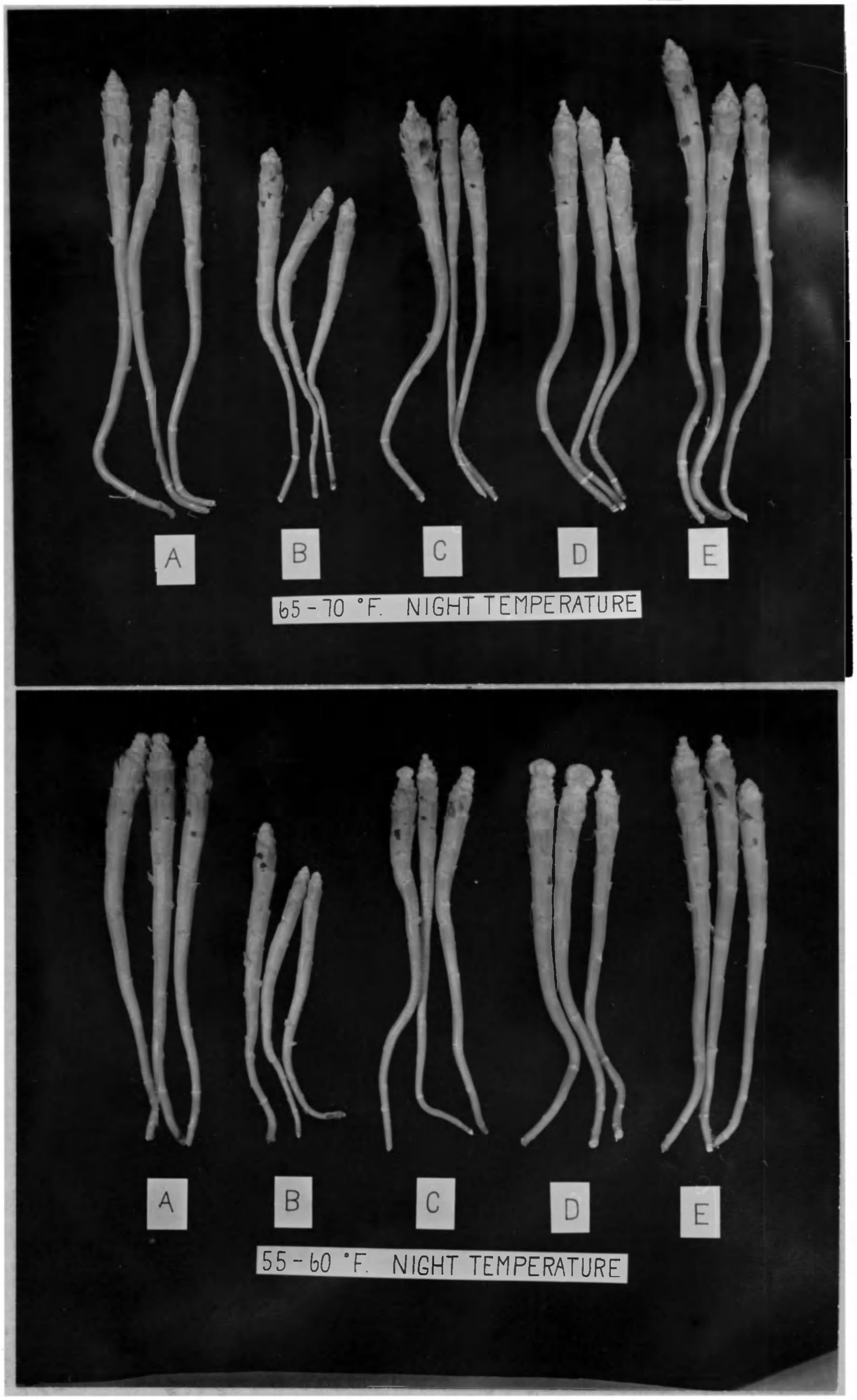


Figure 13. Experiment III, Greenhouse.
Representative plants of nitrogen deficiency experiment raised under 65-70 F. night temperature.
(A) N. continuously. (B) -N from 1/4 to 1/20.
(C) -N from 1/31 to 2/18. (D) -N from 2/18 to 3/9.
(E) -N from 3/9 to termination of the experiment.
Seed planted 11/28.

Figure 14. Experiment III, Greenhouse. Representative plants of nitrogen deficiency experiment raised under 55-60 F. night temperature. (A) N. continuously. (B) -N from 1/4 to 1/20. (C) -N from 1/31 to 2/18. (D) -N from 2/18 to 3/9. (E) -N from 3/9 to termination of the experiment. (Seed planted 11/29)

Figure 15. Experiment III, Greenhouse.
Representative plants of nitrogen deficiency experiment raised at 65-70 F. and 55-60 F. night temperatures.
(A) N. continuously. (B) -N from 1/4 to 1/20.
(Seed planted 11/28)



Figures 16. Experiment III, Greenhouse.
Length of stem of nitrogen deficiency experiment.
(A) N. all the time.
(B) -N from 1/4 to 1/20. (C) -N from 1/31 to 2/18.
(D) -N from 2/18 to 3/9. (E) -N from 3/9 to termination of the experiment raised at 65-70° F. (F) and 55-60° F. (G) night temperatures and harvested March 11.

12 and in Figures 17, 18, 19, 20, 21, and 22. The decreases found in fresh weight and length of stem resulting from lower concentrations of various components were expected. Decreased rates of initiation of nodes were encountered only in cases of serious deficiency. This decreased rate of initiation of nodes was followed by a significantly higher number of nodes initiated before differentiation of the inflorescence primordia.

Experiment V. Greenhouse.

All significant factorial effects in fresh weight and length of stem in the nitrogen-nutrition x photoperiod x temperature experiment were positive (Table 13) and the results may be summarised as follows:

(1) The relative importance of the three variable environmental factors, as determined by their effects on the fresh weight, were (a) nitrogen nutrition, (b) photoperiod and (c) temperature.

(2) Of the interactions only the two primary interactions, involving nitrogen nutrition, were of any importance concerning the increase in fresh weight.

(3) The relative importance of the three variable environmental factors as determined by their effects on length of stem were (a) nitrogen nutrition, (b) photoperiod and (c) temperature.

(4) Of the interactions, only the two primary interactions involving temperature were of any importance concerning length of stem.

Table 10 . Experiment IV, Greenhouse. The effects of six levels of nitrogen nutrition on fresh weight, length of stem, and number of nodes initiated in cauliflower plants at successive dates of harvest, (sand culture in the greenhouse, planted February 17, 1951).

Date of harvest	Parts per million of nitrogen						L.S.D. 5% level	Mean	Coefficient of Variability
	205	112	61	33	18	10			
	Fresh weight of plants								
Mar. 20, '51	0.63	0.54	0.40	0.38	0.41	0.40		0.46	
Apr. 1, '51	3.12	3.17	2.60	2.37	2.27	2.20	0.53	2.62	37.12
Apr. 13, '51	12.15	11.86	9.04	7.39	5.92	3.48	1.53	8.31	39.09
Apr. 28, '51	49.1	51.7	36.1	23.2	16.6	11.3	7.5	31.3	32.99
May 19, '51	203	216	203	107	66	46	22	124	22.73
	Length of stem, cm. per plant								
Apr. 1, '51	4.26	4.19	3.50	3.42	2.94	2.70	0.20	3.50	9.72
Apr. 13, '51	9.31	8.75	7.95	6.70	5.22	4.09	0.47	7.00	11.53
Apr. 28, '51	15.77	15.68	13.90	10.48	7.01	5.72	0.86	11.43	9.96
May 19, '51	24.27	23.33	20.79	15.60	11.70	9.69	1.33	19.22	10.10
	Number of nodes per plant								
Mar. 20, '51	8.5	8.3	7.9	7.9	7.8	7.9	0.3	8.1	5.88
Apr. 1, '51	12.1	12.2	12.2	11.9	12.2	12.5	N.S.	12.2	8.50
Apr. 13, '51	18.6	19.6	19.1	19.2	18.8	16.5	1.7	18.6	14.61
Apr. 28, '51	35.3	35.7	34.2	32.8	34.2	32.2	4.1	34.1	14.27
May 20, '51	41.3	38.8	33.1	36.0	40.9	50.8	6.0	40.2	17.52

Table 11. Experiment IV, Greenhouse. The effects of four levels of phosphorus nutrition on fresh weight, length of stem, and number of nodes initiated in cauliflower plants at successive dates of harvest, (sand culture in the greenhouse, planted February 17, 1951).

Date of harvest	Parts per million of phosphorus				L.S.D. 5% level	Mean	Coefficient of variability
	Fresh weight, grams per plant						
Mar. 20, '51	0.54	0.49	0.54	0.47		0.51	
Apr. 1, '51	3.17	3.33	3.36	1.77	0.53	2.88	37.12
Apr. 13, '51	11.9	11.4	11.0	3.4	1.5	9.43	39.09
Apr. 28, '51	51.7	51.5	35.8	10.3	7.5	37.3	32.99
May 19, '51	216	235	145	46	22	161	22.73
	Length of stem, cm. per plant						
Apr. 1, '51	4.19	4.46	3.92	2.17	0.20	3.69	9.73
Apr. 13, '51	8.75	9.31	7.67	3.26	0.47	7.25	11.53
Apr. 28, '51	15.66	15.92	11.14	4.62	0.86	11.84	9.96
May 19, '51	23.33	23.28	16.28	8.43	1.33	17.83	10.10
	Number of nodes per plant						
Mar. 20, '51	8.3	8.1	8.2	7.9	0.3	8.1	5.88
Apr. 1, '51	12.2	12.1	12.1	11.3	0.6	11.9	8.50
Apr. 13, '51	19.6	18.7	19.1	15.4	1.7	18.2	14.61
Apr. 28, '51	35.7	33.4	36.8	29.8	4.0	33.9	14.27
May 19, '51	38.8	32.2	35.0	46.2	6.0	38.1	17.52

Table 12 Experiment IV, Greenhouse. The effects of four levels of potassium nutrition on fresh weight, length of stem, and number of nodes initiated in cauliflower plants at successive dates of harvest, (sand culture in the greenhouse, planted February 17, 1951).

Date of harvest	Parts per million of potassium 86	20	10	5	L.S.D. 5% level	Mean	Coefficient of variability
	Fresh weight, grams per plant						
Mar. 20, '51	0.54	0.35	0.38	0.31		0.39	
Apr. 1, '51	3.17	1.75	1.25	1.01	0.53	1.80	37.12
Apr. 13, '51	11.9	5.0	3.7	1.9	1.5	5.6	39.09
Apr. 28, '51	51.7	14.6	6.0	3.1	7.5	18.9	32.99
May 19, '51	216.0	37.1	12.3	5.2	22	67.7	22.73
	Length of stem, cm. per plant						
Apr. 1, '51	4.19	2.88	2.14	1.73	0.20	2.74	9.72
Apr. 13, '51	8.75	5.02	3.70	2.96	0.47	5.11	11.53
Apr. 28, '51	15.68	7.38	5.15	4.05	0.86	8.07	9.96
May 19, '51	23.33	12.28	7.92	5.82	1.33	12.34	10.10
	Number of nodes per plant						
Mar. 20, '51	8.3	7.9	7.9	7.6	0.3	7.9	5.88
Apr. 1, '51	12.2	12.3	11.8	11.2	0.6	11.9	8.50
Apr. 13, '51	19.6	17.9	17.2	15.6	1.7	17.6	14.61
Apr. 28, '51	35.7	35.0	25.8	21.8	4.0	29.6	14.27
May 19, '51	38.8	44.8	36.1	29.7	6.0	37.4	17.52

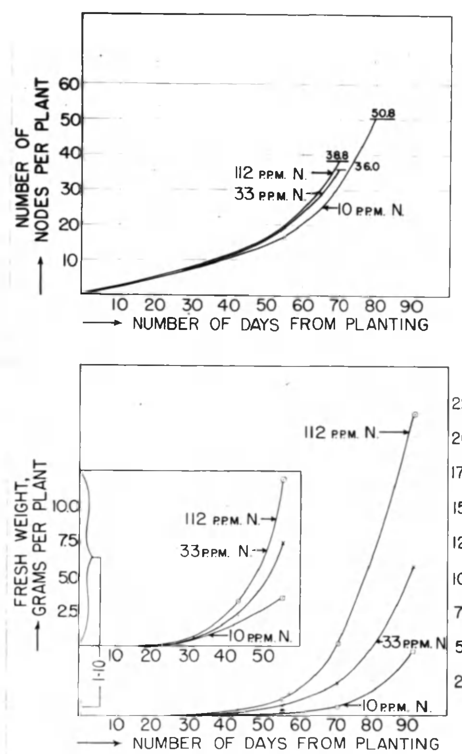


Figure 17.
Experiment IV, Greenhouse. Growth curves (fresh weight) rate of initiation of nodes and mean number of nodes initiated before initiation of inflorescence primordia in the cauliflower variety The Forbes under three levels of nitrogen nutrition. Seed planted 2/17/51.

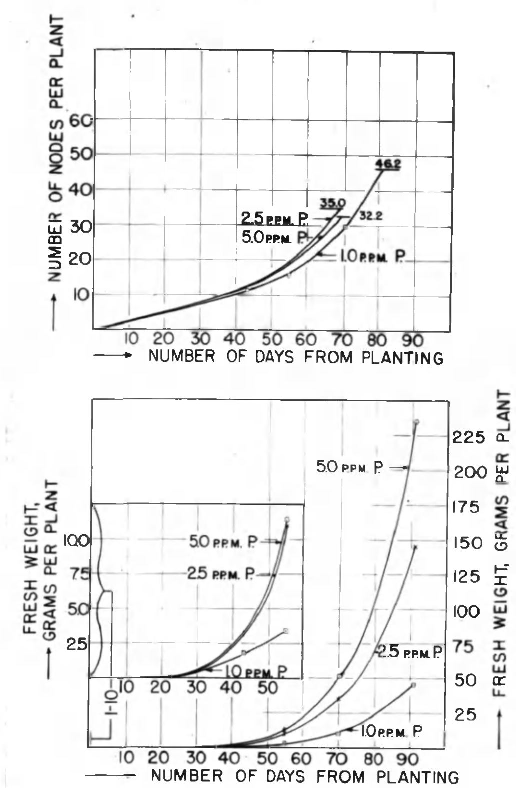


Figure 18.
Experiment IV, Greenhouse. Growth curves (fresh Weight) rate of initiation of nodes and mean number of nodes differentiated before initiation of inflorescence primordia in the cauliflower variety The Forbes raised under three levels of phosphorus nutrition. Seed planted 2/17/5

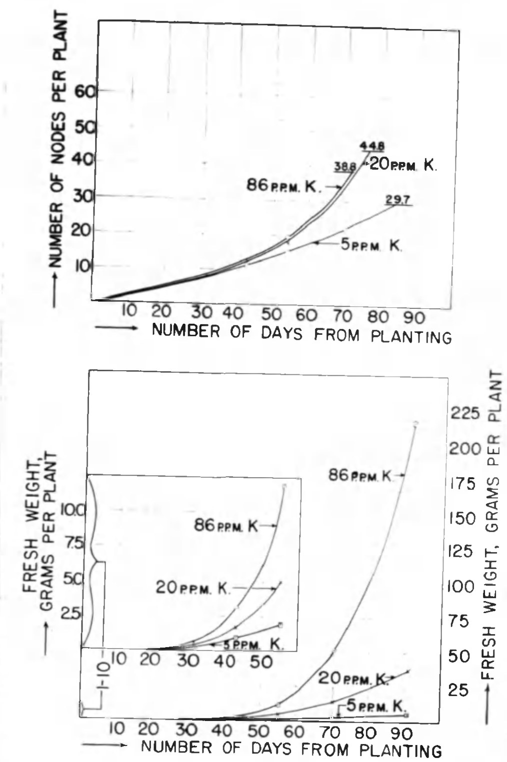


Figure 19.
Experiment IV, Greenhouse. Growth curves (fresh weight) rate of initiation of nodes and mean number of nodes initiated before differentiation of inflorescence primordia in the cauliflower variety The Forbes raised under three levels of potassium nutrition. Seed planted 2/17/51.

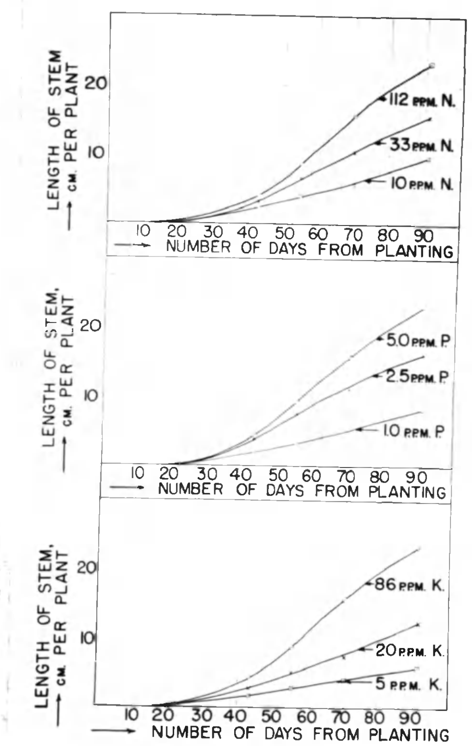


Figure 20.
Experiment IV, Greenhouse. Growth curves (length of stem) for cauliflower variety The Forbes under three levels of nitrogen, phosphorus, and potassium nutri tion. Seed planted 2/17/51.

Figure 21. Experiment IV, Greenhouse.
Representative plants from nitrogen, phosphorus and potassium nutrition experiment. Variety The Forbes planted 2/17/51.

Figure 22. Experiment IV, Greenhouse.
Representative plants from nitrogen, phosphorus and potassium nutrition experiment. Variety The Forbes planted 2/17/51.

The effects of nitrogen nutrition, photoperiod and temperature on the rate of initiation of nodes differs somewhat from the effects on fresh weight and length of stem. The order of importance of the primary effects on node initiation are (a) temperature, (b) nitrogen nutrition and (c) photoperiod. The interactions seem to have minor influence on the rate of initiation of nodes except for the primary interaction temperature x nutrition.

Discussion

The main purpose of the study was to disclose the environmental conditions responsible for premature heading in cauliflower. The effects of the environment on the fresh weight and length of stem serve as a background for evaluation of the degree to which the plants respond in general to the treatments.

Decreases in night temperature from 65-70° to 55-60° F. lowered the mean node number of the cauliflower variety Snowball M from 58.2 to 45.2 in Experiment II. A decrease in mean number from 59.8 to 50.7 was encountered in Experiment III with the same variety raised under identical temperature conditions as Experiment II. The variety The Forbes was used in Experiment V. This variety also responded to a decrease in night temperature from 65-70° to 55-60° F. The difference in mean number of nodes between the two treatments was 5.3. The conclusion is, therefore, that temperature is the factor which causes premature heading in cauliflower.

Decreases in photoperiods, in nitrogen, phosphorus, or potassium nutrient levels show either no significant differences or an increase in number of nodes compared to optimal levels. These increases in number of nodes were associated with a decreased rate of initiation. It is possible that temperature may have entered the photoperiodic experiment as a bias since the plants exposed to 8-hour photoperiods were covered with black sateen cloth during 16-hours of the photoperiodic cycle. It is also possible that temperature enters the nitrogen, phosphorus and potassium nutrition experiment as a bias because of the slower rates of initiation of nodes. This delayed the differentiation of the inflorescence until later in the spring when the increased outside temperature made it impossible to keep the greenhouse temperatures at the desired levels.

Hence it may be stated that causes of the increases in node numbers as a result of decreases in levels of nutrition of particular elements or exposure to 8-hour photoperiods are either not significant or uncertain as to cause.

Decreases in length of photoperiod, level of nutrition and temperature were associated with slower rate of initiation of nodes in all experiments, but these effects were surprisingly small when compared with the drastic effects of the treatments on fresh weights and length of stems. It is therefore impossible to judge the physiological age of the plants from their size.

Nitrogen deficiency and 8-hour photoperiod during early phases of growth did not have any decreasing effects on the fresh weight of the plants at the termination of the experiments although the decrease in fresh weight during the treatments were very distinctive. A more rapid rate of growth followed such treatments and the plants eventually reached the size of the ones exposed to optimal conditions the entire time. It has been demonstrated that plants exposed to unfavorable conditions during the seedling stage surpassed the ones exposed to more favorable conditions. Thus Thompson (56) reported the beneficial effects of lower temperature during the propagation period for the subsequent growth of onion plants in the field, while Bremer (9) reported similar effects of short photoperiods on the further growth of onion plants in the field. Carew et al (14) reported increased yield of cauliflower plants after exposure to short photoperiod in the seedling stage. These effects were associated with an increased number of nodes as shown elsewhere in this thesis.[1] The conclusion was drawn that the beneficial effects were due to the increased time for establishment in the field give the plants exposed to short photoperiod because of the increased number of nodes and also the slower rates of initiation under short photoperiods. It is doubtful whether this is the whole explanation since the time differences are rather small and similar effects are found in cauliflower plants which are not transplanted.

Summary

Decrease in temperature from 65-70° to 55-60° F. night temperature was demonstrated to cause a decrease in mean number of nodes initiated before initiation of the inflorescence and thus to cause premature heading.

Serious decrease in length of photoperiod and in level of nutrition was associated with an increase in number of nodes, thus causing post mature heading.

Decreases in length of photoperiod, nutrient level and temperature were associated with decreased rate of initiation of nodes, but to a

[1] See Section III.

surprisingly small degree compared to the drastic effects of the treatments on the fresh weight andlength of stems of the plants.

The significance of check in growth during early stages of development was discussed.

Table 13. Experiment V, Greenhouse. Factoral effects of nitrogen nutrition (2) x photoperiod (2) x temperature on fresh weight, length of stem, and number of nodes initiated in cauliflower plants at successive dates of harvest, (sand culture in the greenhouse, planted February 17, 1951).

Date of harvest	Factoral effects: 112 ppm vs 10 ppm N	16-hr. vs 8-hr. photoper.	65-70° F. vs 55-60° F.	Nutr. x photoper.	Nutr. x temp.	Photoper. x temp.	Nutr. x photoper. x temp.	L.S.D. 5% level	Mean	Coefficient of variability
	Fresh weight, effects in gram per plant									
Mar. 19, '51	+ 0.01	+ 0.05	+ 0.14	+ 0.03	+ 0.01	+ 0.05	+ 0.01		0.41	
Apr. 1, '51	+ 0.56	+ 0.47	+ 0.91	+ 0.24	+ 0.35	+ 0.36	+ 0.14	0.37	2.19	43.95
Apr. 10, '51	+ 2.14	+ 1.08	+ 1.44	+ 0.91	+ 1.04	+ 0.64	+ 0.35	0.66	5.00	41.03
Apr. 28, '51	+16.9	+ 4.88	+ 4.68	+ 4.28	+ 4.58	+ 3.06	+ 2.70	3.94	25.2	35.16
May 20, '51	+77.9	+22.6	+12.6	+17.9	+14.2	+ 0.3	+ 0.4	12.0	113.2	22.74
	Length of stem, effects cm. per plant									
Apr. 1, '51	+ 0.52	+ 1.59	+ 1.03	+ 0.47	+ 0.29	+ 0.21	+ 0.18	0.15	2.86	17.54
Apr. 10, '51	+ 1.25	+ 1.59	+ 1.47	+ 0.59	+ 0.62	+ 0.56	+ 0.23	0.20	4.61	13.48
Apr. 28, '51	+ 3.80	+ 2.50	+ 1.81	+ 0.70	+ 0.95	+ 1.06	+ 0.47	0.49	8.96	12.28
May 20, '51	+ 6.22	+ 4.61	+ 1.46	+ 0.47	+ 1.57	+ 1.81	+ 0.65	0.69	16.70	9.16
	Number of nodes, effects nodes per plant									
Mar. 19, '51	+ 0.1	+ 0.1	+ 0.6	+ 0.1	± 0.0	± 0.0	± 0.0	0.2	8.2	6.59
Apr. 1, '51	− 0.1	+ 0.4	+ 1.3	+ 0.3	± 0.0	− 0.1	+ 0.1	0.3	12.4	7.74
Apr. 10, '51	+ 0.7	+ 0.6	+ 1.7	+ 0.6	+ 0.4	+ 0.7	+ 0.3	0.5	15.8	10.51
Apr. 28, '51	+ 4.3	+ 2.0	+ 2.4	+ 1.8	+ 2.2	+ 1.6	+ 1.0	1.9	28.4	14.74
May 20, '51	+ 1.0	− 0.8	+ 5.3	+ 2.4	+ 4.1	+ 1.9	− 0.1	3.0	44.1	15.19

Table 14. Experiment V, Greenhouse. Fresh weight of cauliflower plants at successive dates of harvest for the different factorial combinations in the nitrogen nutrition (2) x photoperiod (2) x temperature experiment, (sand culture in the greenhouse, planted February 17, 1951).

Date of harvest	Nutr. & temp. Photo-period	112 ppm nitrogen 65-70°F.	112 ppm nitrogen 55-60°F.	112 ppm nitrogen Sum	10 ppm nitrogen 65-70°F.	10 ppm nitrogen 55-60°F.	10 ppm nitrogen Sum	Sum 65-70°F.	Sum 55-60°F.	Sum Total	Mean	L.S.D. 5% level	Coefficient of variability
Mar. 19, '51	16-hour	0.69	0.30	0.99	0.60	0.24	0.84	1.90	0.54	1.83	0.46		
	8-hour	0.42	0.23	0.65	0.48	0.22	0.70	0.90	0.55	1.45	0.36		
	Sum	1.11	0.53	1.64	1.08	0.46	1.54	2.19	1.09	3.28			
	Mean			0.41			0.39	0.55	0.27		0.41		
Apr. 4, '51	16-hour	5.20	1.67	6.87	2.65	1.10	3.75	7.85	2.77	10.62	2.86		
	8-hour	2.78	1.26	4.04	1.75	1.07	2.82	4.53	2.33	6.86	1.72		
	Sum	7.98	2.93	10.91	4.40	2.17	6.57	12.38	5.10	17.48			
	Mean			2.73			1.64	3.10	1.28		2.19	0.37	45.95
Apr. 10, '51	16-hour	13.10	5.16	18.26	4.22	1.85	6.07	17.32	7.01	24.33	6.08		
	8-hour	7.13	3.15	10.28	3.30	2.08	5.38	10.43	5.23	15.66	3.92		
	Sum	20.23	8.31	28.54	7.52	3.93	11.45	27.75	12.24	39.99			
	Mean			7.14			2.86	6.94	4.06		5.00	0.66	41.03
Apr. 28, '51	16-hour	66.3	36.3	102.6	9.3	8.4	17.7	75.6	44.7	120.3	30.1		
	8-hour	36.5	29.5	66.0	7.4	7.9	15.3	43.9	37.4	81.3	20.3		
	Sum	102.8	65.8	168.6	16.6	16.3	33.0	119.5	82.1	201.6			
	Mean			42.1			8.3	29.9	20.5		25.2	3.94	35.16
May 20, '51	16-hour	256.7	204.1	461.1	36.1	42.1	78.2	292.8	246.5	539.3	134.8		
	8-hour	176.3	126.8	303.1	28.8	34.3	63.1	205.1	161.1	266.2	91.6		
	Sum	433.0	331.2	764.2	64.9	76.4	141.3	497.9	407.6	905.5			
	Mean			191.1			35.3	124.5	101.9		113.2	12.0	22.74

Table 15. Experiment V, Greenhouse. Length of stem of cauliflower plants at successive dates of harvest for the different factorial combinations in the nitrogen nutrition (2) x photoperiod (2) x temperature experiment, (sand culture in the greenhouse, planted February 17, 1951).

Date of harvest	Photo-period	Nutrition and temperature: 112 p.p.m. nitrogen: 65-70°F.	112 p.p.m. nitrogen: 55-60°F.	112 p.p.m. nitrogen: Sum	10 p.p.m. nitrogen: 65-70°F.	10 p.p.m. nitrogen: 55-60°F.	10 p.p.m. nitrogen: Sum	Sum 65-70°F.	Sum 55-60°F.	Sum Total	Mean	L.S.D. 5% level	Coefficient of variability
April 1	16-hour	6.72	2.80	9.52	4.18	2.11	6.29	10.90	4.91	15.81	4.95		
	8-hour	2.76	1.34	4.01	1.97	1.08	3.05	4.64	2.42	7.06	1.77		
	Sum	9.39	4.14	13.53	6.15	3.19	9.34	15.54	7.33	22.87			
	Mean			3.38			2.34	3.89	1.83		2.86	0.15	17.54
April 10	16-hour	10.91	5.10	16.01	5.60	3.18	8.78	16.51	8.28	24.79	6.20		
	8-hour	4.97	2.46	7.43	2.82	1.84	4.66	7.79	4.30	12.09	3.02		
	Sum	15.88	7.56	23.44	8.42	5.02	13.44	24.30	12.58	36.88			
	Mean			5.86			3.36	6.08	3.15		4.61	0.20	13.48
April 28	16-hour	19.87	12.03	31.90	8.04	5.86	13.90	27.91	17.89	45.80	11.45		
	8-hour	10.44	7.26	17.70	4.71	3.43	8.14	15.15	10.69	25.84	6.46		
	Sum	30.31	19.29	49.60	12.75	9.29	22.04	43.06	28.58	71.64			
	Mean			12.40			5.60	10.77	7.15		8.96	0.49	12.28
May 5	16-hour	33.49	25.30	58.79	12.99	13.44	26.43	46.48	38.74	85.22	21.31		
	8-hour	18.42	14.48	32.90	7.75	7.72	15.47	26.17	22.20	48.37	12.09		
	Sum	51.91	39.78	91.69	20.74	21.16	41.90	72.65	60.94	133.59			
	Mean			22.92			10.48	18.16	15.24		16.70	0.69	9.16

Table 16. Experiment V, Greenhouse. Number of nodes of cauliflower plants at successive dates of harvest for the different factorial combinations in the nitrogen nutrition (2) x photoperiod (2) x temperature experiment, (sand culture in the greenhouse, planted February 17, 1951).

Date of harvest	Photo-period	Nutrition and temperature: 112 ppm nitrogen			Nutrition and temperature: 10 ppm nitrogen			Sum	Sum	Sum	Mean	L.S.D. 5% level	Coefficient of variability
		65-70°F.	55-60°F.	Sum	65-70°F.	55-60°F.	Sum	65-70°F.	55-60°F.	Total			
Mar. 19, '51	16-hour	9.1	7.8	16.9	9.1	7.6	16.7	18.2	15.4	33.6	8.4		
	8-hour	8.5	7.8	16.3	8.3	7.6	15.9	16.8	15.4	32.2	8.1		
	Sum	17.6	15.6	33.2	17.4	15.2	32.6	35.0	30.8	65.8			
	Mean			8.3			8.2	8.8	7.7		8.2	0.2	6.59
Apr. 1, '51	16-hour	14.3	11.2	25.5	14.4	11.1	25.5	28.7	22.3	51.0	12.8		
	8-hour	12.8	11.1	23.9	13.3	11.0	24.3	26.1	22.1	48.2	12.1		
	Sum	27.1	22.3	49.4	27.7	22.1	49.8	54.8	44.4	99.2			
	Mean			12.4			12.5	13.7	11.1		12.4	0.3	7.74
Apr. 10, '51	16-hour	20.6	14.8	35.4	16.8	13.4	30.2	37.4	28.2	65.6	16.4		
	8-hour	16.4	14.0	30.4	16.3	14.2	30.5	32.7	28.2	60.9	15.2		
	Sum	37.0	28.8	65.8	33.1	27.6	60.7	70.1	56.4	126.5			
	Mean			16.5			15.2	17.5	14.1		15.8	0.5	10.51
Apr. 28, '51	16-hour	43.5	28.9	72.4	25.5	23.6	49.1	69.0	52.5	121.5	30.4		
	8-hour	30.8	27.5	58.3	23.2	24.5	47.7	54.0	52.0	106.0	26.5		
	Sum	74.3	56.4	130.7	48.7	48.1	96.8	123.0	104.5	227.5			
	Mean			32.7			24.2	30.8	26.1		28.4	1.9	14.74
May 29, '51	16-hour	54.1	30.8	84.9	47.9	40.6	88.5	102.0	71.4	173.4	43.4		
	8-hour	54.8	40.6	95.4	40.6	43.5	84.1	95.4	84.1	179.5	44.9		
	Sum	108.9	71.4	180.3	88.5	84.1	172.6	197.4	155.5	352.9			
	Mean			45.1			43.2	49.4	38.9		44.1	3.0	15.19

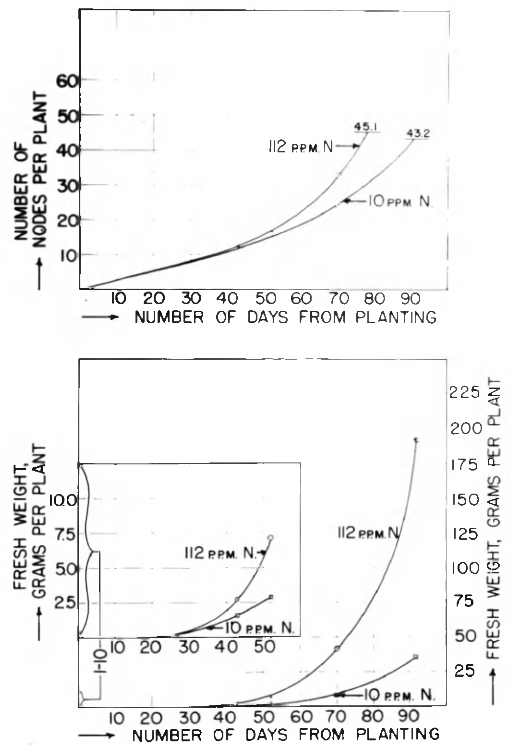


Figure 23. Experiment V, Greenhouse. Growth curves (fresh weight) rate of initiation of nodes and mean number of nodes initiated before initiation of inflorescence primordia in the cauliflower variety The Forbes under two levels of nitrogen nutrition. (Seed planted 2/17/51).

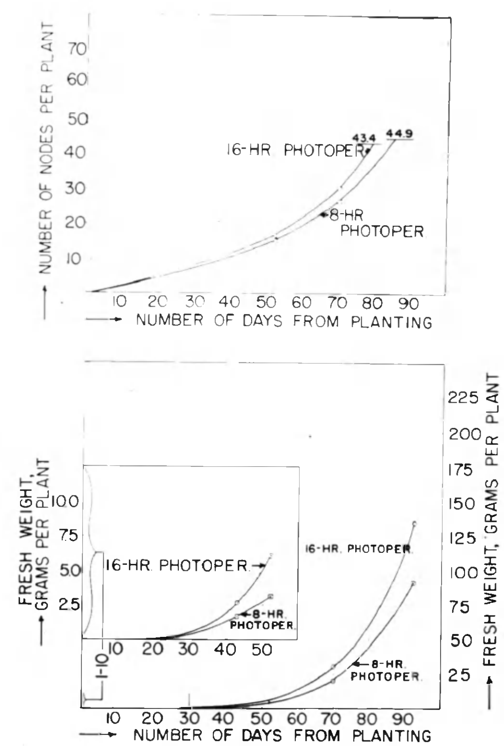


Figure 24. Experiment V, Greenhouse. Growth curves (fresh weight) rate of initiation of nodes and mean number of nodes initiated before initiation of inflorescence primordia in the cauliflower variety The Forbes under 16-hour photoperiod and 8-hour photoperiod. (Seed planted 2/17/51).

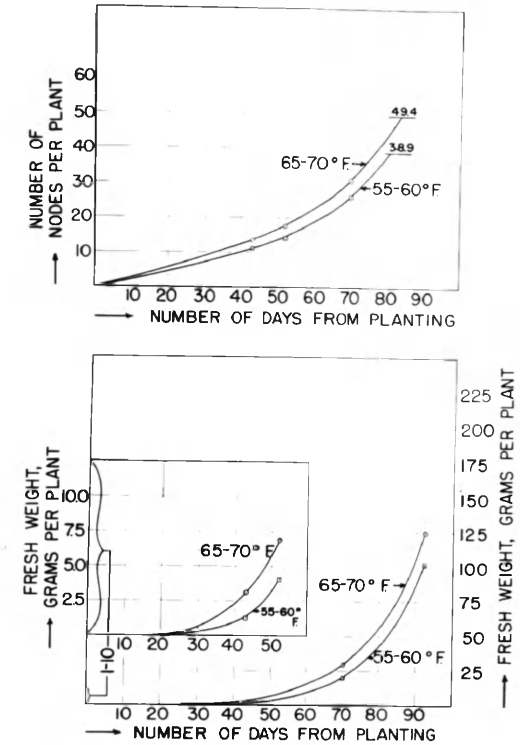


Figure 25. Experiment V, Greenhouse. Growth curves (fresh weight) rate of initiation of nodes and mean number of nodes initiated before initiation of inflorescence primordia in the cauliflower variety The Forbes under 65-70° and 55-60°F. night temperature. (Seed planted 2/17/51).

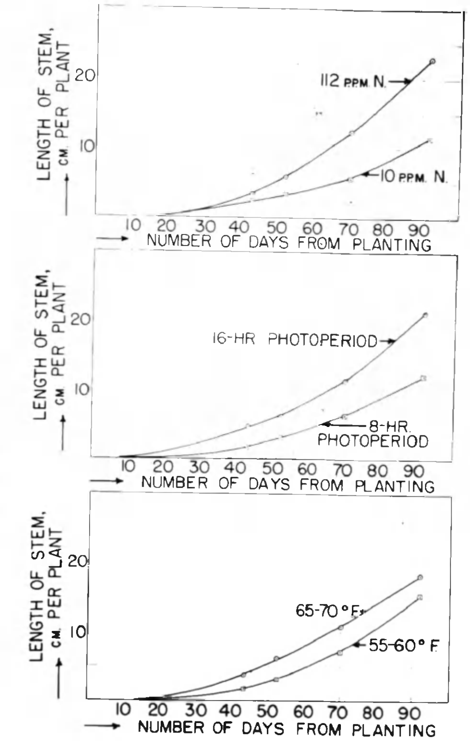


Figure 26. Experiment V, Greenhouse. Growth curves (length of stem) for the nitrogen nutrition, photoperiod and temperature experiments. (Seed planted 2/17/51).

Figure 27. Experiment V, Greenhouse.
Representative from nitrogen x temperature x photoperiod experiment, with cauliflower variety The Forbes planted 2/17/51.

Figure 28. Experiment V, Greenhouse.
Representative from nitrogen x temperature x photoperiod experiment with cauliflower variety The Forbes planted 2/17/51, picture taken 5/19/51.

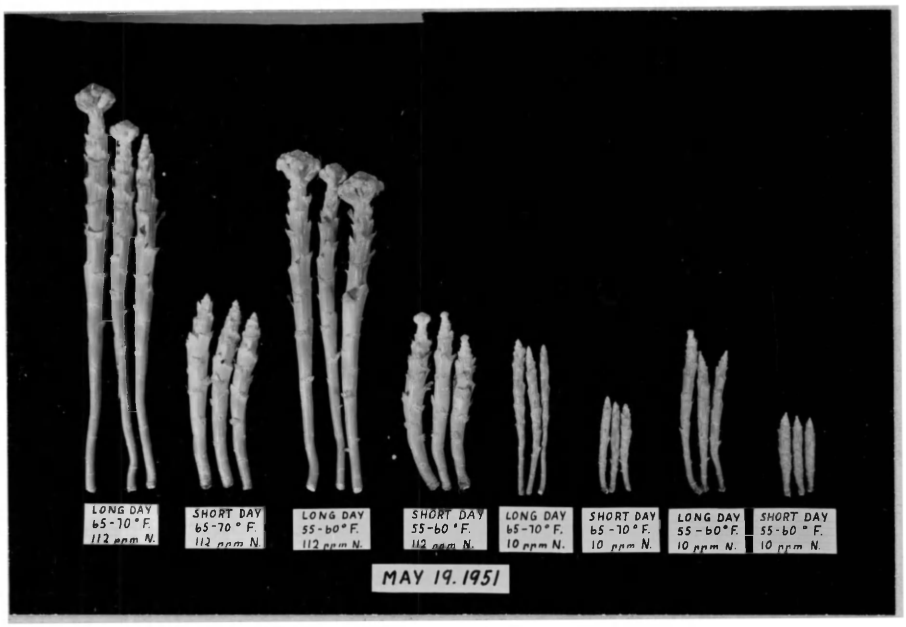


Figure 29. Experiment V, Greenhouse. Length of stem of plants from nitrogen x photoperiod x temperature experiment, with cauliflower variety The Forbes planted 2/17/51.

SECTION VI

A STUDY OF THE EFFECTS OF ENVIRONMENT ON GROWTH AND DEVELOPMENT IN CAULIFLOWER, (C) STUDIES IN CONTROLLED ENVIRONMENT IN CABINETS

Introduction

The importance of temperature for premature heading in cauliflower was clearly demonstrated in Section V where night temperatures were controlled by thermostats while the day temperatures were manually controlled and varied considerably with the outside weather conditions. This, plus the limited range of available temperature levels, excluded the possibility of finding the quantitative relationship of temperature to growth and development in cauliflower by studies in the greenhouse. Such information was desirable and a study was undertaken in controlled environments in cabinets under artificial light of sufficiently high intensity and of the right quality to give normal rates of growth and development.

Review of Literature

Increased temperatures (55-60° F.) were reported in Section V to increase the number of nodes initiated before initiation of the inflorescence primordia in cauliflower. Only one reference to temperature in relation to cauliflower production has been found. Wood and James (62) studied cauliflower production in the tropics and reported that the mean maximum temperatures for the months of October through April ranged from 83.1 to 87.0 °F., while the mean minimum temperatures for the same months ranged from 66.3° to 71.7° F. Only cauliflower varieties from India headed under those environmental conditions.

Miller (39A) reported a study of seed stalk development in cabbage. Cabbage plants were kept in the vegetative stage for two years by exposing the plants to 60-70 F. temperature in the greenhouse. The heads split, formed new leaves and headed repeatedly for eight times in succession during those two years. Plants exposed to 50-60 F. temperature in the green--house initiated inflorescences after several months. The initiation was greatly accelerated by 60 days exposure to cold storage.

Bremer (6, 7 and 8) studied the growth and development of radish, carrot and lettuce under controlled temperatures in hotbeds. Samplings were made at successive dates of harvest and rates of growth were illustrated graphically. He found that the day-neutral head lettuce variety Tom Thumb did not head at constant temperatures above 18°C, nor did it head if the mean daily temperature exceeded 18°C.

Gergory and Purvis (18, 19, 20) studied the effects of vernalization on leaf number in rye and found that all rye varieties developed 7 leaves before initiation of infloresence primordia. The following 18 nodes were indeterminate and could develop either leaves or bracts, with primordia of apkielets, depending on the environment. All of these 18 nodes developed leaves in unvernalised winter rye, while completely vernalized winter rye developed only 7 leaves and appeared like spring rye. Winter rye was completely vernalized after 14 weeks exposure to cold treatment. Rye could be partly vernalized by photoperiodism and leaf number could be reduced to 16 by photoperiodic vernalization.

Response of onions in bulbing, initiation of inflorescence and to seed stalk development as a result of nitrogen nutrition, photoperiod and temperature, has been reported by several authors. Allard and Garner (1)

Scully et al (51), McClelland (37), Thompson et al (56), Heath (25, 26) found that high temperatures prevented bolting and promoted bulbing in all stages of development. Thus high temperature the first season caused the sets to develop only a few leaves and to form bulbs very early. No inflorescence primordia were initiated the following winter. If larger sets capable of initiation of inflorescence primordia were subjected to high temperature during the early part of the storage, no inflorescence primordia were formed in them. Sets grown under conditions of high temperature the second season did not bolt, but formed bulbs again. He also found that the temperature effect on bulbing and seed-stalk development was modified by daylength. Short photoperiod inhibited bulbing completely, but it allowed for bolting if the temperature was not too high.

Heath and Matur (27) also studied leaf development in onion. They found three different kinds of leaves; ordinary leaves, thickened scales and non thickened scales. The number of ordinary leaves varied, but the number of scales stayed fairly constant. The onion sets had three thickened scales and 7 non thickened scales. They state that there appears to be a minimum total number of leaves (leaves plus scales) which must be initiated before inflorescence primordia can be formed.

The relation of temperature to plant growth and development in vegetable crops has been summarized by Thompson (55). This resume shows that most work has been done on the effects of low temperature on bolting or premature seedstalk development. Low temperature is the main factor in inducing inflorescence primordia and further development is influenced by both length of day and temperature. Short photoperiod often causes inflorescence primordia to stay dormant or die. In such cases the plants are converted over from the reproductive to the vegetative phase. High temperature on the other hand prevents initiation of the inflorescence primordia.

Materials and Methods

Description of the controlled environment room. The controlled environment studies were carried out in a cold storage room at the University of Maryland, Department of Horticulture. The size of the cold storage room was 6' x 12'. The room was equipped with refrigeration machinery of high capacity. Four growth chambers with glass tops were constructed. A panel of lamps hanging from the ceiling and extending beyond the cabinets provided artificial light. This panel (Figure 1) was provided by the Division of Photoperiod at the U.S.D.A., Plant Industry Station, Beltsville, Maryland. It consisted of 18 General Electric 96" Standard Cool White Slimline fluorescent tubes (formerly called 4500 White) with the 2" lampholders spaced as close as possible. On both sides of the fluorescent tubes there was one row of seven 100-watt inside-frosted incandescent-filament lamps. The nine 220-volt ballasts were placed on a frame outside the cold storage room. One row of incandescent lamps was connected to each of the hot lines of the 220-volt fluorescent circuit so that the entire light panel was balanced. A 220-volt time switch was included in the circuit. The switch turned the light on and off automatically as desired.

The cabinets were made of 1/2" plywood and displayed the following features (Figure 1).

(1) Four growth chambers with inside measurements 19x41x29 inches, and with a glass top.

(2) False floors over an air heating and distribution chamber, inside measurements 19x41x15 inches.

(3) Two 150-watt heating elements placed above adjustable slits over 8x8 inches square cold air ducts running under the air distribution chambers.

(4) Fans for air circulation in the ducts and cabinets.

(5) Bimetal thermostats in the doors of the cabinets which controlled the temperature through relay switches placed on the end elevation of the cabinets.

(6) Ten glazed earthenware crocks as described in Section V.

(7) Copper-constantan thermocouples for continuous recording of temperatures. The thermocouples were tied to a small stake in three of the crocks of each growth chamber and located at a level just over the top of the plants. They were rotated systematically within the cabinets with the plants.

(8) The distance from the light panel to the glass top was eight inches, while the distance from the light panel to the top of the crocks was 29 inches.

The temperatures of Series I were measured with a potentiometer and copper-constantan thermocouples using melting ice as reference. The temperatures of Series II were continually recorded by Minneapolis Honeywell, Brown Instrument Division, continuous temperature recorder using iron-constantan thermocouples. The temperatures show a slight downward trend in the Series III experiments. It is possible that this represents a bias which entered the experiments by the exhaustion of the battery of the temperature recorder.

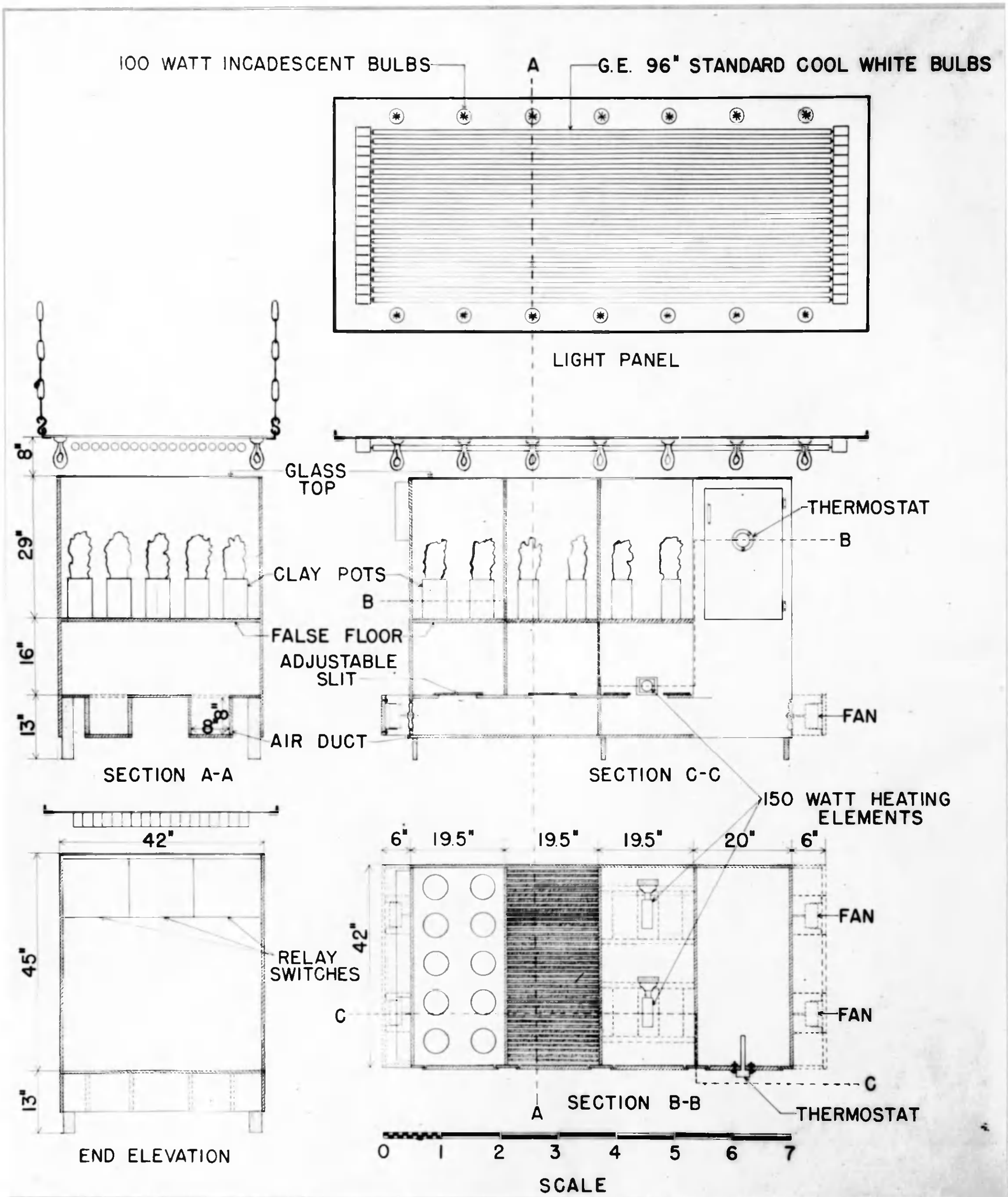


Figure 1. Illustration of the constructions made in the cold storage room which consisted of a light panel and four temperature-controlled growth cabinets.

<u>Tests of the cabinets.</u> The intensity and the quality distribution of the light in the temperature controlled cabinets are shown in Table 1. The light intensity was measured with a Weston light meter which gives the intensity of the light in foot-candles. Borthwick and Parker[1] found that excellent growth could be obtained with General Electric 96" Standard Cool White Slimline fluorescent light (formerly called 4500 White) if 10% incandescent light was added. It is apparent that the intensity and quality distribution of the light was not perfect, but it would have been very difficult to improve the situation hence variation within the cabinets was eliminated by systematic movement of the plants.

Keeping the temperatures constant during the photoperiod and the dark cycle proved to be extremely difficult and was not fully accomplished. The difficulties were caused by the more than four kilowatts of light radiation during the photoperiod of which a large part entered the cabinets. The excess radiated heat had to be disposed of by air circulating fans. The variation encountered during the three series of temperature experiments are summarized in Table 2. It is apparent that the temperature of the photoperiod was higher than the dark period for the 45°F. cabinets while the temperature of the dark period exceeded the light period in the 75 F. cabinet. Best control was obtained in the 55° and 65°F. cabinets.

<u>Design and general description of experiments.</u> All three series of experiments in the cabinets were carried on in sand culture using the same glazed earthenware crocks and the same method of planting as described elsewhere.[2]

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[1] Personal communication.

[2] Section V.

Table 1. Intensity and quality distribution of light in temperature controlled cabinets. Measurement taken on the top of the crocks at the 9 locations in each cabinet indicated by the recorded figures.

Type of light	45°F. cabinet			65°F. cabinet			75°F. cabinet			55°F. cabinet		
Incandescent	140	145	136	150	156	158	160	159	152	134	147	156
Inflorescent	1190	1200	1120	1260	1290	1250	1300	1340	1300	1160	1210	1200
Incandescent + inflorescent	1310	1330	1260	1410	1470	1410	1420	1490	1430	1310	1390	1380
Incandescent	135	132	128	139	142	142	145	143	140	131	136	137
Inflorescent	1290	1310	1230	1380	1420	1380	1420	1480	1420	1290	1370	1340
Incandescent + inflorescent	1400	1420	1350	1510	1580	1510	1560	1610	1560	1420	1520	1490
Incandescent	145	143	138	143	147	148	151	145	145	132	142	141
Inflorescent	1170	1180	1100	1210	1200	1210	1280	1260	1260	1120	1180	1190
Incandescent + inflorescent	1300	1310	1250	1350	1350	1350	1410	1400	1410	1280	1310	1320
Incandescent, mean		136			147			149			139	
Inflorescent, mean		1139			1289			1340			1229	
Incand. + inflores., mean		1335			1438			1477			1380	
Per cent incandescent		10.2			10.2			10.0			10.1	

Table 2. Mean temperatures for the photoperiod, the dark period and for the 24-hour cycle and the respective standard deviation of the means for the three series of experiments in the controlled environments in the cabinets.

Series & cabinets	Photoperiod		Dark period		Photoperiod + dark period	
	Mean ° F.	$S\bar{X}$	Mean ° F.	$S\bar{X}$	Mean ° F.	$S\bar{X}$
Series I. 16-hr. photoperiod, 8-hr. dark period*						
75° F. cabinet	74.2	± 0.43	74.7	± 0.57	74.4	± 0.51
65° F. cabinet	65.1	± 0.46	65.2	± 0.38	65.1	± 0.42
55° F. cabinet	55.4	± 0.35	54.7	± 0.40	55.2	± 0.38
45° F. cabinet	49.7	± 0.54	46.0	± 0.86	48.5	± 0.70
Series II. 16-hr. photoperiod, 8-hr. dark period						
75° F. cabinet	75.8	± 0.35	78.0	± 0.33	76.5	± 0.34
65° F. cabinet	69.9	± 0.12	69.8	± 0.26	69.9	± 0.19
55° F. cabinet	56.8	± 0.23	56.7	± 0.25	56.8	± 0.24
45° F. cabinet	51.2	± 0.17	46.3	± 0.06	49.6	± 0.14
Series III. 12-hr. photoperiod, 8-hr. dark period						
75° F. cabinet	69.6	± 0.41	73.1	± 0.26	71.4	± 0.35
65° F. cabinet	67.1	± 0.15	69.5	± 0.22	68.3	± 0.20
55° F. cabinet	55.2	± 0.20	55.2	± 0.19	55.2	± 0.20
45° F. cabinet	48.9	± 0.16	41.4	± 0.13	45.2	± 0.15

*Gradual breakdown of the refrigeration occurred in this experiment. The temperature measurement includes the period up to this breakdown only.

Series 1 included one variable only, namely, the four temperature levels. Seed of the variety Snowball M was planted in the crocks in the greenhouse at the U.S.D.A., Plant Industry Station, Beltsville, Maryland on February 17, 1951. The germinated plants were thinned out to 8 plants to the crock and moved into the cabinets on March 6. They were exposed to a 16-hour photoperiod and an 8-hour dark period. Gradual breakdown of the refrigeration system started about the first of April. This impaired the results of the experiment.

The nutrient solution used was solution 1 of the nutrition experiments reported elsewhere.[1] Nutrient deficiency symptoms which appeared in the later stages of growth in the greenhouse experiments were exagerated in the 65° and 75°F. cabinet.

The plan for the experiment called for a study of fresh weight, length of stem, and number of nodes initiated at successive dates of harvest. However, the relatively high intensity of florescent light shortened the internodes so much that measurements of stem length were omitted.

Series 11 included three levels of potassium nutrition and three levels of magnesium nutrition, superimposed on the four temperature levels. The nutrient level of the other elements was the same as in solution 1, except for the chlorine anion which accompanied the potassium salt, and the increase in sulphate ion concentration which accimpanied the magnesium salt. An increase in the potassium concentration to 160 p.p.m. cured the deficiency symptoms, while the magnesium did not have any effect. The data for the superimposed nutrition experiment were not given since they were

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[1]See Section V.

of minor importance and only 2 replicates were used in each cabinet.

The cauliflower variety The Forbes was used in Series II. The seed was sown in the crocks in the greenhouse on May 3, 1951 and thinned and moved into the cabinets on May 12. The plants were exposed to 16-hour photoperiods and 8-hour dark periods. The refrigeration system and the temperature recorder functioned satisfactorily throughout the experiment.

Series III included, besides the four regular temperature treatments, alternative photoperiod and dark period temperatures for the 55° and 75° F. treatments. This was accomplished by exchanging 5 crocks in the 55° and 75° F. cabinets at 8 A.M. and 8 P.M. daily. The photoperiod and the light period were changed to 12 hours each for this reason. The cauliflower variety The Forbes was used. Seed was planted in crocks in the greenhouse on December 6. The nutrient solution was solution 1 except that the potassium level was raised to 160 p.p.m. The refrigeration system and the temperature recorder functioned satisfactorily. The experiment had to be terminated before initiation of the inflorescence in the 45° F. cabinets.

The statistics computed for the successive dates of harvest include mean fresh weights and mean number of nodes per plant. Standard deviations of the means, standard deviations of the means times the t at the 0.05% level, and the coefficient of variability were also calculated. These statistics rather than analysis of variance were used in order to facilitate the evaluation of the particular curves.

The curves showing rates of initiation of nodes were drawn through points of mean number of nodes initiated at successive dates of harvest in the respective cabinets. Number of days until initiation of the inflorescence were found by extrapolating the curves for rates of initiation beyond the last date of harvest before the initiation of the inflorescence primordia to the mean number of nodes initiated before initiation of the inflorescence in the various cabinets.

The growth curves (fresh weight) were drawn through points of mean yield at the successive dates of harvest in the respective cabinets.

Results

<u>Series I, cabinets.</u> Increased rate of initiation of nodes with increased temperature up to 65.1° F. was demonstrated in the controlled environment studies. A further increase in rate of initiation with a raise in temperature to 74.4° F. was found during the early phases of growth but were later surpassed by the plants exposed to 65.1° F. (Table 3, Figure 2).

Inflorescence primordia were not initiated in the plants exposed to 74.4° F. at the time of termination of the experiment, although the mean number of nodes initiated exceeded those of the other treatments. (Table 3, Figure 2). Initiation of the inflorescence primordia in the plants exposed to 65.1°, 55.2° and 48.5° F. occurred after 42, 46 and 52 days when the mean number of nodes were 59.4, 45.4 and 37.7 respectively.

Great increases in fresh weight were found with increases in temperatures up to 65.1° F. while the fresh weight growth curves for 74.4° and 65.1° F. crossed around 40 days after start of temperature treatment. Representative plants from the four temperature treatments at three dates of harvest are shown in Figure 4.

The results of series I are not indicative of the quantitative effects of temperature since a gradual breakdown of the refrigeration system started late in April.

<u>Series II, cabinets.</u> The effects of the temperatures on initiation of nodes in the second series of temperature experiments were increased

Table 3. Series I, Cabinets. Fresh weight and number of nodes initiated in cauliflower plants under four different temperatures in controlled conditions in cabinets at successive dates of harvest, (sand culture, planted February 17, 1951).

Date of harvest	N[1]	Number of nodes: $\bar{x}$[2]	$s\bar{x}$[3]	$s\bar{x}t$[4]	C.V.[5]	Fresh weight per plant: $\bar{x}$	$s\bar{x}$	$s\bar{x}t$	C.V.
48.5 ± 0.7° F. Cabinet									
March 6, '51	20	5.0				0.06			
" 12, '51	10	5.7	0.15	0.3	8.42	0.13			
" 16, '51	23	6.4	0.10	0.2	7.81	0.15			
" 23, '51	20	7.1	0.05	0.1	3.38	0.30			
" 30, '51	10	8.8	0.20	0.5	7.16	0.59	0.04		20.33
April 8, '51	8	11.4	0.26	0.6	6.49	1.45	0.11	0.26	21.37
" 15, '51	10	16.6	0.34	0.8	6.51	4.68	0.29	0.66	19.66
" 28, '51	10	37.7	1.27	2.9	10.61	34.75	2.39	5.41	21.75
55.2 ± 0.4° F. Cabinet									
March 6, '51	20	5.0				0.06			
" 12, '51	10	6.3	0.15	0.3	7.62	0.15			
" 16, '51	20	7.3	0.11	0.2	6.44	0.29			
" 23, '51	19	8.8	0.15	0.3	6.14	0.73			
" 30, '51	10	11.5	0.17	0.4	4.61	2.22	0.10	0.23	14.4
April 8, '51	8	18.9	0.69	1.6	8.89	6.68	0.80	1.89	33.23
" 15, '51	10	30.0	1.56	3.5	16.47	19.11	1.69	3.84	27.84
" 28, '51	10	46.6	1.63	3.7	11.09	81.21	1.71	3.87	22.28
65.1 ± 0.4° F. Cabinet									
March 6, '51	20	5.0				0.06			
" 12, '51	10	6.9	0.10	0.2	4.35	0.22			
" 16, '51	20	8.3	0.11	0.2	5.66	0.41			
" 23, '51	20	11.3	0.22	0.5	8.67	1.87			
" 30, '51	20	17.3	0.28	0.6	7.28	6.19	0.35	0.73	25.36
April 8, '51	8	34.3	1.70	4.0	12.83	22.40	2.41	5.70	30.40
" 15, '51	5	47.0	1.98	5.5	9.40	60.30	5.03	13.96	18.67
" 28, '51	5	59.4	6.15	17.1	22.02	181.80	12.8	35.53	15.79
74.4 ± 0.5° F. Cabinet									
March 6, '51	20	5.0				0.06			
" 12, '51	10	7.7	0.15	0.3	6.23	0.31			
" 16, '51	20	9.3	0.11	0.2	5.05	0.63			
" 23, '51	20	13.9	0.26	0.5	8.42	3.26			
" 30, '51	20	21.6	0.65	1.4	13.47	9.82	0.71	1.49	32.18
April 8, '51	8	32.9	0.90	2.1	7.69	28.60	1.91	4.62	18.88
" 15, '51	5	43.4	1.40	3.9	7.21	58.14	2.56	7.11	9.85
" 28, '51	5	63.0	2.68	7.4	9.52	159.00	3.63	10.08	5.83

1 Number of plants harvested.
2 Mean.
3 Standard deviation of the mean.
4 Standard deviation of the mean x t 0.05.
5 Coefficient of variability.

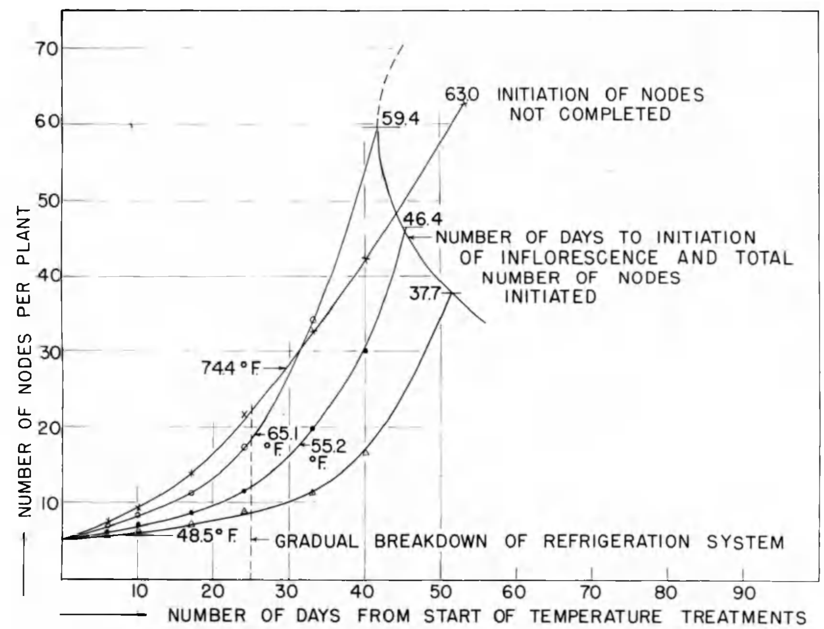

Figure 2. Series I cabinets. Rate of initiation of nodes and total number of nodes initiated before initiation of inflorescence primordia in the cauliflower variety Snowball M raised at four temperature levels in controlled environment in cabinets.

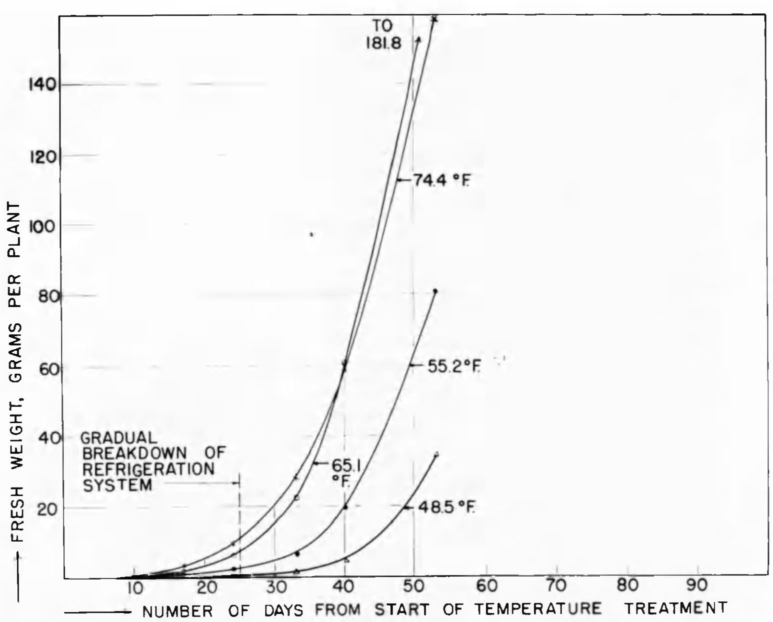

Figure 3. Series I cabinets. Growth curves (fresh weight) for cauliflower variety Snowball M raised at four temperature levels in controlled environemtn in cabinets.

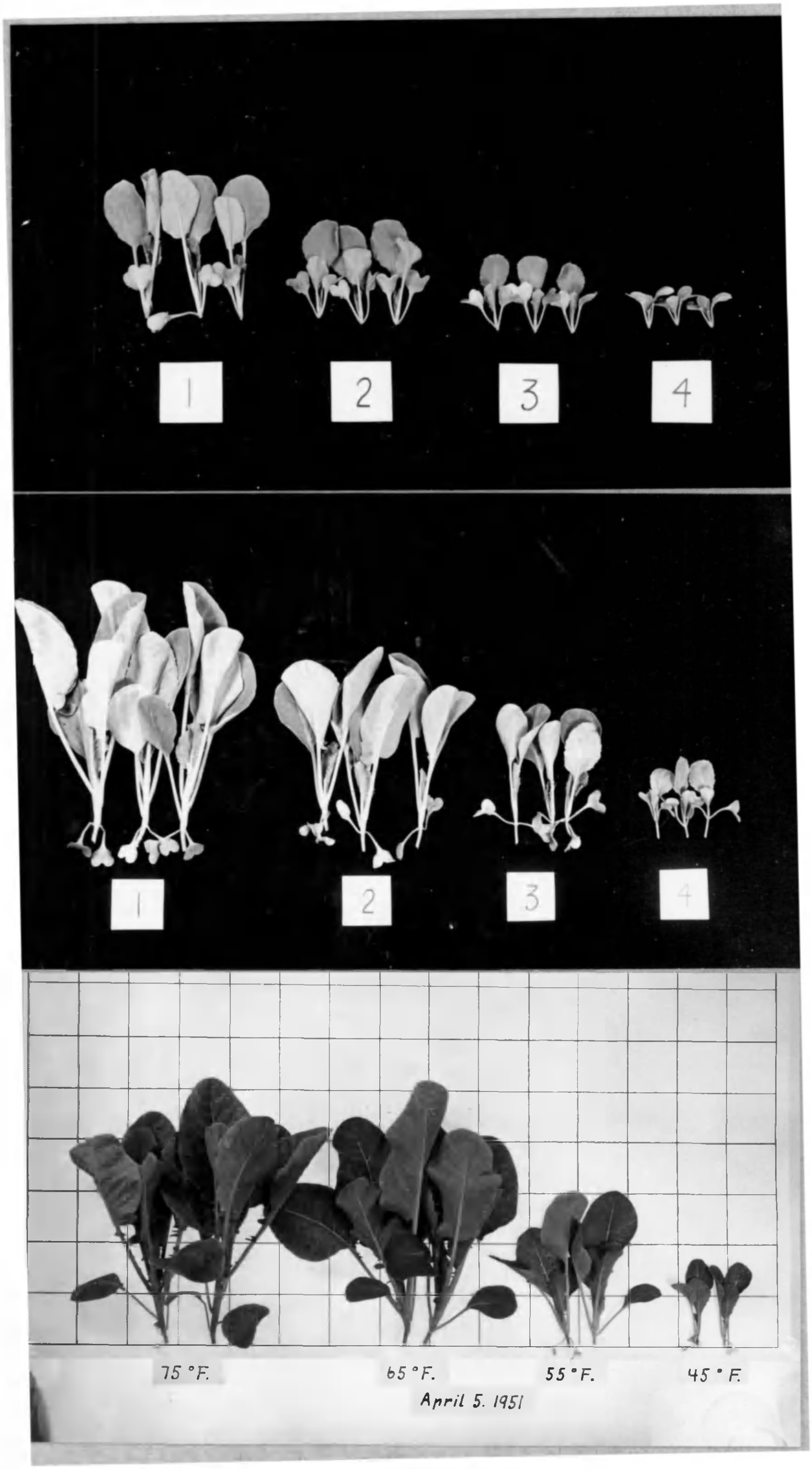

Figure 4. Series I cabinets. Representative plants from controlled environment studies in cabinets. Upper series were harvested March 12, middle series March 23 and lower series April 5. Plants labeled A were raised in 74.4° F, B in 65.1° F., C in 55.2° F., and D in 48.5° F. cabinets.

rate up to 69.9° F., while the rate of initiation in plants exposed to 76.5° F. was surpassed during later phases of growth by the plants given 69.9° F. (Table 4, Figure 5). Initiation of the inflorescence did not take place in the plants exposed to 76.5° F., although the mean number of nodes per plant at the time of termination of the experiment was as high as 67.3. Initiation occurred in the 69.9°, 56.8° and 49.8° F. cabinets after 41, 52 and 87 days when their mean number of nodes were 40.4, 22.4 and 20.1 respectively.

Increases in fresh weight were encountered up to 69.9° F., while a further increase in the temperature rather decreased than increased the yield (Table 4, Figure 6).

Series III cabinets. Rates of initiation for comparable temperatures were lower in the series III experiment than in the former. This may be the result of shortening the photoperiod from 16-hour to 12-hour, which reduced the light energy available for photosynthesis by 1/4. The general trend in rate of initiation of nodes for the different constant temperature levels was similar in series II and III, with rate of initiation at the two upper temperature levels crossing in both series (Table 5, Figure 7).

The highest temperature of this series was decreased to 71.4° F. and differentiation of the inflorescence occurred at this temperature. The number of days until initiation of the inflorescence in the 71.4°, 68.3° and 56.8° F. cabinets were 57, 53 and 58 days when the plants had initiated 48.5, 45.2 and 26.3 nodes respectively. Plants of the 46.3° F. treatment did not reach the stage of initiation of the inflorescence before termination of the experiment.

Rates of initiation at the alternative day and night temperatures were intermediate between the two constant temperatures and differentiation of

Table 4. Series II Cabinets. Fresh weight and number of nodes initiated in cauliflower plants under four different temperatures in controlled conditions in cabinets at successive dates of harvest. (sand culture, planted May 3, 1951.

Date of harvest	N	Number of nodes $\bar{x}$	$s\bar{x}$	$s\bar{x}t$	C.V.	Fresh weight per plant $\bar{x}$	$s\bar{x}$	$s\bar{x}t$	C.V.
49.6 ± 0.1° F. Cabinet									
May 12, '51	98	4.2				0.021			
June 17, '51	40	8.2	0.06	0.1	4.39	0.196	0.011	0.02	35.50
July 15, '51	20	13.5	0.20	0.4	6.59	2.66	0.21	0.44	34.59
Aug. 8, '51	10	19.8	0.20	0.5	3.18	12.20	1.53	3.46	39.80
Aug. 18, '51	10	20.1	0.41	0.9	6.42				
56.8 ± 0.2° F. Cabinett									
May 12, '51	98	4.2				0.021			
June 5, '51	40	8.9	0.13	0.3	9.33	0.496	0.042	0.08	52.00
June 17, '51	20	13.2	0.22	0.5	7.65	2.33	0.21	0.44	40.34
July 15, '51	10	22.4	0.64	1.5	8.97	41.40	5.10	11.50	37.74
Aug. 18, '51	10	22.4	0.50	1.1	7.05	78.60	5.90	13.30	23.66
69.9 ± 0.2° F. Cabinet									
May 12, '51	98	4.2				0.021			
May 29, '51	41	9.3	0.13	0.3	8.71	0.702	0.05	0.10	45.59
June 5, '51	20	13.9	0.30	0.6	9.57	3.14	0.24	0.50	33.76
June 17, '51	10	29.7	1.60	3.6	17.04	18.80	1.84	4.16	31.01
July 15, '51	10	40.4	2.65	6.0	20.74	123.00	10.10	22.80	26.02
76.5 ± 0.3° F. Cabinet									
May 12, '51	98	4.2				0.021			
May 29, '51	39	10.1	0.20	0.4	12.08	0.976	0.023	0.05	46.39
June 5, '51	20	15.0	0.39	0.8	11.53	3.52	0.34	0.71	43.46
June 17, '51	10	26.6	1.23	2.8	14.62	18.50	2.20	4.98	37.57
July 15, '51	10	67.3	0.91	2.1	12.45	106.00	7.64	17.30	22.89

Table 5. Series III Cabinets. Fresh weight and number of nodes initiated in cauliflower plants under four different temperatures in controlled conditions in cabinets at successive dates of harvest. (sand culture, planted November 22, 1951).

Date of harvest	N	Number of nodes				Fresh weight per plant			
		$\bar{x}$	$s\bar{x}$	$s\bar{x}t$	C.V.	$\bar{x}$	$s\bar{x}$	$s\bar{x}t$	C.V.
45.2 ± 0.2° F. Cabinet									
Dec. 12, '51	20	5.9	0.10	0.2	7.63	0.10			
Jan. 1, '52	20	7.8	0.14	0.3	7.95	0.21			
Jan. 19, '52	20	9.2	0.17	0.4	8.04	0.43	0.04	0.08	37.20
Feb. 23, '52	10	13.1	0.20	0.5	5.34	3.29	0.23		32.31
55.2 ± 0.2° F. Cabinet									
Dec. 12, '51	20	6.5	0.11	0.2	7.85	0.13			
Jan. 1, '52	20	10.2	0.14	0.3	6.08	0.79	0.07	0.15	36.70
Jan. 19, '52	20	15.5	0.22	0.5	6.45	3.77	0.21	0.45	34.67
Feb. 23, '52	10	26.3	0.60	1.4	5.55	44.40	5.10		36.49
58.3 ± 0.2° F. Cabinet									
Dec. 12, '51	20	7.3	0.11	0.2	6.44	0.17			
Dec. 19, '51	20	9.1	0.18	0.3	9.12	0.44			
Jan. 1, '52	20	14.5	0.31	0.7	9.59	2.79	0.25	0.52	40.14
Jan. 19, '52	18	29.1	1.58	3.3	22.95	13.40	1.43	3.02	45.15
Feb. 23, '52	8	42.5	2.90	6.8	19.53	81.00	11.40		39.51
71.4 ± 0.4° F. Cabinet									
Dec. 12, '51	20	7.6	0.09	0.2	5.26	0.19			
Dec. 19, '51	20	9.6	0.14	0.3	6.25	0.53			
Jan. 1, '52	18	14.6	0.37	0.8	10.41	2.52	0.25	0.53	42.46
Jan. 19, '52	5	26.0	1.14	3.8	9.81	12.00	1.19	3.30	22.25
Feb. 23, '52	10	48.5	1.90	4.3	12.37	71.00	12.40		55.35

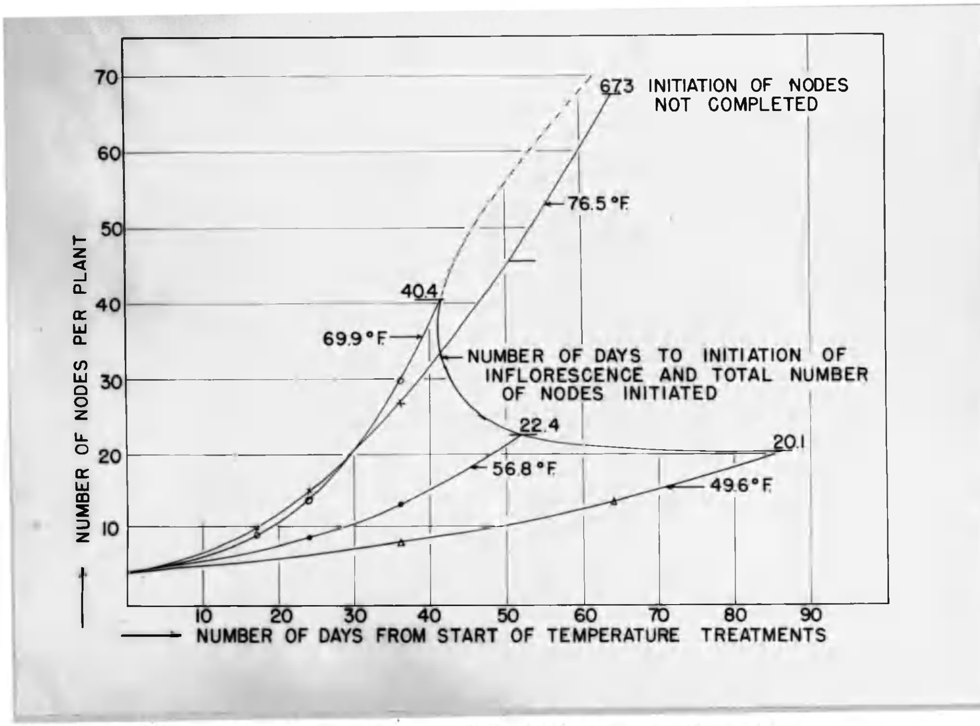

Figure 5. Series II cabinets. Rate of initiation of nodes and total number of nodes initiated before initiation of inflorescence primordia in cauliflower variety The Forbes raised at four temperature levels in controlled environment in cabinets.

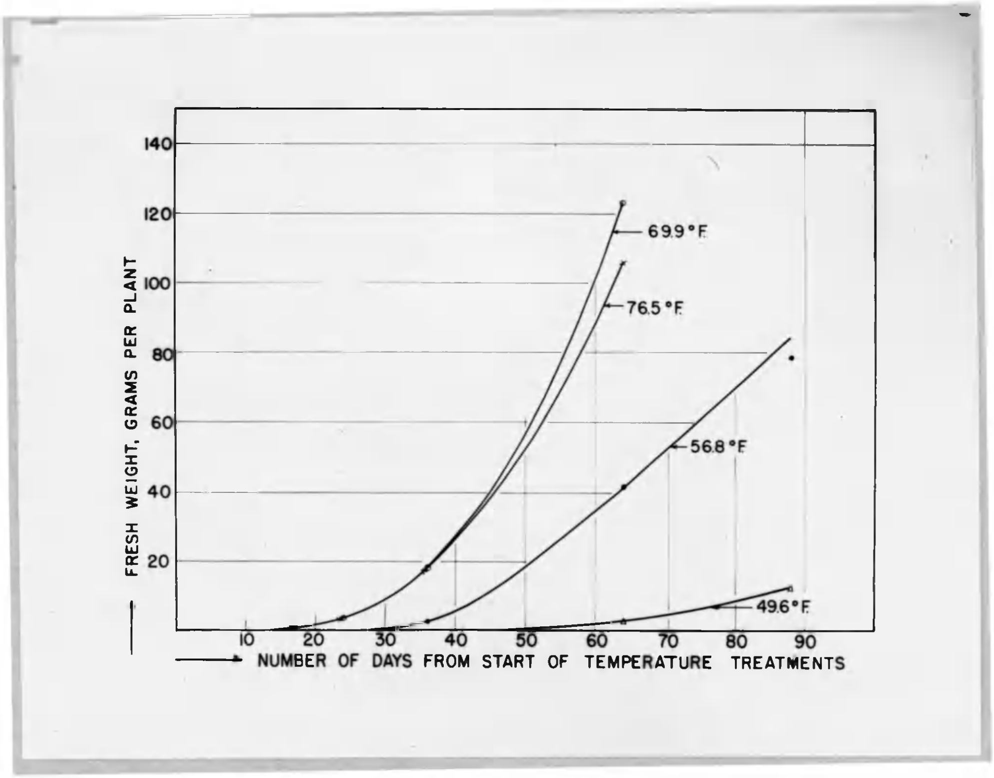

Figure 6. Series II cabinets. Growth curves (fresh weight) for cauliflower variety The Forbes raised at four temperature levels in controlled environment in cabinets.

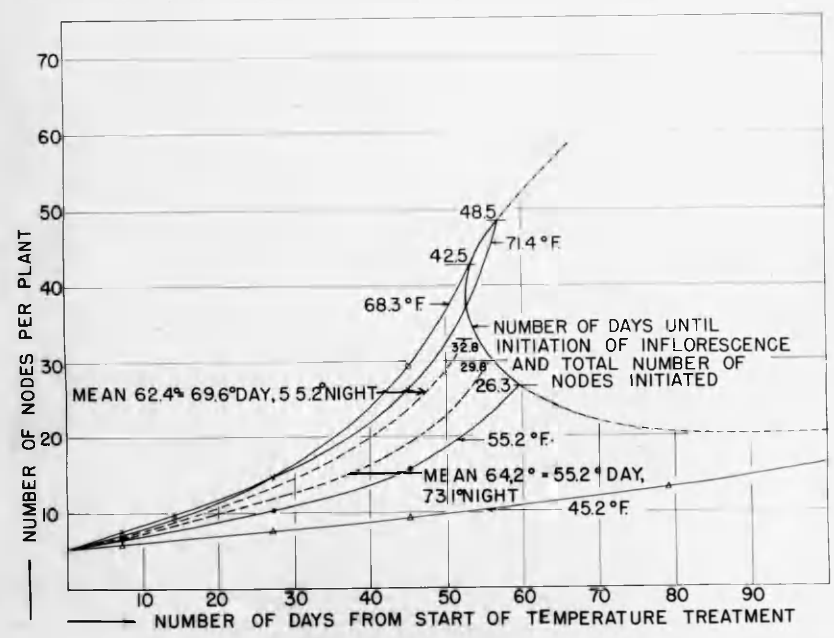

Figure 7. Series III cabinets. Rate of initiation of nodes and total number of nodes initiated before initiation of inflorescence primordia in cauliflower variety The Forbes raised at four temperature levels and also two alternative photoperiod and dark period temperatures in controlled environment in cabinets.

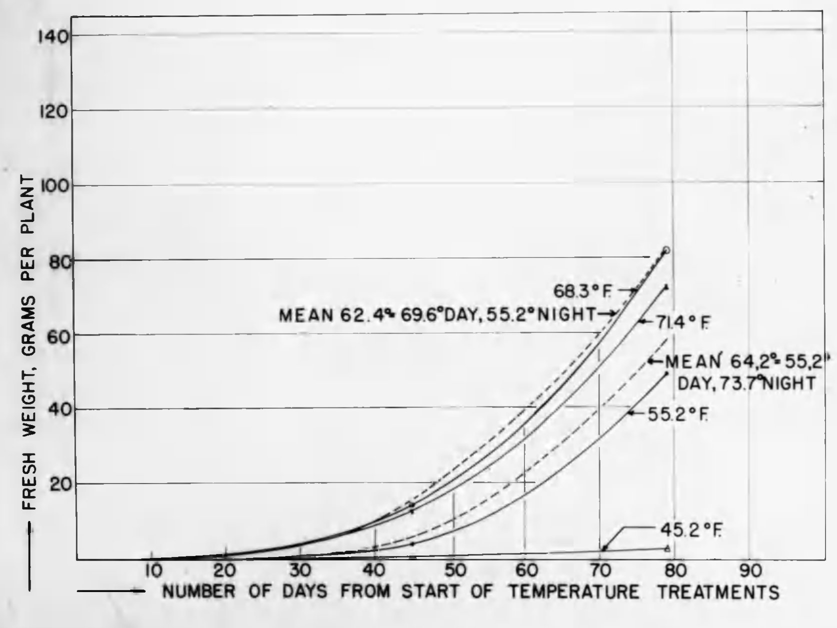

Figure 8. Series III cabinets. Growth curves (fresh weight) for cauliflower variety The Forbes raised at four temperature levels and also at two alternative photoperiod and dark period temperatures in controlled environment in cabinets.

the inflorescence primordia occurred at dates intermediate between the 77.4° and 55.2° F. (Table 5, Figure 7). The alternating temperature treatments started four days after the plants were moved into the cabinets and the exchange of plants was omitted 5 times during the duration of the experiment. These curves must, therfore, be viewed with reservations.

Growth rates were also considerably slower in series II than in the former two series. The highest rates of growth were encountered with plants exposed to alternating temperatures 69.6° day and 55.2° F. night. The reverse situation resulted in considerably less growth (Table 5, Figure 7).

Discussion

Number of nodes initiated proved to be a useful measurement for the study of development in cauliflower as it was for Gregory and Purvis (18, 19, 20) in their study of the development of rye. A lower limit of 7 leaves was demonstrated by rye in their studies. Heath and Mathur (27) found that a lower limit of leaves plus scales appeared to be essential before differentiation of the inflorescence could take place in onion sets. Initiation of 20 nodes had to be completed before differentiation of the inflorescence primordium could occur in the cauliflower variety The Forbes. However, it is likely that other varieties of cauliflower display different lower limits since an early variety from India headed with only 7 nodes, while varieties later than The Forbes may show higher node limits.

The maximum temperature at which initiation took place in these experiments was 71.4° F. while the minimum temperature where differentiation did not occur was 76.5° F. The upper limit for initiation of the inflorescence in the cauliflower variety The Forbes must be between those two temperatures. This maximum appears to be below the mean temperatures for the tropics reported by Wood and James (62). Yet the cauliflower varieties from Sutton and Son, Calcutta, India, headed under tropical conditions. Two explanations for this phenommnon are possible. (1) Cauliflower varieties display differences in upper temperature maxima at which initiation may occur. (2) Cauliflower varieties display differences in degree-hours below certain maxima at which initiation may occur. It is likely that both these explanations have to be considered in thinking of the entire cauliflower population (summer and winter cauliflowers).

The cauliflower is variously listed as biennial or annual by the different authors. Both seem to be right considering all cauliflowers. The early varieties from India are annuals, while the latest varieties of winter cauliflower are biennials. All other varieties of cauliflower display different degrees of biennial habit.

It is interesting that both the maximum temperature for initiation of inflorescence and the temperature at which the lower limit of nodes are encountered occur within the range commonly encountered under field conditions. An explanation for the more frequent occurence of buttoning in the spring crop is suggested. The low temperatures encountered in the spring may make the plants differentiate inflorescence prematurely and warm dry conditions following such premature heading may decrease the growth and result in buttoning. The reverse situation is usually the case in the fall. Cauliflower plants are raised and transplanted to the field under warm weather conditions. They stunt and do not grow very well, but neither does initiation of the inflorescence take place because the temperature is too high. Rain and cooler temperatures are usually associated in the fall. The plants initiate the inflorescence and the development of the curd takes place under ideal conditions for cauliflower production.

Cauliflower seed production in many places is limited because of the short season. For this reason, the plants are sown the previous fall, wintered over in greenhouses and transplanted to the fields where the selections are made. This means that the cauliflower plants raised for seed production are exposed to low temperatures during the entire winter. Such is not commonly the case with cauliflower raised for the market. Selection for seed production is, therefore, made under other conditions than those usually given the plants by the truck farmers. These environmental differences may not be serious, since excellent cauliflower seed has been produced in the past, but breeders of cauliflower may find guidance in this study of the effects of temperature on growth and development of cauliflower.

Alternative day and night temperatures seem to influence development in a different manner than they influence growth. Thus rate of initiation and mean number of nodes initiated before differentiation of the inflorescence seem to be the same for the same mean temperature whether it is constant or alternating during the 24-hour cycle, while the increase in fresh weight is much larger for the same mean temperature if the day temperature is high and the night temperature is low. Definite proof for this statement is lacking at the moment. Bremer (7) found that heading or no heading in the lettuce variety Tom Thumb was determined by the mean temperature. Whether alternating or constant, he did not get head formation if the mean temperature was above 18° C.

Considerable work has to be done before the effects of temperature on growth and development in cauliflower are fully known. To shorten the time until initiation of the infloresscence is of considerable interest for cauliflower seed production. It may be possible to do this by exposing the plants to optimum 60-70° F. until the minimum 20 nodes are initiated and, thereafter expose them to cold treatment for a few days for the initiation of the inflorescence and again give them optimum temperatures for further growth and development. Data for such a procedure are not available at the moment.

Summary

The controlled environment studies demonstrate the effects of temperatures on growth and development of cauliflower and also explain the association of development with earliness and yield.

There appears to be an upper temperature limit beyond which initiation of the inflorescence does not take place and the cauliflower plants remain in the vegetative phase. The highest temperature at which initiation occurred in the cauliflower variety The Forbes was 71.4° F. and the lowest temperature at which initiation did not take place was 76.5° F. The upper limit for initiation must be between those temperatures. Initiation occurred at all temperatures below this limit, but the number of nodes initiated before initiation of the inflorescence varied tremendously.

Initiation of the inflorescence cannot take place in the cauliflower variety The Forbes regardless of temperature as long as the leaf number is below 20 nodes.

Number of days until differentiation of the inflorescence was determined by rate of initiation and nodes and mean number of nodes initiated. Very small differences in number of days until initiation of the inflorescence were found in the region 60-70° F. since the increase in node numbers

were counteracted by the increased rate of initiation. The decrease in node number below 60° F. was more than counteracted by the decreased rate of initiation so that a delay in initiation of the inflorescence occurred.

The increase in rate of initiation was associated with increased rate of growth. Overall increase in rate of initiation and fresh weight accumulation occurred up to 70° F. and this temperature seems to be the optimum temperature under the conditions of these experiments. However, it is more safe to recommend 60-70° F. as the most suitable temperature for cauliflower production.

Rate of initiation of nodes seemed to be the same for the same mean temperatures whether the temperature was constant or alternating during the 24-hour cycle, while fresh weight accumulation was greatly accellerated by alternating high day temperatures and low night temperatures.

The results of these experiments are compared to results of cauliflower experiments from the tropics, the implications for breeding of cauliflower are discussed and problems for future research pointed out.

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APPENDIX

SECTION III

A STUDY OF MORPHOLOGICAL DIFFERENCES AND THEIR RELATION TO YIELD AND EARLINESS IN SUMMER CAULIFLOWER

Introduction

Few, if any, cultivated plants show as many morphological differences as the species Brassica oleracea. Only a very few of these differences have been assigned to specific genes. Most of the differences appear to be quantitatively inherited or the effect of genes plus modifiers. It is of considerable importance to find and to measure such differences and to correlate them in order to insure progress in the desirable direction. This paper concerns measurable differences in morphological characteristics among varieties of cauliflower and the relationship of these characteristics to earliness and yield.

Review of Literature

Chiefly, two characteristics seem to have been involved in the classification of cauliflower varieties. One of these was physiological, namely, earliness, the other was one of the morphological characteristics, density of the heads. The latter seems to be the older characteristic for classification. Thus DeCandolle (16) said that the French gardeners raised "Le Dur" (the hard), "Le Semi Dur" (the semi-hard) and "Le Tendre" (the soft or tender) which was the most upright in growth. DeCandolle stated further that these subvarieties founded on different degrees of firmness of the "footstalks," were far from offering a constant characteristic, and seemed principally to depend on the nature of the ground, and the influence of the climate. Nilson (40) mentioned in his description of the cauliflower, that excellent varieties had short primary branches which gave the curds a very dense appearance when cut longitudinally. Kraus (30) measured the density of the curd by dividing the weight of the heads into depth times width, and recorded the results as an index of density.

Lund and Kiærschou (35) classified the varieties on the basis of earliness, named the classes after the best known variety in each class, and used morphological characteristics for the description of the classes. They divided the population of flowering kale into four groups, namely (1) Erfurter group, (2) Lenormand group, (3) Winter cauliflower group or heading broccoli group, and (4) Genuine broccoli. The following morphological characteristics were used in their description: length of stem, color of leaves, development of flower buds on curd, sessile versus petiolate leaves, and incisions in the leaves.

Bremer (5) reported a survey of the cauliflower population by observation trials, and he classified the cauliflower varieties into four main groups with subdivisions. Habit of growth, color of leaves, earliness and other cultural indexes were used as classification characteristics. He, like Lund et al (35), named the classes after known varieties.

Nordisk Jordbrugsforskeres forening (Society of northern agricultural scientists) took up the question of standardization of classification and the use of approved reference varieties in their variety testing. Lamprecht (34) proposed four groups of cauliflower based entirely on earliness. The two latest maturing of Lamprecht's groups were practically eliminated from the seed trade by the further development of the cauliflower industry in the Scandinavian countries. Early and late varieties of the Erfurter group are the only ones used today, and these varieties are classified in a very exact order of maturation with reference to a standard. A new method for calculating earliness was introduced by Lamprecht (33). It has been modified by Lamm et al (31) who also described the method in English.

The Swedish experiment stations (32) used an organoleptic scoring system for several morphological characters like density, smoothness of the curd, ricy heads and so forth. Their organoleptic ratings were used to eliminate varieties with undesirable characters. The Danish vegetable trials (24) also used an organoleptic scoring system, and their ratings were incorporated with the yield and quality grading data into a common index upon which the recommendation or rejection of varieties were based.

The diversified climate in U.S.A. calls for a greater range in varieties of cauliflower than is used in northern Europe. Thus the winter cauliflowers, or the heading broccolis, are of great importance in the southeastern and southwestern United States. Thompson (57) divided the cauliflowers into two main groups: (1) The early to midseason varieties (true cauliflowers). (2) The late varieties including all Pacific Coast strains plus St. Valentine and White Cap. Such a distinction is also made in England by the Ministry of Agriculture and Fisheries (21) and by Oldham (41) in his late book "Brassica Crops and Allied Cruciferous Crops." He also arranged the varieties according to the month of harvest and gave the respective dates of planting in another column. Ferry Morse (17) has named many of their strains of winter cauliflower after the month of harvest of the particular variety. This was also done in Italy as reported by Great Britain, Ministry of Agriculture and Fisheries (22).

The development of cauliflower production in the tropics called for special varieties that would head under conditions of high temperature. Such varieties have been developed by Sutton and Son Ltd., Calcutta, India, and the varieties have been tried in experiments by Paul (46), Rodrigo (50), and Wood et al (62). They have also been tried in the U.S.A., but found worthless since they all headed prematurely under conditions of cooler temperature.

Only cauliflower varieties of the early and late Erfurter or Snowball group, which are commonly grown in the U.S.A. and in the Scandinavian countries, were included in this experiment. It would have been desirable to include a greater range of varieties; however, this would have entailed a year round growing season. Idaho, where these experiments were conducted, does not offer such climatic conditions.

Materials and Methods

The experiment was conducted near Lewiston, Idaho during the 1948 season. Lewiston is located at the confluence of the Clearwater and Snake Rivers at 46 40" N. latitude and 117 W. longitude. The altitude is about 1200 feet above sea level. The climatic conditions for that locality during the 1948 spring season, (Table 1), were more rainy and cooler than normal which favored the cauliflower crop, and excellent yields were obtained.

The twenty-two varieties of cauliflower were tested in complete randomized block design, with four replications. The plot size was 4 x 22 feet and consisted of 3 rows 12 inches apart. The distance between the plants in the rows was 13 inches. The middle row in each plot was sampled during the period of leaf initiation and was removed early before crowding of the adjoining rows. The distance at time of

Table 1. Temperature and rainfall records at the Lewiston Airport for 1947 and 1948 seasons and the 45-year average for Lewiston, Idaho.

	May	June	July	Aug.	Sept.
Average temperatures, degrees Fahrenheit					
Lewiston airport 1948	55.8	68.4	68.8	68.8	62.5
Lewiston airport 1947	46.6	64.0	74.3	71.3	63.8
Lewiston City 45-year average	59.1	67.4	76.1	74.2	64.1
Average precipitation, inches					
Lewiston airport 1948	4.80	1.18	2.05	0.15	0.49
Lewiston airport 1947	0.38	2.43	0.03	0.13	2.36
Lewiston City 45-year average	1.50	1.46	0.49	0.48	0.89

*Data obtained from U. S. Weather Bureau records. The weather station was moved from the City of Lewiston to the Lewiston Airport in 1946. The experimental field was located about 400 yards from the weather station.

harvest was, therefore, 18 x 24 inches which gave 28 plants per plot.

The seed was sown on March 26 in nursery beds in the field, and the seedlings were transplanted to the field on May 15 to 20. The plants were very small at the time of transplanting and had no soil attached to the roots. They were transplanted with a special dibble and not watered. Some difficulty was encountered with cutworms and some replanting was necessary. This was done during the first ten days after the original transplanting.

The experimental field had been used for snap beans the previous season, and a green manure crop of winter rye was sown the previous fall. Two hundred pounds of ammonium sulfate per acre were applied in the spring previous to plowing.

Irrigation water was applied once a week after the rainy spring season was over. The field was not quite level, and block one and two were flooded somewhat when irrigated. This affected the total growth appreciably but it did not seem to influence the rate of plant development. Leaf number and earliness were the same in all the blocks.

Harvesting was done twice a week after the plants reached maturity. They were considered mature when the heads had developed maximum size without elongation of the flowering branches and spreading out of the head. The plants were cut at the soil surface and analyzed for the different characteristics. Every plant was handled individually. This limited the number of plants that could be examined in a day to about 200.

The data recorded at harvest were: (a) total weight of plant, (b) total weight of leaves, (c) net weight of head, (d) classification of the head according to U. S. standards, (e) width and depth measurements of the head, and (f) leaf counts and classification into the following three classes: (1)missing leaves counted by their abscission scars, (2) elongated leaves, extending above the curd, and (3) short leaves, not extending above the curd. Figure (1) shows cauliflower heads with the leaves removed to the first flower branch. The cotyledon leaves were not counted, but all the leaves between the cotyledon leaves and the first leaf with an axillary flower branch were counted. These points may be determined precisely. However, some difficulty was encountered when fungi or insects had destroyed the abscission scars. The heads were cut just below the first inflorescence branch (Figure 2); hence the head weights were net, as were also the yield figures calculated from them. This method of handling the heads was used in order to facilitate leaf counting and in order to eliminate errors in the trimming operation.

The experimental results were subjected to analysis of variance for reliability of interpretation. A variation of the method developed in Sweden by Lamm and Tometrop (31) was used for calculation of earliness. According to their definition, biological earliness is expressed as the numberof days from planting to harvest of 1/4, 1/2 or 3/4 of the respective yields. Biological earliness as used in this paper is the number of days from transplanting to harvest of 1/4, 1/2 or 3/4 of the total number of plants, respectively. The earliness figures were calculated by interpolation between harvesting dates. The formula for calculating the volume of an oblate spheroid as described by Turrell and Vanselow (58) was used for calculating the volume of the heads. The average head weight divided by the average head volume was recorded as density.

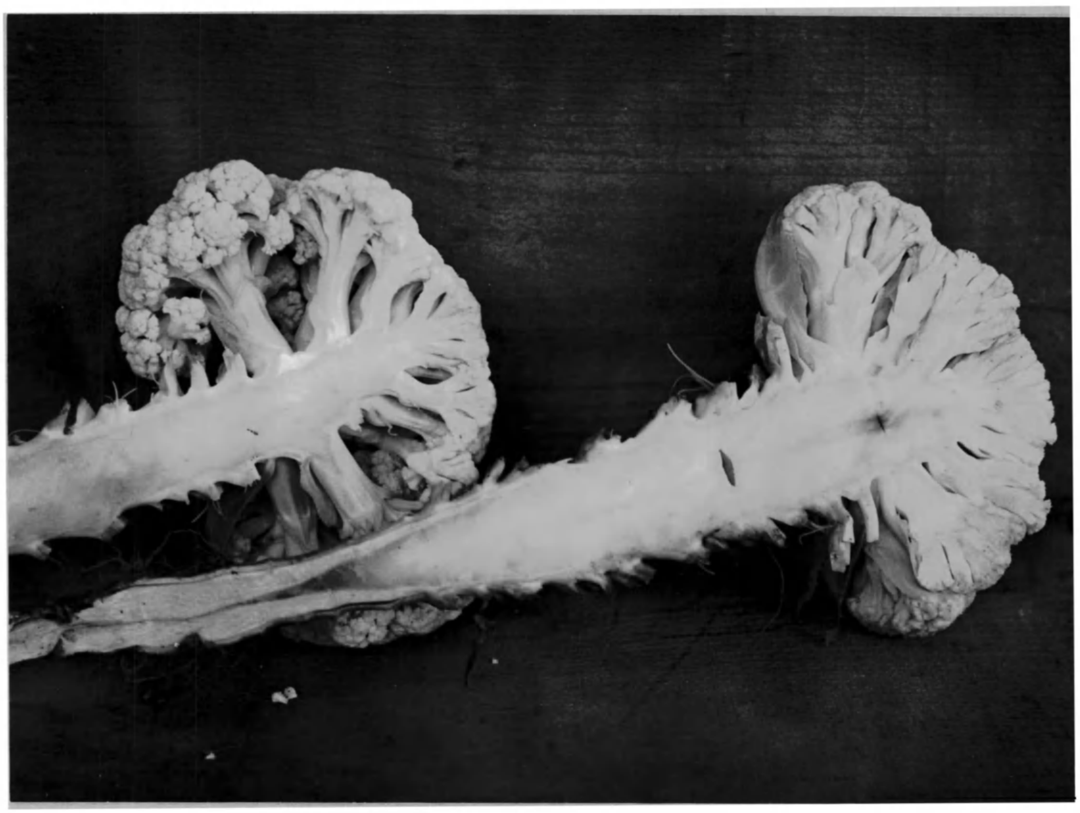

Figure 1. Cauliflower plants with the leaves stripped off up to where the first flower branch begins.

Figure 2. Cauliflower trimming. Commercial method of trimming shown on two heads at left. Two heads at right as trimmed in these experiments.

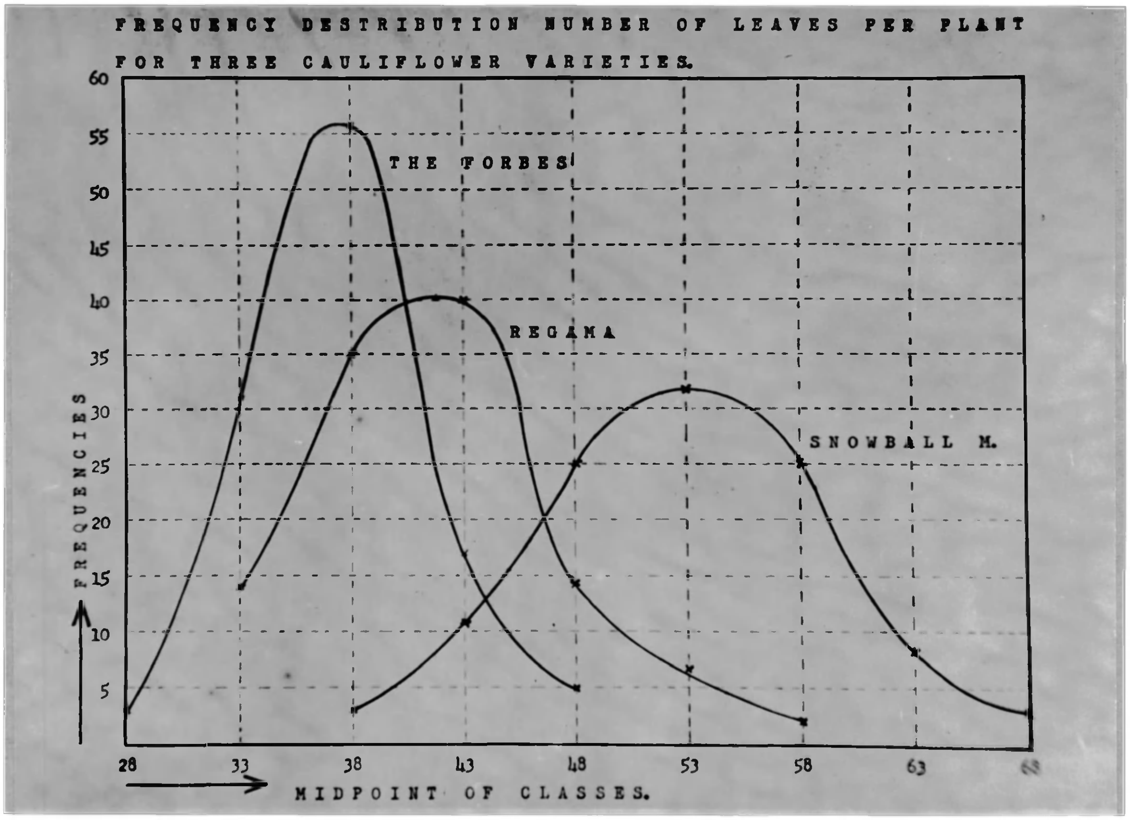
FREQUENCY DESTRIBUTION NUMBER OF LEAVES PER PLANT
FOR THREE CAULIFLOWER VARIETIES.
THE FORBES
REGAMA
SNOWBALL M.
FREQUENCIES
60
55
50
45
40
35
30
25
20
15
10
5
28
33
38
43
48
53
58
63
68
MIDPOINT OF CLASSES.

Figure 8.

Experimental Results

The yield figures of the twenty-two varieties or strains tested showed that the highest yielding variety produced more than twice the yield of the lowest (Table 2). The figures are net yield since all the leaves were removed and the stems cut just below the head. It was found that 30 to 50 per cent should be added to these figures if the yield data obtained are to be comparable to records from other experiments or to commercially harvested cauliflower where part of the leaves are included in the yield records.

The other physiological and morphological characteristics studied, weight of leaves, number of leaves, number of days from transplanting to harvest, and density of the heads also showed a great variation among varieties (Table 3).

The relationship of the different characteristics studied are interesting (Table 4). The correlation coefficients were all significant at the 1 per cent level, but some of them explained too little of the total variation to be of any great importance. However, the high correlation between yield of heads and leaf weight showed that leaf growth determines to a great extent the size of the crop which may be harvested. Leaf number and earliness also showed a high correlation i.e. varieties with few days from planting to harvest had a small number of leaves.

The frequency distribution for leaf number per plant (Table 5); and frequency curves for three varieties (Figure 3); showed differences among varieties in range of variation. Class intervals of five were selected because of the 2/5 leaf arrangement in cauliflower. An examination of the data gave evidence that the heaviest yielding varieties had the highest frequency of number of leaves in class 51-55 leaves per plant The

Table 2. Grades and total yield of heads in tons per acre of 22 cauliflower varieties.

Variety or strain	Yield of heads, tons/acre U. S. I	U. S. I & II	Total
Snowball M 4086	7.19	8.10	8.13
Snowball D 1538	5.90	6.80	6.96
Snowball Y 6158	6.29	6.70	6.88
Snowball X 5090	5.04	5.73	6.56
White Mountain 147/13x	5.12	5.96	6.39
Impr.Holland Erfurter	4.77	5.75	6.23
Snowball (1)	5.15	5.84	6.21
Early Snowball 247	4.30	5.56	6.12
Forbes Reliance	4.64	5.40	5.87
Impr. Super Snowball	3.73	5.51	6.52
Codania	5.48	5.79	5.95
Regama	3.56	4.90	5.48
Erfurter	4.42	4.96	5.28
The Forbes	4.37	5.04	5.26
Super Snowball (2)	2.46	3.64	4.30
Safir	3.45	4.11	4.28
Snowball A 2098	1.83	3.20	3.81
Super Snowball (3)	2.29	3.36	3.68
Early Snowball	3.41	3.97	5.65
Snowdrift 1-690 c	1.46	2.18	3.89
Super Snowball 1-91	0.97	2.18	3.65
Dry Weather	0.75	1.89	4.15
L.S.D. (19:1 odds)	2.27	1.98	1.86
Mean	3.94	4.85	5.51
Coefficient of variability (per cent)	40.7	28.8	23.8

Table 3. Total yield and weight of leaves in tons per acre, and average number of leaves per plant, days from transplanting to harvest of ½ of the plants and density of the heads of 22 cauliflower varieties.

Variety or strain*	Total yield tons/acre	Total wt. of leaves tons/acre	Number of leaves per plant	Days from transplant. to ½ harvest	Density of heads
Late varieties					
Snowball M 4086	8.13	16.5	50.8	83.1	0.95
Snowball D 1538	6.96	14.6	49.8	82.3	0.93
Snowball Y 6158	6.88	15.1	53.8	87.8	0.96
Snowball X 5090	6.56	15.2	51.5	87.3	0.92
White Mountain	6.39	15.8	50.4	83.3	0.87
Impr.Holland Erfurter	6.23	14.7	49.3	82.5	0.86
Snowball (1)	6.21	16.6	52.9	85.0	0.95
Early Snowball 247	6.12	13.8	51.2	86.5	0.92
Forbes Reliance	5.87	12.5	47.6	83.4	0.95
Early varieties					
Imp. Super Snowball	6.52	15.8	39.8	78.0	0.54
Codania	5.95	13.8	42.4	77.7	0.63
Regama	5.48	13.5	41.4	76.7	0.58
Erfurter	5.29	14.0	41.6	74.7	0.59
The Forbes	5.26	12.8	37.5	73.4	0.55
Super Snowball (2)	4.30	13.5	39.7	74.4	0.59
Safir	4.28	12.2	41.4	73.9	0.60
Snowball A 2098	3.81	10.4	38.1	74.6	0.55
Super Snowball (3)	3.68	9.7	37.7	73.5	0.58
Very late or off types					
Early Snowball	5.65	23.6	58.2	90.6	0.94
Snowdrift 1-690 c	3.89	18.2	50.9	90.5	0.78
Super Snowball 1-91	3.65	13.4	45.1	81.8	0.64
Dry Weather	4.15	16.5	45.8	88.2	0.82
L.S.D. (19:1 odds)	1.86	4.0	2.1	4.5	0.21
Mean	5.51	14.6	46.2	81.5	0.76
Coefficient of variability (per cent)	23.8	19.6	3.3	3.9	19.7

*The same varieties as in table 2.

Table 4. Coefficients of correlation and of determination for total yield, earliness ($\frac{1}{2}$ of the plants harvested), weight of leaves and average number of leaves per plant.

Correlation of characters	r^2	r
Yield times weight of leaves	0.769	+ 0.877**
Yield times number of leaves	0.208	+ 0.457**
Yield times earliness	0.166	+ 0.408**
Earliness times number of leaves	0.803	+ 0.896**

**Significant at the 99 per cent level.

Table 5. Frequency distribution of leaf number per plant.

Variety	Mean	Midpoints of each class										S
		28	33	38	43	48	53	58	63	68	73	
Early Snowball	58.2		1	3	16	10	25	10	13	14	20	112
Snowball Y 6158	53.3			3	11	25	32	25	8	3	5	112
Snowball (1)	52.9			9	18	24	23	17	8	6	6	111
Snowball X 5090	51.5	1	1	6	13	32	30	18	5	4	2	112
Early Snowball 247	51.2		1	9	17	28	27	15	8	4	3	112
Snowdrift 1-690 c	50.9		5	15	18	14	21	17	12	3	5	110
Snowball M 4086	50.8			5	17	24	46	16	3	1		112
White Mountain 147/13	50.4	1	2	8	16	30	27	17	4	3	2	110
Snowball D 1538	49.8			7	23	30	35	10	2		2	109
Imp. Holland Erfurter	49.3	1	8	10	25	22	22	12	5	5	3	111
Forbes Reliance	47.6			13	25	33	22	11	2	1		108
Dry Weather 245	45.8		10	29	34	8	13	5	7	3	2	111
Super Snowball 1-91	45.1	5	14	28	27	11	5	5	6	3	6	110
Codania	42.4	1	7	31	48	19	4	1	1			112
Erfurter	41.6		13	39	46	10	1			2	1	112
Regama	41.5		14	35	40	14	7	2				112
Safir	41.4		30	41	12	12	5	9	2	1		112
Imp. Super Snowball	39.8	6	25	38	24	6	9	4				112
Super Snowball (2)	39.7	7	37	33	17	6	5	1	1	2	3	112
Snowball A 2098	38.1	2	33	45	26	5	1					112
Super Snowball (3)	37.7	4	41	36	20	7	2		1			111
The Forbes	37.5	3	31	56	17	5				2	1	112
Summation		31	273	499	508	375	362	195	88	55	60	2447

heaviest yielding of the early varieties had 41-45 leaves per plant, and the earliest had 36-40 leaves per plant.

Discussion

Recommendations of varieties cannot be made with complete confidence since the experiment was conducted for one season only. The efficiency of the design may also be questioned, since the coefficient of variability was 23.8 per cent for the total yield data. This was due to partial flooding of two blocks during irrigation, and should not be considered as a reason for change in design.

It is interesting to note that the earliness and number of leaf data showed much less variability than the yield records. Thus earliness and number of leaves had a coefficient of variability of 3.9 and 3.3 per cent respectively. Lamm et al (32) have reported similar variability for earliness in cauliflower. When they applied analysis of variance to a series of variety tests they also found that the ranking of the varieties would not be altered from year to year although the interaction of year times earliness was significant, because the variance for varieties was significantly higher than the interaction variance. Thus it appears that one can place considerable confidence in the earliness data, and small differences can be tested with relatively little effort.

The high correlation between earliness and number of leaves is interesting and hears out the relation of physiology to morphology. Leaf counting may prove to be an additional tool for further improvement of earliness in cauliflower varieties. There is a limit to improvement in this direction, however, since the varieties from India headed after initiation of only seven nodes[1] and the plants were of the size of a small transplant only when the initiation of the inflorescence took place. There was not enough of the vegetative organs present to nurse a curd to a marketable size. One has encountered cauliflower of marketable size with only 20-25 leaves, but it would be hazardous to raise a cauliflower variety which normally headed with such a low number of leaves since the slightest retardation of the growth, at any time during the season, would result in "buttoning."[2] It is possible that the development of an extraordinarily early variety with a small number of leaves might prove desirable for controlled conditions in greenhouses or coldframes.

Another positive correlation has to be taken into account if one desires high yield in cauliflower, namely, leaf and head weight. Leaf weight is again increased by a higher number of leaves, and a pronounced development of the leaves. A higher number of leaves give the plants longer time for establishment in the field after transplanting and before initiation of the curd takes place. This insures a more vigorous growth of the leaves.

The striking differences in density of the heads are an indication that there is more reason to consider it in a breeding program than is usually done. The housewife prefers the dense heads, but the freezing an pickling industry may profit with the less dense varieties which are more easily trimmed for processing. This question is left open for future research.

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[1] Unpublished observation trials.

[2] "Buttoning is a popular term for the small and unmarketable cauliflowers encountered in the fields.

The desirability of the use of individual plant records for vegetables, where the entire plant is harvested, should be stressed. Frequency curves can be plotted, standard deviation computed, and also coefficient of variability and these statistics will be characteristic of the varieties, not of the experimental technique as is the case when the statistics are computed from the plot yields. Such a procedure will mainly be of value for plant breeders as a guide for knowing when a new variety is homogenous enough for release.

Summary

The 22 varieties of summer cauliflower of the Erfurter or Snowball group tested could be divided into two groups which differed in four characteristics, namely, yield, earliness, number of leaves, and density of the heads.

The yield of the heads showed a high positive correlation with weight of the leaves, and the weight of the leaves seemed to be associated with a higher number of leaves which by the additional time required for their initiation enabled the plants to become firmly established in the field before initiation of the inflorescence.

Earliness and number of leaves also showed high positive correlation. Thus the varieties with the fewer days from transplanting to harvest had the smallest number of leaves.

A lower density was associated with the early varieties. Such varieties also had longer internodes on the main stem and the foliage did not cover the heads as well as the later varieties.

Frequency tables for number of leaves per plant showed that the best varieties had the smallest range, and that the later varieties generally showed a wider range than did the early varieties.

SECTION IV

A STUDY OF THE EFFECT OF ENVIRONMENT ON GROWTH AND DEVELOPMENT IN CAULIFLOWER, (A) EFFECTS OF TREATMENTS OF TRANSPLANTS ON SUBSEQUENT GROWTH AND DEVELOPMENT IN THE FIELD

Introduction

Producers of cauliflower frequently sustain losses in returns because of the occurrence in their fields of small unmarketable cauliflower heads popularly called "buttons." The buttoned condition is most frequently encountered in the spring crop of summer cauliflower in the United States, while the July-August season is the most difficult season for cauliflower production in northern Europe.

The problem is best stated by asking some questions concerning the phenomenon of buttoning. What is a button? Is it a hereditary response or is it a consequence of the environment? If the latter is the case, is the buttoned condition associated with premature (earlier) heading, or is it merely undernourishment of the plants? Which, if any, environmental factor causes premature heading? How can losses due to buttoning be avoided under field conditions? Some of the answers to these question are given in the following 3 parts of this thesis.

Review of Literature

The first question asked in the Introduction, "What is a button", is not agreed upon by the different authors. Bailey (4) considered buttoning in cauliflower the failure of head formation in cabbage, and other "rogues" and abnormalities as indications that the development in these races was not yet fixed and that the forms were interrelated. The Danish vegetable trials (24) recognized the importance of the selection of suitable varieties and conducted a series of variety tests terminating during July and August (season for buttoning). They found tremendous variation among varieties in their ability to withstand climatic conditions favoring buttoning. The ability of the particular varieties to give a good crop under less favorable conditions was associated with a relatively high number of leaves and late maturity as reported elsewhere.[1]

Robbins et al (49), however, produced buttons in cauliflower artificially in sand culture experiments by growing them in a nutrient solution deficient in nitrogen. They state that buttoning is the same as premature heading and that this condition is caused by nitrogen deficiency. They suggested that other factors which influence nitrogen absorption may cause buttoning.

Carew and Thompson (14) performed similar experiments to those of Robbins et al, and they obtained similar plant responses. They stated, however, that it is doubtful, in view of their data, that buttoning is the same as premature heading because heads were initiated at the same time in all cases. The heads only appeared much earlier in nitrogen deficient plots because of less foliage. Carew and Thompson also did extensive field work and found that the most important factor besides nutrition in preventing buttoning was the age of the transplants. Transplanting 4 to 6 week-old plants gave the highest yield of marketable heads.

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[1] Section III.

Another important discovery was that a check in growth either by short-day treatment, drying out of flats, or exposure to cold temperature did not cause buttoning where the treatment was applied in the seedling stage.

Kraus (30) conducted extensive work on pruning of cauliflower at the time of transplanting to the field. He showed that pruning delayed maturity and decreased yield of cauliflower.

Babb (3) has reported results of experiments on the effects of hardening and level of nutrition on various plants. He found that hardening delayed maturity and caused lower yield of cauliflower plants. He found that high nitrogen application in the seedling stage decreased yield. The same effect was found with nitrogen application in the field in one case, but this effect was not significant. He did not state the age of plants at the time of transplanting.

It has been shown by Went (59) that shading and daylength have a very marked effect upon growth of cauliflower. Check plots (plants not shaded) gave greatest head weight and leaf weight, but leaf number seemed to be increased by short day. The significance of his results is doubtful since the experiment was not carried out with replicated plots.

Materials and Methods

The first three of these experiments were conducted near Lewiston, Idaho, during the 1948 season. The fourth experiment was conducted at the University of Maryland, College Park, Maryland, during the spring season of 1950. The climatic conditions at Lewiston during the 1948 season are described elsewhere.[1] The spring season at College Park during

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[1] Section III.

1950 was very cold with frequent frosts in April and the first part of May followed by warm and dry weather in the latter part of May and June when the cauliflowers were harvested. The climatic conditions were very unfavorable for cauliflower and small yields were obtained in this experiment.

The experiments were limited to treatments of the transplants (seedlings) during the propagation period and the effects of the treatments were measured during the subsequent growth and development in the field. The factorial design was selected as the most suitable design for answering the questions raised in the Introduction. Varieties were included as one variable in all experiments.

Experiment I consisted of a 2 x 2 x 2 factorial designed experiment for testing the effects of photoperiods given the seedlings in the coldframe, age of transplants at transplanting time, and variety, on the subsequent growth and development in the field. The actual treatments were as follows:

Photoperiod: 9 hours vs. 12-15 hours (normal day).

Age of transplants: 7 weeks vs. 9 weeks.

Varieties: Safir vs. Snowball A.

This provided 8 factorial combinations. Two replicates were used for each combination.

The seed was sown in flats in the greenhouse on March 27. The seedlings were transplanted to flats on April 3 and moved to the coldframe where photoperiodic treatment was started according to plan on April 5. The 9-hour photoperiod was accomplished by covering the glass of the frame with black roofing paper at 5:00 P.M. and uncovering at 8:00 A.M. The 7-week transplants were transplanted to the field on May 17, and the 9-week transplants on May 31. The different combinations were sampled for study of growth and development on the following dates: May 17 and 30 in the coldframe; June 14, 22, 27 and July 5 in the field.

Experiment II consisted of a 2x 2 factorial design for testing the effect of moisture supply in the flats and variety on the subsequent growth and development in the field. The actual treatments were as follows:

Moisture supply: normal vs. low (watered slightly only when wilted).

Varieties: Safir vs. Snowball A.

This provided 4 factorial combinations. Two replicates were used for each combination.

The seed was sown in flats in the greenhouse on March 27. The seedlings were transplanted to flats on April 3 and moved to the coldframes where the moisture treatments were started on April 5 and then transplanted to the field on May 20. The low moisture treated plants were watered only slightly when they showed wilting. However, the treatment was interrupted because of excessive rain and leakage through the coldframe windows.

Experiment III consisted of a 2 x 2 factorial design for testing the effect of pruning in the field on subsequent growth and development. The actual treatments were as follows:

Pruning: Not pruned vs. pruned (expanded leaves pruned to 1/2" of the petioles).

Varieties: Satir vs. Snowball A.

This provided 4 factorial combinations. Two replicates were used for each combination.

The seed was sown in the greenhouse on April 8, transplanted to flats and moved to the coldframe on April 22. The plants were transplanted to the field on May 24. Table (1) gives the dates of pruning and number of leaves removed.

Table 1. Experiment III, pruning dates and number of leaves removed per plant.

Date of pruning	Number of leaves removed
June 1	3
June 12	4
June 20	4-6
June 30	4-6
Total	15-19

Experiment IV consisted of a 2 x 4 factorial design for testing the effect of exposure of seedlings to low temperature and varieties of cauliflower upon their subsequent growth and development in the field. Actual treatments were as follows:

Temperatures: 60-65° F. during the whole propagation period vs. 40° F. for 30 days followed by 60-65° F. until transplanting time.

Varieties: Snowball m, The Forbes, January and U.S.D.A. Plant Introduction Service No. 181860.

This gave 8 factorial combinations and 4 replicates were used for each combination.

The plants for cold treatment were sown in soil in 9" clay pots, covered with clean sand and placed in the laboratory for germination on January 30. The germinated plants were moved to a cold storage room at 40° F. on February 7. They were given a 15-hour photoperiod by means of incandescent light of relatively high intensity. The plants not exposed to low temperature were planted in clay pots in the greenhouse on February 26. All combinations were transplanted to flats on March 8 when the greenhouse plants that were sown later had reached a size similar to the ones in the cold storage. The flats were placed in the greenhouse and remained there until transplanting to the field on April 10. Hard frost was predicted by the Weather Bureau a few days after transplanting. The experiment was saved by covering all the plants with soil. The were uncovered again when the danger of killing frost was over.

The individual plots were similar in all four experiments (Figure 1). Samplings were made before crowding of adjacent plants and the distance at the time of final harvest was 18 x 24". The plots then had 28 plants each.

The culture of the plants in the field and the data obtained are described elsewhere.[1]

Number of leaves initiated at the specific dates of sampling is not the total number present, but the number which could be distinguished by the naked eye. The curve for the initiation of leaves is, therefore, probably lower than the true value.

Results

The data were presented as factorial effects because this method permitted the use of one of the dimension of the tables for the different characteristics studies. This made it easy to compare the effects of environment on the different characteristics. The effects are the actual differences on a plot yield basis and they can be directly compared to the statistic L. S. D.

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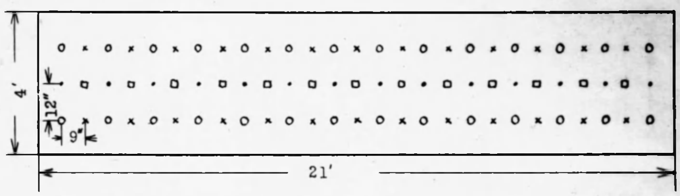
[1] Section III.

Figure 1a. Design of single plot for the factorial experiments.



Plot size, 4 by 21 feet = 84 square feet.
Distance between plants when transplantet, 9 by 12 inches.
Distance between plants at final harvest, 18 by 24 inches.
x = For first and second sampling.
• = For third sampling.
□ = For fourth sampling.
o = For final harvest at maturity.

Figure 1.

(least significant difference) appearing in the respective columns. Ease of understanding is sacrificed somewhat by this procedure since it is not commonly used. This is mainly the case with the interactions, but the clue to a correct interpretation is always found in the ranking of the primary effects.

Experiment I. Effects of Daylength, Age of Transplants and Variety

The primary effects on yield were all positive and significant at the 5% level in all but one case, (7-week old transplants vs. 9-week old transplants for U.S. No. 1 yield)(Table 2). The greatest effects were found in the total weight of plants. This is what could be expected since the total weight of plants include all the variation of the above ground parts of the plant. The results may be summarized as follows: (1) Seven-week old transplants gave a higher yield than the nine-week old transplants. (2) Plants exposed to 9-hour photoperiod in the seedling stage out-yielded plants exposed to normal day. (3) The variety Safir gave higher yields than Snowball A. Of the interactions only the total weight of plants showed an effect exceeding the odds of 19:1. However, the trends were the same in the other yield columns. The interaction of transplants times daylength showed that daylength treatment was not so important for 7-week old transplants as it was for 9-week old transplants. The interaction of daylength times variety showed that the variety Safir responded more positively to 9-hour photoperiod than Snowball A. did. The triple interaction showed that the variety Safir responded more positively when transplanted when 7 weeks old and given a 9-hour photoperiod than the variety Snowball A did.

Table 2. Experiment I. Factorial effects in plant weights in kg. per plot.

Treatments compared	Effects in kg. per plot: Weight of plants	Weight of heads: U.S. No. 1	Weight of heads: U.S. No. 2	Total
7-week transplants vs. 9-week transplants	+ 4.0*	+ 0.26	+ 1.41	+ 1.15
9-hour photoperiod vs. 12-15-hour photoperiod	+ 5.4	+ 1.90	+ 1.36	+ 1.11
Variety Safir vs. Variety Snowball A	+ 5.6	+ 2.30	+ 1.87	+ 1.53
Interactions				
Age of transplants x photoperiod	- 1.9	+ 0.09	- 0.68	- 0.51
Age of transplants x variety	+ 1.3	+ 0.50	+ 0.45	+ 0.48
Photoperiod x variety	+ 1.9	+ 0.52	+ 0.67	+ 0.38
Age of transplants x photoperiod x variety	+ 2.1	+ 0.73	+ 0.77	+ 0.63
L.S.D. (19:1 odds)	1.6	1.40	0.91	0.70
Mean	26.3	3.32	5.31	6.07
Coefficient of variability (per cent)	5.2	35.8	14.5	9.7

*Figures presented in the table are factorial effects calculated on the basis of plot yield. A plus sign indicates that the first treatment is superior to the second treatment in the column. A minus sign indicates the opposite effect.

Daylength and age of transplants were shown to have a marked effect on earlinees (Table 3). Thus 7-week old transplants were about a week earlier than 9-week old transplants. A 9-hour photoperiod delayed maturity. This was especially true for the first one-half of the plants harvested. The differences between varieties was significant only for the latest part of the crop. This means that Safir had a longer harvesting season than the variety Snowball A.

Number of leaves developed gave interesting results (Table 4). Thus, the age of plants at the time of field transplanting had significant but small effects. The 7-week old transplants developed on the average two more leaves than the 9-week old transplants. Photoperiod had a more marked influence. The 9-hour day plants averaged 3.6 more leaves than those given a normal day.

The coefficients of correlation and determination were calculated between the different characteristics. It should be pointed out that the correlation coefficients are not of any great value for such a small number of variants. They were merely calculated for comparison to the coefficients found in the large variety test reported elsewhere.[1] The comparison showed the same trend however.

Effects upon two characters which may be classified as factors of quality, namely, density and buttoning are shown in Table 5. Different types of abnormal cauliflowers are shown in Figure 2. There was some significant increase in buttoning when 9-week old transplants were used compared to 7-week old transplants. Of the varieties, Safir gave the smallest percentage of buttons. The primary effect of length of photoperiod did not exceed the chance value, but the interaction of age of transplants times

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[1]Section III.

Table 3. Experiment I. Factorial effects in weight of heads and in the number of days from transplanting to harvest of 1/4, 1/2, and 3/4 of the mature plants, respectively.

Treatments compared	Total yield kg. per plot	Days from transplanting to 1/4 harvest	1/2 harvest	3/4 harvest
7-week transplants vs. 9-week transplants	+ 1.15	- 6.9	- 6.1	- 7.1
9-hour photoperiod vs. 12-15-hour photoperiod	+ 1.11	+ 8.9	+ 4.4	+ 2.7
Variety Safir vs. Variety Snowball A.	+ 1.53	+ 1.4	- 0.0	+ 4.1
Interactions				
Age of transplants x photoperiod	- 0.51	- 3.3	+ 2.1	+ 0.5
Age of transplants x variety	+ 0.48	- 2.2	- 2.2	- 2.1
Photoperiod x variety	+ 0.38	- 0.0	+ 1.3	+ 2.4
Age of transplants x photoperiod x variety	+ 0.63	+ 1.1	+ 1.7	+ 0.4
L.S.D. (19:1 odds)	0.70	3.2	3.0	3.0
Mean	6.07	62.7	71.3	77.1
Coefficient of variability (per cent)	9.7	4.3	3.6	4.0

Table 4. Experiment I. Factorial effects in weight of heads, earliness, weight of leaves per plot and in number of leaves per plant.

Factors compared	Total yield kg. per plot	Days from transplanting to 1/2 harvest	Weight of leaf kg. per plot	No. of leaves per plant
7-week transplants vs. 9-week transplants	+ 1.15	- 6.1	+ 2.5	+ 1.8
9-hour photoperiod vs. 12-15-hour photoperiod	+ 1.11	+ 4.4	+ 3.9	+ 3.6
Variety Safir vs. variety Snowball A	+ 1.53	- 0.0	+ 3.2	+ 3.7
Interactions				
Age of transplants x photoperiod	- 0.51	+ 2.1	- 1.1	- 0.5
Age of transplants x variety	+ 0.43	- 2.2	+ 0.8	- 0.4
Photoperiod x variety	+ 0.38	+ 1.3	+ 1.2	- 1.1
Age of transplants x photoperiod x variety	+ 0.63	+ 1.7	+ 1.2	- 0.1
L.S.D. (19:1 odds)	0.70	3.0	1.1	1.5
Mean	6.07	71.3	17.5	40.6
Coefficient of variability (per cent)	9.7	3.6	5.4	3.1

Table 5. Experiment I. Factorial effects in weight of heads, earliness, percent of buttoned plants, and density of head.

Factors compared	Total yield kg. per plot	Days from transplanting to 1/2 harvest	Percent buttons	Density of head*
7-week transplants vs. 9-week transplants	+ 1.15	- 6.1	- 16.1	- 0.03
9-hour photoperiod vs. 12-15-hour photoperiod	+ 1.11	+ 4.4	- 7.1	+ - 0.11
Variety Safir vs. variety Snowball A	+ 1.53	+ - 0.00	- 11.6	+ 0.06
Interactions				
Age of transplants x photoperiod	- 0.51	+ 2.1	+ 10.6	+ 0.04
Age of transplants x variety	+ 0.48	- 2.2	- 2.7	+ - 0.00
Photoperiod x variety	+ 0.38	+ 1.3	- 6.3	- 0.00
Age of transplants x photoperiod x variety	+ 0.63	+ 1.7	- 4.5	+ 0.03
L.S.D. (19:1 odds)	0.70	3.0	10.2	0.04
Mean	6.07	71.3	25.9	0.60
Coefficient of variability (per cent)	9.07	3.6	33.4	6.2

*Density calculated by $\frac{\text{weight}}{\text{volume}}$. Volume calculated as follows: $4/3\ \pi\ a^2b$

Figure 2. Different kinds of abnormal cauliflower heads.

daylength was significant. A 9-hour photoperiod did not decrease the tendency to button for 7-week old transplants but decreased the buttoning 17.6% in 9-week old transplants.

The results of the pre-harvest samplings offer an explanation for the effect of photoperiod and age of transplants on the subsequent yield and development in the field (Tables 6 and 7 and Figure 3. Rate of leaf initiation was decreased only slightly at the time of transplanting of the 7-week transplants, while in the 9-week transplants it was checked severely. The comparable curves for a 9-hour photoperiod were always lower than the 12-15-hour photoperiod, but the final number of leaves initiated was highest for the 9-hour photoperiod as previously described. Thus three effects of photoperiodism were found.(1). The 9-hour photoperiod withstood transplanting better than 12-15-hour photoperiod. (2) Rate of leaf initiation was lower under the 9-hour photoperiod and (3) Short photoperiod increased the final number of leaves initiated.

The 9-hour photoperiod produced a very marked check in the growth of plants in the coldframe. The plants were only half the size of the normal day plants at time of transplanting to the field. This was true both for the early and late transplanting. The plants given 9-hour photoperiod continued to be smaller until the first part of July when they started to grow rapidly and soon surpassed the normal day plants. The starting point of heavy growth was very closely associated with the time of completion of leaf initiation.

Late transplanting caused a check in growth in the flats and in the field. The check of growth in the flats was because of crowding, and the check of growth in the field was apparently due to the very hardened condition of the plants.

Table 6. Experiment I. Average number of leaves per plant at specific sampling dates.

Treatment: Age of transplants	Treatment: Photoperiod	Average No. of leaves before trans. to field: 5/17	5/30	Average number of leaves at sampling dates in the field: 6/14	6/22	6/28	7/5	Average number of leaves at final harvest
9 weeks	12-15 hour	11.5	16.7	21.4	26.5	28.1	35.9	37.7
7 weeks	12-15 hour	11.5		27.4	35.4	34.5	38.0	40.0
9 weeks	9 hour	10.9	15.3	20.7	26.6	27.9	35.1	41.6
7 weeks	9 hour	10.9		25.8	32.4	34.6	40.5	43.1
L.S.D. (19:1 odds)				2.6	2.8	2.3	3.1	2.1
Mean		11.2	17.0	23.8	30.2	31.3	36.9	40.7

Table 7. Experiment I. Average weight per plant at specific sampling dates.

Treatment		Average wt. of plants in grams before transplanting to field		Average wt. of plants in grams at sampling dates in the field				Average wt. in grams of plants at final harvest
Age of trans-plants	Photo-period	5/17	5/30	6/14	6/22	6/28	7/5	
9 weeks	12-15 hour	6.22	12.9	15.4	40.6	73.5	147.2	737
7 weeks	12-15 hour	6.22		52.3	119.1	165.1	224.1	948
9 weeks	9 hour	3.25	7.0	14.4	39.4	62.3	134.6	992
7 weeks	9 hour	3.25		40.8	96.6	118.5	212.4	1072
L.S.D. (19:1 odds)				6.0	25.8	40.9	82.1	85
Mean		4.74	10.0	30.7	73.9	104.9	179.6	937

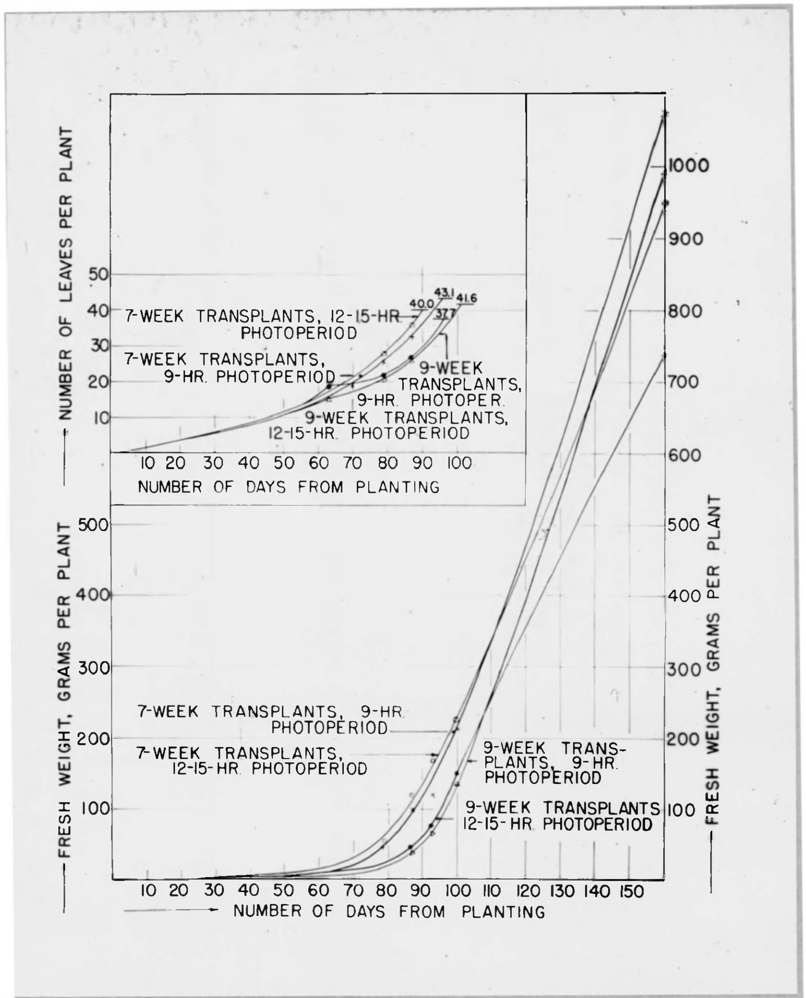

Figure 3. Experiment I. Growth curves (fresh weight), rate of initiation of nodes and mean number of nodes initiated before differentiation of the inflorescence primordia in cauliflower varieties Safir and Snowball A. Different treatments given during propagation in coldframes.

Experiment II. Effects of Moisture Supply and Variety

No significant differences were found in Experiment II, (Table 8). This may have been due to the rainy spring season and the leaky frame windows which caused interruption of the treatments, but it may also have been due to the small size of the experiment (only 7 degrees of freedom) hence it may be stated low moisture in the seedling stage seems to be beneficial rather than detrimental.

Experiment III. Effects of Pruning and Variety

This experiment was planned to test the effect of pruning on the subsequent development and was bound to give results because of the drastic treatments (Table 9). The idea behind the experiment was that pruning would cause a decrease in leaf area and, thereby, decrease photosynthesis. The decreased photosynthesis would again cause a decreased CHO/N ratio and an increased initiation of vegetative organs (leaves). The leaf number of the pruned plants was 7 leaves higher than the unpruned plants. This was the highest increase in leaf number obtained. Whether it was followed by biochemical changes is not known since the material was not analyzed.

Experiment IV. Effect of Temperature During the Seedling Stage and Variety

Only two of the four varieties included in this experiment headed before the outside temperature became too warm. The result of the experiment was, therefore, calculated as a 2 x 2 factorial experiment and is presented in the same way as the other experiments (Table 10).

Significant differences between varieties were the only effects found in this experiment. It is interesting to note, however, that the mean

Table 8. Experiment II. Factorial effects in weight of plants, in weight of heads, in number of days from transplanting to ½ of the plants were harvested, and in number of leaves per plant.

Factors compared	Total weight of plants kg. plot	Total weight of heads kg. plot	Days from transplanting to ½ harvest	Number of leaves per plant
Low moisture supply vs. normal moisture supply in the seedling stage	+ 2.2	+ 0.72	+ 5.2	+ 4.1
Variety Safir vs. Variety Snowball A	+ 1.1	+ 1.13	+ 4.4	+ 2.3
Moisture x Variety	- 2.2	- 0.46	- 3.8	- 5.4
L.S.D. (19:1 odds)	NS	NS	NS	NS
Mean	16.5	5.97	71.0	42.3
Coefficient of variability (per cent)	12.9	17.4	4.5	7.0

Table 9. Experiment III. Factorial effects in weight of plants, in weight of heads, in days from transplanting to 1/2 of the plants harvested, in number of leaves per plant and in head density.

Treatments compared	Total weight of plants kg. plot	Total weight of heads kg. plot	Days from transplant-ing to 1/2 harvest	Number of leaves per plant	Density of heads
Not pruned vs. pruned	+ 24.0	+ 6.0	- 10.2	- 7.3	- 0.24
Variety Safir vs. Variety Snowball A	+ 3.5	+ 1.5	- 3.4	- 0.3	- 0.02
Pruning x variety	- 0.8	+ 0.5	+ 1.5	+ 3.4	± 0.00
L.S.D. (19:1 odds)	3.3	1.0	5.1	4.1	NS
Mean	25.9	5.5	77.7	27.0	0.75
Coefficient of variability (per cent)	3.9	7.7	2.9	3.8	21.7

Table 10. Experiment IV. Factorial effects in total weight of plants, total weight of heads, number of leaves per plant and density of heads.

Factors compared	Total weight of plants kg. plot	Total weight of heads kg. plot	Number of leaves per plant	Density of heads
Not exposed to low temperature vs. exposed to 40° F. for 30 days	+ 0.51	- 0.07	± 0.00	+ 0.02
Variety Snowball M vs. var. The Forbes	+ 1.47	+ 0.36	+ 4.0	+ 0.19
Temperature x varieties	- 0.32	+ 0.06	+ 0.3	- 0.00
L.S.D. (19:1 odds)	1.03	0.31	0.7	0.06
Mean	13.08	2.41	33.6	0.70
Coefficient of variability (per cent)	6.98	11.40	1.85	7.14

leaf number for both varieties was very much lower than that encountered in the three previously described experiments.

Discussion

The title of this chapter contains the words growth and development. Neither of these two words have one and only one specific meaning. Thus growth may be either an increase in fresh weight, an increase in dry weight, an increase in the size of the plants, or an increase in the size of a particular organ. Growth means increase in fresh weight for the purpose of this thesis unless otherwise stated.

The English word development is commonly used to describe changes which take place. If there are no changes there is no development or if there are changes in a particular direction, there is development in that direction.

The introduction of the concept of vernalization confused the terminology. The word development has been defined by authors as the progress of a plant toward the completion of the life cycle viz. the production of flowers, fruits and seeds. One does not agree to such a limitation of a common descriptive term and the word development is used to describe progressive changes which take place.

The first question which the experiment was designed to answer was whether premature heading occurred in cauliflower. A high correlation existed between the number of leaves and earliness as reported elsewhere.[1] This means that the number of leaves can be used as a measure of premature heading and that a decrease in the number of leaves of treated plants, compared to check plants, must be considered as a measure of premature

[1] Section III.

(earlier) heading. Only one of the treatments given the transplants showed a decrease in the number of leaves, namely, the use of 9-week old transplants. The difference compared to the 7-week old check plants was not high although it exceeded the 5 per cent level of significance. However, an interesting fact was brought out by a summary of the mean leaf number in the same variety in the different experiments and observations made. Such a summary is given in Table 11 for the varieties Safir, The Forbes and Snowball M. It is apparent that only a small part of the variation among the means occurred within the experiments where the environmental factor, responsible for it, could have been identified. Most of the variation was encountered between the different tests and could, therefore, not be assigned to any particular environmental factor. The conclusion is that premature (earlier) heading occurs in cauliflower, but only environmental factors modifying, not determining the leaf number, have been identified since the main difference among the mean leaf numbers within the varieties occurred between experiments not within the experiments.

What answer does the experiment give to the next question, namely, is premature heading the same as buttoning? It is shown in Experiment I that the 9-week old transplants headed prematurely and this was followed by an increase in buttoning. The entire experiment at the University of Maryland headed prematurely and most of these plants buttoned also. The conclusion that premature heading is the same as buttoning seems, therefore, obvious but should be questioned for two reasons. First, an increased number of leaves was also associated with buttoning in the pruning experiment, and second, plants were encountered which produced excellent heads with as low or lower number of leaves than in the premature heading plots. The question is thus left open, although one feels confident that

Table 11. Summary of range in variation in mean number of leaves per plant within varieties observed under different environmental conditions.

Variety	Environmental conditions	Mean number of leaves
Safir	Variety test, Lewiston, Idaho	41.4
"	Long day, young transplants, Expt. I	41.4
"	Long day, old transplants, Expt. I	39.1
"	Short day, young transplants, Expt. I	45.1
"	Short day, old transplants, Expt. I	44.4
"	Not pruned, Expt. III	44.9
"	Pruned, Expt. III	52.4
"	In greenhouse, Moscow, Idaho*	29.0
The Forbes	In variety test, Lewiston, Idaho	37.4
" "	Not exposed to cold, Expt. IV	31.4
" "	Exposed to cold, Expt. IV	31.7
" "	Planted directly in field, Maryland 1950*	58.0
Snowball M	In variety test, Lewiston, Idaho	50.8
" "	Not exposed to cold, Expt. IV	35.7
" "	Exposed to cold, Expt. IV	35.4
" "	Planted directly in field, Maryland 1950*	67.0

*Not reported elsewhere.

excellent yields may be obtained from premature headed plants, but that the danger of buttoning is increased if the plants are exposed to an environment which promotes premature heading.

The Idaho tests confirmed the experiments by Carew et al (14). The exposure of transplants to a 9-hour photoperiod increased the yield and decreased the danger of buttoning. The leaf counts showed that this increase in yield was associated with an increased number of leaves and delayed maturity. This effect of a 9-hour photoperiod is called post mature heading. Low moisture for the seedlings gave a similar effect although the effect did not exceed the 5 per cent level of significance. Babb (3) found that high nitrogen application to seedlings decreased subsequent yield. Thus it seems that transplants raised under luxurious conditions cannot compete with the ones exposed to moderate conditions.

The beneficial effect of using young transplants as recommended by Carew et al (14) on the basis of their experiments was confirmed. An explanation for these recommendations can be found from the sampling data and curves for leaf initiation and growth of plants constructed from the data. Early transplanting gave the plants ample time for establishment in the field before initiation of the inflorescence, while initiation occurd in the flats or shortly after transplanting to the field on the older transplants. This resulted in buttoning. An interaction between varieties and age of transplants was expected and also found. This interaction might have been larger if the difference between varieties had been more pronounced.

The results of these experiments must be considered negative from a commercial point of view since the treatments of the transplants recommended in order to raise the yield also delayed maturity. If higher yields are desired they can be obtained more cheaply by the selection of later varieties.[1] If earliness is desired one may use larger and, therefore, older transplants and can avoid check in growth at transplanting time by use of transplants with an undisturbed root system.

Summary

Premature heading was found to occur in cauliflower but the condition of premature heading could not be assigned to a specific environmental factor since it occurred between experiments and not within an experiment.

Premature heading was associated with buttoning under certain conditions, but buttoning also occurred without premature heading and premature heading occurred without buttoning.

The danger of buttoning was increased if the plants were exposed to an environment favoring premature heading since the heads were initiated earlier, thus giving the plants shorter time for establishment in the field.

A 9-hour photoperiod increased the number of leaves as did low moisture in the flats and pruning of the plants. This may be called post mature heading.

The increase in the number of leaves was followed by higher yield except in the pruning experiment and also by delayed maturity. These beneficial affects may be obtained at no additional cost by the selection of later varieties.

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[1]See Section III.

VITA

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