Influence of chemical bud pruners on concentration of fruit ripening for mechanized harvest in the cultivated strawberry, *Fragaria* x *ananassa* Duch.

by

Elden James Stang

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
DOCTOR OF PHILOSOPHY

Major: Horticulture

Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

For the Major Department

Signature was redacted for privacy.

For the Graduate College

Iowa State University
Ames, Iowa

1973

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I. INTRODUCTION

A. Preamble

In recent years the need for a mechanized system of harvesting for strawberries has become increasingly apparent. The decreasing availability of harvest labor, high labor costs and steadily increasing imports of lower cost berries produced outside the U.S. stresses this urgent need for a means to facilitate harvesting for producers in this country.

The nature and growth habit of the strawberry plant, its morphology and fruit ripening pattern, frustrates any effort to develop any single or simple system of culture encompassing all the varied combinations of soils and climates in which strawberries are grown. It is this uniqueness of the strawberry which also can and has often frustrated attempts at picking the fruit by machine with minimal injury and at the peak of yield, ripeness and quality. The sequential fruit development and maturity over a 2 to 3 week period would, in any attempts to harvest sequentially, require a technology which at present is far too costly or too complicated for the many medium or small-sized commercial operations ranging from 30 to 100 acres.

Since much of the industry will thus be left with the alternative once-over mechanical harvest, at least for fruit to be processed, the economic feasibility of any mechanized harvesting system will depend primarily on the total yield of

commercially acceptable fruit obtained at any given time. This total yield will be a function of both the capabilities of the machine and the concentration of fruit ripening of the particular cultivar to be harvested at any given time in its particular harvest period.

The literature review, however ponderous or fragmented it may appear, is this writer's attempt to bring together those aspects of the mechanization of strawberry harvesting considered to be of greatest current interest and importance. Other factors not immediately apparent will undoubtedly surface within the near future as industry needs change and research efforts converge on those needs.

B. Objectives

The objectives of the studies outlined here are to examine some of the influences of chemical bud pruners on subsequent plant behavior, fruit development and maturity. A second objective which developed as work progressed is to evaluate the potential application of some objective measures of fruit maturity to a rapid procedure for determining yield potentials in once-over harvests of existing cultivars and selections.

II. REVIEW OF LITERATURE

A. The Status of Strawberry Harvest Mechanization

The need for a mechanized harvesting system for strawberries is no longer questioned by most research workers, commercial growers or processors involved in this highly specialized industry. Producers and processors increasingly voice concern over the decreasing availability of harvest labor, high labor costs and increasing economic pressure from imported lower-priced berries. Along with other production costs, costs for hand harvesting have spiralled so that harvesting expenses may now account for 1/3 - 3/4 of the total (22). In the past 2 decades, imports of frozen strawberries produced and packed in Mexico increased tenfold from 10 million pounds in 1953 to 103 million in 1969, approximately half the U.S. consumption of frozen strawberries for the latter year (36). The price per pound delivered in Michigan was 16¢, a price reflecting substantially lower labor costs and below the price at which Michigan growers could deliver strawberries to the processor. In 1970, the Mexican strawberry industry applied a self-imposed export quota of 80 million pounds of frozen strawberries to stabilize prices and reduce glutting on the U.S. market.

Probably the greatest problem facing most commercial growers in the U.S. at present is the lack of availability of an adequate number of pickers at harvest time. Although there

is some promise of a reduction in labor costs through machine harvesting, initial studies comparing hand harvesting costs with costs of machine harvesting indicate that mechanized harvesting probably will not reduce costs appreciably (22). The greatest benefit from a mechanical harvester thus would probably not be measured solely in terms of potential reduced labor costs but in the ability to get the fruit harvested at the proper time. Since all prototype harvesters developed to date involve a once-over picking, losses of green and damaged fruit will substantially reduce total yields. If labor availability continues to decrease, the most important advantage provided by machine harvesters, at least in the early stages of development, will be their ability to get the fruit out of the field at the peak of yield, ripeness and quality.

These losses in green and damaged fruit in once-over mechanical harvesting stress the importance of several other features involved in mechanization. Denisen at Iowa State University was perhaps the first strawberry breeder to become aware of the need for concentrated ripening clones which ripen all or most of the usable fruit at one time[1]. Other breeders have since initiated programs with the objectives of producing strawberry cultivars or evaluating existing cultivars with characteristics adapting them to a once-over harvest,

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[1]Denisen, E. L., Iowa State University, Ames, Iowa. Personal communication, 1973.

including such characters as concentrated ripening, and increased firmness and resiliency of flesh to withstand mechanical handling (49, 61, 66, 67). In addition, the need for a functional, efficient capping machine capable of rapid and clean calyx removal becomes increasingly apparent as mechanized harvesting approaches the point of becoming a commercially feasible reality. At present, fruit destined for processing and freezing is capped by hand in the field by pickers before being brought into the processing plant. The large volumes of fruit gathered rapidly by a machine harvester will require an efficient mechanical means for calyx removal, theoretically providing an additional reduction in cost to the processor. Damage levels normally incurred in existing machines indicate that rapid processing within a period of several hours will also be required to reduce losses of fruit to a minimum.

Since 1959, when Iowa State University first initiated a program to breed and select strawberry cultivars for machine harvesting, a number of universities have developed prototype strawberry harvesters (2, 3, 34, 37, 60). These institutions include Iowa State, Illinois, Oregon State, Arkansas, Louisiana State and Guelph (Ontario). More recently Michigan State University and the University of California have developed or are in the planning stages for development of harvesters (59). Except for two prototype harvesters developed recently at Iowa State University, all of the machines

designed to date employ a stripping or scooping action of various types of tines or teeth for fruit gathering and removal (83, 84). One type developed in Oregon mows fruit and leaves in clusters (46). All of these harvesters, except the University of California's (presently in the planning stages) are also designed only for once-over picking. With these systems, total usable fruit generally is reduced 25 - 40% with up to 40% requiring immediate processing due to bruising (59).

A number of features existing in present prototype harvesters appear to be unique and adaptable in terms of reducing injury to fruit in picking or handling. The initial model of the University of Arkansas harvester used a pneumatically assisted stripping unit in which high velocity air at approximately 6000 feet per minute was used to lift the berries off the ground, allowing the stripping fingers to pick the fruit with reduced injury (60). A more recent commercial model of this unit built by Blueberry Equipment Manufacturing Co., Michigan has been tested and apparently will be available for the market in 1973 (55). In another innovative development using an air blast, Quick and Denisen at Iowa State University designed a prototype model in which an air blast is used to carry picked fruit up an inclined plane from the picking head to a collection conveyor (68). At Oregon State University, two prototype harvesters named the "Stripper" and the "Clipper" have been tested (3, 46). The "Stripper" employs tines designed to move at right angles to the direction of travel,

across the fruiting bed. A newer machine, the "Clipper" mows off the fruit and leaves at ground level, harvesting entire fruit clusters. The fruit clusters are then run over a "cluster breaker" to remove the fruit from the trusses. The "cluster breaker" consists of a series of power driven rollers with a wringing action. Fruit removal is accomplished as the fruit stems are pulled through the rollers. Fruit harvested by this system is destined solely for processing due to damage in the mechanical destemming and capping operations. Commercial adaptation of the destemmer has not been reported.

The Louisiana and Illinois programs in mechanical harvesting are apparently now in an inactive stage. Both harvesters employed a stripping tine system for fruit removal.

Because of high damage levels obtained with existing machine harvesters, a different system of cultivation and fruit removal was proposed in 1970 at Iowa State University for fresh market fruit (83). In this system, plastic netting is laid on the strawberry beds just prior to growth in spring. Leaves and fruit trusses then grow through the netting with fruit forming on top of the netting. The machine proposed for this system is designed to pick up the netting, mow off fruit trusses below the netting, transport the fruit on the netting to a collection conveyor and roll up the netting for subsequent storage and reuse. Initial tests suggest sharply reduced fruit injury levels with this system. The program is now in an inactive stage pending work on a simpler system not

requiring the somewhat detailed cultural methods inherent in the use of the plastic netting.

In 1972, a new prototype harvester employing flexible vinyl tips, counterrotating in pairs was built and tested at I.S.U. (84). The vinyl tips, cone-shaped with a series of spirally arranged ridges, were effective in both pickup, fruit removal and transport for a short distance. Damage to fruit, when compared with stripping tine harvesters, was reduced from 25 - 30% to 5% or less in small samples obtained in testing. In January 1973, the vinyl-tipped picker head was turned over to Blueberry Equipment, Inc. for testing in combination with the pneumatic fruit pickup system developed by Arkansas researchers.

In California, high yields obtained in multiple pickings over a long growing season will require that any mechanical harvesting system for strawberries must be capable of multiple selective picking without serious injury to plants. Proposed methods for this type of harvest by mechanical means are still in preliminary stages. It appears likely that any machine designed for multiple pickings will be complicated and expensive, pending a breakthrough in technology which could reduce its complexity and cost.

Although it is important, mechanized harvesting is merely one phase in the mechanization of strawberry production currently being investigated. The diversity of cultural practices involved in strawberry production in the various

regions of the U.S. indicates that considerable work remains to be done in establishing machine harvesting as a commercially feasible means to perhaps lower production costs and more importantly, alleviate problems in obtaining adequate labor for harvesting. In addition, experience in initial phases of mechanization underscores the need for an integrated systems approach. In other words, research on innovative cultural systems and methods of mechanically capping or destemming and handling fruit in large volumes must proceed with mechanized harvesting research before mechanized strawberry production can become a commercial reality. Cultivars adapted to such cultural systems and mechanized handling are yet to be developed and tested on a scale required by such a drastic change in strawberry production methods. For smaller commercial growers, the pick-your-own system of marketing in which the public is permitted to pick fruit for a fee, provides at least an interim solution to harvesting and marketing problems. For many, this system may well become a permanent method for remaining in strawberry production. For others it can simply be a bridge between traditional marketing and harvesting methods and a future system of mechanized strawberry production and harvesting.

B. Chemical Thinning or Chemical Pruning of Fruits, Flowers or Buds: Some Applications and Limitations

Thinning flowers, fruits or buds either through chemical or mechanical means for the purpose of promoting earlier flowering, increased fruit or flower size, timing harvests, or regulating alternate bearing is a common practice in horticultural crops (17, 24). Sachs and Hackett have outlined the methods of controlling plant height, the types of chemicals which have been used and the mode of action of these materials on various horticultural crops (73). Many of these materials including terminal bud killers or inhibitors such as ethylene, fatty acid esters, maleic hydrazide, napthylphthalamic acid (NPA), triiodobenzoic acid (TIBA) and succinic acid-2, 2-dimethylhydrazide (SADH) have been tested for potential height control in plants. Because of their effects in disturbing meristematic activity, except in the case of the fatty acid esters, most of these chemicals have not shown promise for fruit thinning where normal leaf and flower initiation are necessary. Fruit crops, especially apples have long been thinned for improved quality and the regulation of alternate bearing (93). Auchter and Roberts initiated research in the early 1930's on chemical spray thinning of apples with the purpose of entirely defruiting trees of varieties that did not produce adequate financial returns to growers (4). Emphasis then shifted to spray materials which might reduce excessive fruit set to aid in modifying the alternate bearing tendency

in varieties prone to overbearing biennially. Commercial preparations of dinitro-ortho-cyclo-hexyl-phenol and related dinitro compounds including the sodium salt, dinitro-ortho-cresol demonstrated to produce thinning by physical injury to blossoms and physiological shock to trees, were the first promising materials to be evaluated (28, 51, 53). During that same period a series of synthetic growth regulating chemicals, particularly naphthaleneacetic acid (NAA) and naphthaleneacetamide (NAD) were found to be effective in thinning apple fruits when used at low concentrations (13). Of equal significance was the discovery that these materials were effective after the blossom stage and generally after the danger of frost had passed (21). In 1960, Batjer and Westwood reported on the effectiveness of Sevin, 1-napthyl n-methyl-carbamate, a carbamate insecticide, in postbloom thinning of apples (7). Since then the commercial use of Sevin as a fruit thinner has become widespread.

Safe, effective flower or fruit thinning with chemicals in Prunus sp. has not progressed as rapidly as with the apple, due to the propensity of injury to foliage, fruits or shoots, premature fruit softening, or the danger of postbloom frosts (93). The most extensive research on thinning in this genus has been performed in the peach although plums are frequently thinned with chemical sprays where postbloom frosts are not a problem. Elgetol, a trade name for dinitro-ortho-cresol, is fairly effective in arid regions or areas where frosts are not

a problem (17). Response is highly dependent upon weather, tree vigor, intensity of bloom and fairly precise timing. Underthinning is recommended followed by manual thinning with clubs or shock wave shakers. In the past decade 2,3-dichlorophenoxypropionamide (CPA), a hormone, has been demonstrated to be effective in thinning peaches 3 - 4 weeks after bloom (87). Proper timing is essential; at least four methods for timing of the application based on the stage of early fruit development have been outlined and are specific for a variety (27). The optimum period for thinning in the peach with this compound is apparently a relatively short period during endosperm cytokinesis when rapid cell division is occurring (11). The concentration of 3-CPA used has also been shown to specific for a cultivar. "Ethrel", the generic name for 2-chloroethylphosphonic acid is also effective in fruit thinning in peaches (87). Both 3-CPA and Ethrel result in an increased rate of ethylene evolution from immature fruits, although the patterns of evolution differ significantly. "Ethrel", commonly called "Ethephon", has stimulated a prodigious wave of research on the physiological influences of this compound on flowering, vegetative growth and dormancy, abscission, ripening and maturity, freeze and disease resistance and latex flow in plants (96). Promising results in flower or immature fruit thinning in apples, pears, citrus, peaches, prunes, plums, coffee, coconut, tomato and banana have been reported, along with a host of other potentially beneficial morphological and physiological

responses in plants.

Fruit, flower, or bud pruning or thinning in a wide variety of floricultural and ornamental crops is also a common practice. Ornamental trees and shrubs which bear objectionable fruits causing unsightly litter or unpleasant odors, attract insects or interfere with equipment movement under or around them can be sprayed with "Ethephon" for early abscission (96). Reduction or prevention of fruit set has been reported in the olive, black cherry, crabapple and coconut palm. Because of its wide spectrum physiological effects on a variety of plant tissues, the use of Ethephon as a pruner or thinner in floricultural crops may be limited, particularly since leaf abscission in actively growing tissue would likely occur.

The possibilities for selective meristem killing or bud pruning with fatty acid derivatives and their analogs were first outlined by Tso and McMurtrey in 1963, based on work done in the late 1950's (90). In this and a subsequent paper they reported that methyl esters of C^8 to C^{12} saturated fatty acids and C^8 to C^{12} fatty alcohols produced selective terminal kill on axillary shoots or suckers of tobacco without injury to the rest of the plant (89). The C^{10} ester, methyl decanoate, was most active in producing terminal kill. In an experiment with several tobacco cultivars, results were similar using methyl, isopropyl, and butyl esters of C^6 to C^{18} fatty acids in combination with the herbicide isopropyl N-(3-chlorophenyl) carbamate (CIPC) and the addition of surfactants

(91). Nine, ten and eleven carbon chains were most effective in pruning. Sucker control was prolonged with CIPC but resulted in leaf distortion. Isopropyl and butyl esters produced only partial injury; the addition of surfactants enhanced penetration and injury to sucker meristems but did not produce control equivalent to that obtained with methyl esters. Cathey et al. (14, 15, 16) and Steffens et al. (85, 86) extended subsequent tests to include a wide variety of plants ranging from herbaceous floricultural species through semi-woody and woody ornamentals. Observations indicated that the effective range of non-phytotoxic, terminal killing concentrations are narrower for the fatty alcohols than for the esters of fatty acids. Stage of growth determined plant sensitivity, i.e., actively growing meristems were required for effective bud kill. Selectivity of pruning or thinning was lost if both terminal and axillary meristems were in an active stage of growth. At normal rates of methyl decanoate ranging from 0.025 - 0.05 M for herbaceous materials, 0.05 - 0.16 M for semi-woody and 0.16 - 0.27 M for woody plant materials, terminal meristems enclosed in sheaths were not injured. Increasing rates to levels sufficient to kill protected terminals produced injury on leaf tissue on the same plants. All parts of seedlings treated were damaged, while dormant plants showed no apparent injury at the prescribed rates. Promising results with azaleas and chrysanthemum prompted Furuta et al. (26) and McDowell et al. (54) to publish tentative recommendations for commercial

applications on these crops. The rather specific conditions outlined for successful pinching stress the somewhat erratic results which might be obtained with their use. In azaleas: 1) only certain cultivars were responsive, 2) plants were to be watered within a short time before use, 3) foliage must be dry, 4) no pesticides could be applied one week prior to treatment, 5) plants were to be syringed 17 minutes after treatment to remove the chemical trapped on leaves, and 6) ambient temperature must be within 70 - 78° F. Recommendations on chrysanthemums were similar. The specificity of these recommendations may explain why chemical thinning or pruning with methyl decanoate has not yet become a widespread commercial practice.

Uhring examined the effects of spray applications of methyl decanoate in sectioned buds of chrysanthemum collected at intervals from one minute to 216 hours after treatment (92). He concluded that the chemical entered rapidly and bud kill occurred within 15 minutes, as evidenced by breakdown of the nuclear membrane and dispersion of the nucleoplasm throughout the cell. Blackening of cell contents occurred within 45 minutes. Where excess runoff occurred, damage downward on the stem was confined largely to the two outer cell layers of the epidermis. In cells lacking protoplast, superficial damage was not apparent until final stages of tissue and organ destruction occurred in living cells. Diffusion and gravity determined the rate and direction of injury to the

cells.

In a similar investigation on relationship of azalea bud morphology and response to methyl decanoate, Sill and Nelson (75) reported that the abnormally long enclosing sheath of leaves and the greater number of trichomes per unit area of leaf surface within the sheath on vegetative buds apparently accounted for erratic or poor response to the pruning chemical in 'White Gish'. In 'Coral Bells', a cultivar categorized as readily responding, the reduced number of trichomes and shorter clasping leaf sheaths apparently facilitated contact of the spray with the enclosed meristem. In comparing vegetative vs. reproductive buds on 'Red Wing', a cultivar intermediate in difficulty of pruning, it was observed that a greater number of leaf primordia layers in young reproductive buds and the thick cuticle on scales of older reproductive buds apparently reduced penetration of the pinching agent. In the vegetative bud the fewer number of overlapping leaves permitted penetration of the spray, apparent in the injury to the meristematic tissue.

The effects of environmental factors on response of azalea buds to methyl esters of fatty acids, particularly air movement and preconditioning temperatures were investigated by Brabson and Lindstrom (10). Controlled air movement at rates of 8. - 10 m.p.h. in wind tunnels for 5 hr. after treatment were demonstrated to have no significant effect on shoot apex necrosis. Preconditioning temperatures of 50° F night - 60°

day and 80° night - 90° night were maintained for 10 days prior to treatment. Plants maintained at the low temperatures prior to treatment were satisfactorily pinched even at concentrations below the 3 - 5% normally recommended for azaleas. The authors considered that this phenomenon resulted from the possible slowing down of metabolic activity and retarded reproductive development in plants preconditioned at lower temperatures.

The mechanism for selectivity in different tissues of chrysanthemum has since been investigated (62). Unlike azaleas, selectivity in chrysanthemum is apparently a property of the cuticle thickness which acts as a penetration barrier. With undisturbed cuticle small quantities of methyl decanoate penetrate resulting in only moderate and reversible alterations to the ultrastructure of the cell. The alterations, visible in electron micrographs, appear as aggregates of vesicles in the cytoplasm and vacuole. No destruction of organelle membranes occurs, and symptoms visible to the eye are not detected. With disrupted cuticle, however, membrane destruction of organelles occurs rapidly. Another investigation on the effect of methyl decanoate on ultrastructure and rates of disruption showed that membrane disruption could be closely timed with the browning of shoots or flowers (63). Within one minute after cell penetration vesicles formed within the nucleus followed shortly thereafter by nuclear membrane disruption. In the same study red cabbage anthocyanin was

observed to leak from vacuoles after 10 minutes. Thus, the permeability properties of the plasmalemma and tonoplast membranes are apparently lost about the same time nuclear membrane destruction occurs.

In vegetables, flower, fruit, or bud thinning has received greatest attention on crops which are destined for a once-over harvest, eigher by hand or machine. Flower bud abscission and concentration of fruit set in tomato after treatment with "Ethephon" has been reported (29, 43). In Brussels sprouts, growers have occasionally practiced manual cutting or pinching of the terminal bud to stop further development, increase yields or promote uniformity in size of the remaining sprouts. The value of this practice is apparently controversial (19). Cutliffe's results on the effect of time of disbudding on single-harvest yields and maturity indicates total marketable yields from plants disbudded prior to the 9-whorl stage are actually reduced when compared with single-harvested unpruned plants. Plants terminal pruned at the 9-11 whorl stage did not differ significantly in yield when compared with the single-harvested unpruned plant. Optimum harvest period was advanced by 12-14 days on plants disbudded early at the time the first whorl of buds was formed. The advantage cited was the ability to adjust harvests by timing of terminal bud removal. Chemical pinching has not been reported.

C. Concentrated Ripening and Objective Measurement of Maturity in the Strawberry

Historically, strawberry breeding and research on strawberries has always been directed toward varietal development and cultural methods which would result in relatively long picking seasons and large-fruited cultivars which would ripen at fairly constant rates to spread picking loads throughout the season (20). As the need for mechanization of harvesting has become increasingly apparent, however, new objectives for breeding programs have been outlined for strawberries (2, 59, 66). Denisen[1] was probably the first breeder to extensively select for concentrated ripening and other characteristics such as easy capping or brittle pedicel, and firmness or fruit flesh resiliency (23). At least four other breeding programs now are actively selecting for these same characteristics to facilitate picking and subsequent capping operations (23, 36). Although some progress has been made, no cultivar combining all or most of these characteristics has yet been described or released. Several existing cultivars showing some degree of concentrated ripening have been evaluated (2, 20).

Recently, Moore and Brown evaluated 26 strawberry cultivars and selections for concentration of ripening by comparing single harvest yields with multiple harvest yields in the same cultivar (57). Harvested fruit was graded into five classes

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[1]Denisen, E. L., Iowa State University, Ames, Iowa. Personal communication, 1973.

including decayed, acceptable, color inception ("pink" stage), mature green and immature green. In no instance did any clone yield over 40% acceptable fruit at any single harvest. Peak yields in 'Surecrop' and 'Tennessee Beauty' were obtained when the single harvest corresponded with the fifth picking of the control multiple harvest. Environmental effects were also noted; in one season 'Surecrop' produced higher yields than 'Tennessee Beauty' while the reverse occurred the following season.

Although breeding for concentrated ripening in the strawberry shows promise, there are undoubtedly other approaches worthy of investigation. Although no promising results have as yet been reported the use of growth regulators to enhance ripening rates of green fruit in the field has been suggested (57, 59). Limited testing of "Ethephon" in the field and greenhouse has not demonstrated a noticeable effect on ripening rates when applied at rates up to 2000 ppm at the mature green stage[1]. Fruit in the color inception ("pink") and mature green stages could contribute substantially to increased total single-harvest yields if methods to economically ripen these fruits were developed (57). Fungicides to retard decay in the field or growth regulators to retard maturation in ripe fruits could possibly permit more fruit to ripen on the plant before machine harvest (6, 57). Development of the latter would

[1]Stang, E. J., Iowa State University, Ames, Iowa. Unpublished data, 1971.

undoubtedly require more extensive knowledge of the biochemical, nutritional and hormonal relationships in ripening fruits. The subject of this thesis, chemical pruning of flowers as a possible means for concentrating ripening, is the outgrowth of previous work in which concentrated ripening selections were compared with existing cultivars in both pre- and post-anthesis morphological development of inflorescences (82). In addition to retarded development of late flowers within inflorescences, increased abortion of flowers in concentrated ripening clones apparently contributes to more uniform ripening in the remaining fruits, although the cause for this response has not been established.

Janick and Eggert also suggest induced abortion or pruning of late flowers as a possible means for promotion of concentrated ripening in existing cultivars (44). In analyzing factors affecting fruit size in the strawberry they noted removal of primary blossoms significantly increased secondary fruit weight. Removal of inferior or late blossoms affected size of remaining fruit only slightly. Although no data on ripening rates with selective removal of fruits were reported, their suggestion to achieve uniform ripening is the selective removal of either primary or late blossoms. Possible effects of losses in yield of economically desirable large primary fruit are questioned, however.

Once-over harvests of crops normally harvested over an extended period of time stimulates interest in the characteri-

zation of ripening patterns and rates in order to determine periods of peak ripening for maximizing yields of acceptable fruit. Mechanized harvesting of processing tomatoes initiated a host of studies on plant behavior and fruit removal characteristics which will undoubtedly influence related research on other crops with potentials for machine harvesting (5, 50, 69, 76).

Evaluations of similar factors for the strawberry have not progressed beyond initial stages. Culpepper et al. (18) in 1935 reported on an evaluation of changes in puncture resistance, total soluble and insoluble solids, astringency, acidity and sugar content in strawberry cultivars which has since provided the background for discussion of physiological changes during development. In general, earliest stages of fruit development are characterized by high total solids, low sugar content, moderate to low acidity and high astringency. The period of rapid increase in size of fruit coincides with a progressive increase in water content and decline in total solids and astringency. In early stages of increase in size, a moderate decline in soluble solids is observed which becomes stationary while sugars increase. Titratable acidity increases up to the white or mature green stage. As maturity proceeds, a marked increase in soluble solids and sugars occurs, total solids increase slightly, and titratable acidity decreases. Firmness of the fruit decreases throughout the whole period of development with the most rapid decrease occurring as fruit

changes from mature green to color inception ("pink") stages.

Aside from this early work and Moore and Brown's initial evaluation of strawberry cultivars and selections for once-over harvest, no other concerted effort to characterize cultivar field ripening patterns has as yet been reported (57). Quality evaluations on single harvested fruit of 'Tennessee Beauty' and 'Surecrop' obtained in their work were reported in 1971 (80). Objective quality measures including color readings with the Hunter Color Difference Meter, percent soluble solids, percent total solids, percent total acids, ascorbic and dehyro-ascorbic acid, pH, puree viscosity, shear press and mold count determinations on fresh fruit and fruit acceptable for processing were obtained for single harvests corresponding to the 3rd, 5th, 7th and 9th harvests of a multiple hand picked control. Except for Hunter Color Difference Meter (CDM) "b" readings and percent total acids, significant differences between dates of single harvests were obtained in all other criteria measured. In addition, the data appeared to reflect increasing levels of sound ripe or overripe fruit as dates of harvesting progressed, strongly suggesting that these criteria could also be effectively used to objectively characterize concentrated ripening in the strawberry.

In attempting even an initial foray into the literature on biochemical and physiological research on fruit ripening and post-harvest physiology, one soon encounters a store of information which at the very least appears formidable and at

a second glance, unconquerable. Fortunately, Hulme has recently compiled and edited an excellent series of monographs which effectively bring together the various biochemical and physiological aspects of ripening, maturation and post-harvest development in dessert fruits (39, 40). Although this series deals primarily with those interrelationships of biochemical and physiological changes in ripening and senescing fruits as they may pertain to quality, an examination of the literature outlined soon convinces the reader that these same changes can assist in objective attempts to define and describe maturation, ripening and senescence in horticultural fruits.

In the small fruits, particularly the strawberry, ample literature on quality characteristics exists to suggest that certain physical and biochemical changes occurring in the fruit during maturation and ripening could be used as more precise objective measures of these subjective classifications. Growth changes, including volume, weight and color changes have been measured. Abbot and Webb have shown that fresh berry weight is highly correlated with achene number and achene spacing and that increasing achene spacing is related to receptacle development (1). Janick and Eggert have observed that fruit weight per achene declines with inferior blossom positions (44). Since maturation and coloring of fruits within an inflorescence proceeds sequentially downward in the same direction as fruit size or weight the measurement of these characteristics could possibly provide at least a

partial objective measure of maturation and ripening. This principle has been shown to be effective in mechanized size grading of strawberries from once-over machine harvested plots in Arkansas[1]. In the boysenberry, Rohrer and Luh have shown that fresh fruit weight increases steadily in boysenberries from under-ripe to over-ripe stages of their development (71). In the same report glucose and fructose, the predominant sugars, were observed to increase progressively with increasing stage of maturity. Titratable acidity decreased as maturity progressed; citric and malic acids in particular decreased rapidly during maturation. Citric acid accounted for 79.6 - 86.1% of total acidity along with 8.3 - 17.9% malic acid. Total solids did not vary appreciably in under-ripe through over-ripe stages of maturity.

Although total solids determinations for mature strawberries have frequently been reported, data on systematic evaluations of changes in total solids content of developing strawberries are not generally available (18, 56, 80). Typical values for percent dry weight obtained by drying and subtraction of moisture range from approximately 9 - 10%, with total sugar content reported as approximating 5% of this total (18, 80). In once-over harvests at intervals in the picking season, percent soluble solids were observed to increase from 6.8 - 7.4% as the percent sound over-ripe fruit increased with

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[1]Morris, J. R., University of Arkansas, Fayetteville, Arkansas. Personal communication, 1972.

harvest dates (80). As an objective test for quality, soluble solids consistently showed greater differences than did total solids. The same relationship holds in an examination of changes in the soluble and total solids in fruit at various stages of ripening as reported by Culpepper et al. (18) on fruit of different cultivars ranging from small green to over-ripe stages.

Organic acids are the second largest contributor to the soluble solids of small fruits. Citric acid is the predominant acid in most small fruits with the highest values, approximately 4.5% calculated as % w/w total acids, reported in the black currant (95). In the strawberry, reported values for total acids range from 0.57 - 2.26% w/w with citric acid ranging from 60 - 90% of these totals (30, 56). Hane (33) has examined the acid metabolism in strawberries in detail. Malic acid levels of approximately 0.09% of total acids were reported along with trace levels of shikimic, quinic, succinic, glyceric, glycollic and oxaloacetic acids in mature fruits.

In developing boysenberries, total titratable acidity decreases as fruit matures; the proportion of citric and isocitric acids increases while that of malic acid decreases (71). In strawberries this same relationship appears in measurements of citric acid (30, 80). Total acidity varies significantly by cultivar and is significantly lower in fully ripe or over-ripe fruit. pH significantly increases as ripening proceeds from lightly colored to dark colored or

over-ripe fruits.

Because of the comparative simplicity of chemical methods for estimation and its biological importance, the occurrence of vitamin C (L-ascorbic acid) in foods has been thoroughly investigated. Typical average content of a wide range of freshly harvested fruits and vegetables, expressed in mg/100 g of the edible portion, have been compiled by Olliver (65). In dessert fruits, content ranges from 2 mg/100 g in figs to 300 mg/100 g in the guava. In the small fruits, vitamin C is quantitatively the most important vitamin with average contents ranging from 12 mg/100 g in the cranberry to 210 mg/100 g in black currants (65, 94). An average content for strawberries frequently cited is 60 mg/100 g, apparently based on values originally observed by Ezell et al. in extensive comparative analyses involving 28 cultivars and 16 selections ranging in content from 38.9 - 88.9 mg/100 g (25). Variations in ascorbic acid content due to cultivar and environmental effects are also well documented (12, 25, 38). Fruit maturing under shade has lower levels of ascorbic acid when compared with fruit exposed to full sunlight in the field. Fruits harvested from the same cultivar growing in different soils exhibit different levels of vitamin C. In 'Blakemore' fruit, outer portions of receptacle tissue contain 20% more ascorbic acid than center portions (12). Similar effects were noted by Olliver with 'Jucunda' (64). In 'Klondike', fruits classified as "very green", "pink green" and "ripe" were observed to

contain 23.3 - 24.0, 31.3 - 32.0, and 45.9 - 46.7 mg/ 100 g ascorbic acid, respectively. Olliver in 1938 examined ascorbic acid levels in developing strawberries (64). Total ascorbic acid remained low prior to color development; a rapid increase during color development was then followed by a slight decrease at the end of the season in over-ripe fruit. Although these observations indicate a potential for the use of ascorbic acid levels as biochemical indices of maturity in developing strawberries this specific application has apparently not been investigated. The use of rapid techniques for estimation of ascorbic acid for comparative purposes in varietal quality evaluations or selection in breeding programs has been widely accepted. Morell's technique (58), adapted from Bessey's modifications (8) of earlier photometric methods for determinations of ascorbic acid in blood serum to use on plant tissue extracts permits rapid analysis on large numbers of plant samples. Although the technique was initially developed for evaluation of large numbers of individuals among segregating populations in vegetable breeding trials, the procedures for adaptation to other plant materials were clearly outlined. The use of indophenol dyes, i.e., 2,6-dichlorophenolindophenol as a quantitative indicator was originally reviewed by King (45). A similar technique for the determination of ascorbic and dehydroascorbic acids using 2,4-dinitrophenylhydrazine has since been outlined (70). Sistrunk and Moore successfully employed both methods in quality comparisons of fresh and

frozen fruit of strawberry cultivars and selections in the Arkansas breeding program (80). In analyses of ripe and sound over-ripe fruit from a once-over harvest at intervals in the picking season, ascorbic acid and dehydroascorbic levels differed significantly between harvests. Ascorbic acid increased slightly from 24.4 - 26.3 mg/100 g from early to late harvests with a drop to 20.4 mg/100 g in midseason. Dehydro-ascorbic acid decreased significantly from 24.7 - 18.8 mg/100 g during the same period.

Because it is an important parameter of quality and a universal measure of maturation and ripening for most horti-cultural food products, descriptive terminology related to subjective measures of color abound in the literature. The degree of confusion engendered in such subjective descriptions appears to be almost directly related to the number of indivi-duals active in research on a particular commodity. In fruits, particularly in the strawberry, such terms as "over-ripe, sound over-ripe, firm ripe, sound ripe, color inception, pink, pink-green, very green, etc" are unfortunately only meaningful as they relate to a given cultivar at a particular time and to the individual describing them (25, 80, 82). The problems inherent in subjective characterizations of color have long been recognized. Various instruments and techniques have been developed to obtain reproducible objective measures for color description in foods. Mackinney and Little have outlined the theoretical bases and instrumentation available for color

characterization in foods (52). Although the spectrophotometer is now recognized as the basic instrument in the standardization of color, the lack of homogeneity and the numerous surfaces present on fruits make other instruments more adaptable to rapid color appraisal.

Available instruments can generally be included in 4 categories: 1) additive or subtractive colorimeters; 2) comparators; 3) spectrophotometers; 4) tristimulus photoelectric colorimeters. Additive colorimeters employ three primary colors, occasionally with additional colors to approximately match sample colors. The spinning disk technique is in principle an additive colorimeter. With agricultural products, color disks are spun in close proximity to a sample until a match and specification for the match are obtained. The various subtractive colorimeters employ primary color filters between the light source and the field of view; the emergent beam can then be varied with respect to hue and saturation of the color to match samples. Rotating sample holders are available for nonhomogeneous materials to provide an average color value. Twelve-volt portable field models are also available for measurements on the plant.

Comparators are of little use in direct specifications of color. In use luminous flux transmitted or reflected by a sample is controlled, permitting matches where a sample is to be placed in one grade or another.

Although the spectrophotometer is considered the basic

instrument in the standardization of color a number of disadvantages exist which limit applicability of the various instruments available. Small size of the aperture and the lack of a reflectance attachment in certain instruments prevent measurements on pastes, purees or larger biological specimens. Mechanically unstable elements in the input electrometer tube and shifts in the zero of the photometer system as the photocell compartment is opened or closed have been cited as possible sources of error. With sufficient numbers of samples and careful operational techniques however, a high degree of precision is obtainable. Recorders on recent models eliminate much of the drudgery in obtaining data on large numbers of samples.

With the photoelectric tristimulus colorimeters, or color-difference meters, three measurements are obtained to specify lightness and chromaticity parameters of a sample. The Hunter Color and Color Difference Meter (CDM) has become widely accepted for use in obtaining direct, reproducible values for color of specimens in a variety of industries, including foods, with the use of appropriate standards (41). Various models of the CDM all consist basically of two parts: 1) an optical unit containing the light source, a stage and window for viewing the specimen and vacuum phototubes which accept light reflected from the specimen and 2) an electrical unit containing circuits which convert phototube currents to scale readings proportional to color. A recorder is available on

recent models. In operation, light from a lamp is projected onto the specimen from opposite sides at 45° angles. Reflected light is distributed to the phototubes with appropriate filters; the currents generated are then converted to voltages proportional to spectral functions X, Y, Z obtained with the CIE (Commission Internationale d'Eclairage) standard observer, duplicating visual judgments under CIE illuminant C (Daylight) (41). Tristimulus values of color relative to a standard can be read directly on three visually uniform scales and are readily converted to any of four color scales including color difference (ΔE), Rd and L (45° - 0° luminous reflectance) and two CIE scales (chromaticity and reflectance). Rd is defined as 100 times the amount of light reflected by the sample divided by the amount of light reflected by a perfectly diffusing sample (magnesium oxide) when the light is incident upon the sample at an angle of 45° and the measuring device records the light diffused perpendicularly from the sample (0°). Rd is equivalent to 100Y (CIE), and "a" and "b" are the rectangular coordinates of color (chromaticity) in any plane intersecting the color solid perpendicularly to the white-black axis.

The three values of the "L" scale are L, a_L and b_L. L is equivalent to 10/Rd. Because of different circuit arrangements for Rd and L, "a" and "b" values obtained differ very slightly. With these three scales, it is possible to represent the color of a specimen by position in the three dimensional coordinate system or color solid shown in Fig. 1.

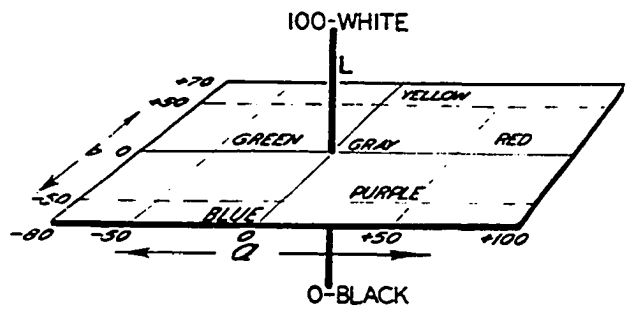

Fig. 1. Diagram showing dimensions of the L, a_L, and b_L color solid. L measures lightness and varies from 100 for perfect white to zero for black, "a" measures redness when plus, gray when zero and greenness when minus, and "b" measures yellowness when plus, gray when zero and blueness when minus.

The vertical axis of this solid goes from white at the top to black at the bottom. Hue (the kind of color) varying from red through orange, yellow, green, blue and purple back to red is determined by direction from this axis. Saturation (visual color intensity) is measured by distance from the gray axis. Thus, the readings can be used to define any color on scales and relate this color to visual impressions.

Reports of colorimetric analyses on small fruits for fresh or frozen fruit quality evaluations or clonal comparisons using the CDM "Rd" and "L" scales are numerous (31, 32, 35, 74, 79, 80). Shah and Worthington have compared the CDM with other methods of color determination and found the CDM to be reliable for strawberries (74). The L scale has consistently been considered most useful for color measurement and specification on plant materials. Where a standard nearly identical to the sample is available, error rarely exceeds 0.2 units,

exceeding slightly the smallest color difference visually detectable by a trained observer (41).

When red color standards are not immediately or readily available the use of Congo red dye to effectively replace color standards normally used with the CDM has also been reported (35).

Sample preparation and pre-treatment can appreciably affect results obtained in color measurement. Variations within small fruits in internal vs. external color stimulated Tinsley et al. to re-evaluate various methods for presenting samples to the CDM using 24 strawberry and 34 raspberry cultivars and selections (88). Variation in sliced or fresh whole berries was found to be high due to lighter centers in certain clones. Cell breakdown in freezing and subsequent thawing resulted in pigment release which reduced variation substantially on the same samples. Blending either fresh or frozen fruit resulted in more homogeneous color and minimized variation within and between fresh and frozen samples of the same strawberry cultivar. A fairly narrow range of the dominant wavelength from 600 - 618 mμ was observed in strawberries. Frozen strawberry samples displayed marked reductions in sample "lightness" ("L") values obtained with the CDM, apparently due to oxidation of pigment during thawing. Values obtained, however, correlated significantly with those obtained on the same blended fresh fruit samples.

III. MATERIALS AND METHODS

A. Preliminary Screening of Some Potential Pruning Chemicals and Surfactants on Strawberries

The following chemical pruning agents and surfactants were tested in various combinations throughout this and subsequent experiments and will hereafter be referred to by their respective compound number or letter designation:

Potential pruning agents	Formulation	Surfactants
PP938[1]	50EC	JF2197[1]
JF2777[1]	50EC	Lissapol NX[1]
JF3457[1]	50EC	WSCP[4]
DNOC (Elgetol®)[2]	19EC	Tween 80®[5]
Off-Shoot-O®[3]	45EC	

In all instances where prepared sprays are hereafter cited, preparations indicate percent of total material per volume of water (v/v). PP938 is a highly active representative of a group of chemical pruning agents for dicotyledenous plants (42). It is similar in its action to the methyl esters

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[1]Obtained from Plant Protection, Ltd., Imperial Chemical Industries, Bracknell, Berkshire, England.

[2]Commercial preparation of 4,6-dinitro-o-cresol.

[3]Methyl decanoate in combination with several other esters and a wetting agent, obtained from Procter & Gamble Co., Product Development Dept., Cincinnati, Ohio.

[4]A water-soluble cationic polyelectrolyte spreader-sticker obtained from Buckman Laboratories, Inc., Memphis, Tennessee.

[5]Commercial preparation of polyoxyethylene sorbitan (mono-oleate).

of long chain fatty acids in that both types selectively destroy terminal meristems. Substantially lower rates, ca. 0.25 percent, will produce apical kill comparable to that obtained with rates normally observed at the usual recommended rate of 5.0% for methyl decanoate. Visual evidence of meristem kill may not be apparent for 2-3 days with PP938; apical kill is often observed within 2-3 hours with methyl decanoate. PP938 may also be active on more plant species. Compound JF3457 is an allylated mixture of three dibasic carboxylic acids reported to produce pruning action similar to that obtained with PP938. Lissapol NX and JF2197 are experimental wetting agents reported to enhance spreading action and penetration of bud pruning chemicals into the apical crown or growing point of the plant. WSCP is a water-soluble cationic polyelectrolyte reputed to be effective as a dispersant, spreader and sticker in agricultural sprays.

1. Test I

In December, 1970, the following treatments were applied to 'Surecrop' strawberry plants.

No.	Treatment	Stage of Inflorescence Development A	B	C	D	E	F
1	JF2777 (1.0%) + Lissapol NX (1.0%)	X		X	X		
2	JF2777 (0.5%) + Lissapol NX (1.0%)		X	X			X
3	JF2777 (0.25%) + Lissapol NX (1.0%)	X	X				X
4	---------- Lissapol NX (1.0%)	X	X	X			
5	JF2777 (1.0%) + JF2197 (1.0%)	X		X			X
6	JF2777 (0.5%) + JF2197 (1.0%)	X	X			X	
7	JF2777 (0.25%) + JF2197 (1.0%)	X	X			X	
8	Check						

Three plants per treatment were randomly selected. Codes were assigned to each stage of development of inflorescences as follows:

A - primary flower emerging, not open

B - primary flower emerging and partially open, secondaries visible

C - primary flower at anthesis, secondaries and tertiaries visible

D - primary flower at anthesis, secondaries and tertiaries partially open

E - post anthesis of primary flower, secondaries at anthesis, tertiaries partially open

F - secondaries and tertiaries at anthesis, quaternary flowers visible

These codes were used throughout this and subsequent studies to establish uniformity in description of inflorescence development. Plants were sprayed to runoff with the treatments.

2. Test II

Because Lissapol NX, the wetting agent, was suspected of possible phytotoxic effects a new test was set up in February, 1971, in which several surfactants were tested alone and in combination with JF2777 on both 'Surecrop' and 'Midway'. Two plants of each cultivar were treated as follows:

No.	Treatment	Stage of Inflorescence Development 'Surecrop' A	B	C	D	E	F	'Midway' A	B	C	D	E	F
1	JF2777 (1.0%) + Lissapol NX (1.0%)	X		X				X		X			
2	JF2777 (0.5%) + Lissapol NX (1.0%)	X	X					X			X		
3	JF2777 (1.0%) + Lissapol NX (0.5%)	X			X			X	X				
4	JF2777 (1.0%) + WSCP (0.5%)	X		X				X		X			
5	JF2777 (0.2%)	X				X		X	X				
6	---------- Lissapol NX (1.0%)	X						X		X			
7	---------- WSCP (0.5%)	X		X				X	X				
8	JF2777 (1.0%) + JF2197 (1.0%)	X			X			X	X				
9	---------- JF2197 (1.0%)	X		X				X	X				
10	JF2777 (0.1%) + Tween 80 (0.5%)	X		X				X			X		
11	---------- Tween 80 (0.5%)	X		X				X				X	
12	Check	X		X				X		X			

3. Test III

In an attempt to measure effects of flower pruning on yield and ripening rates of fruit, a greenhouse experiment was set up in April, 1971, in which 6 plants each of 'Midway' and 'Surecrop' were treated as follows:

Treatment	Material
1	JF2777 (0.5%) + Lissapol NX (1.0%)
2	JF2777 (0.8%) + Lissapol NX (1.0%)
3	JF2777 (0.5%) + JF2197 (1.0%)
4	"Off-Shoot-O" (10.0%)
5	"Off-Shoot-O" (5.0%)
6	---------- Lissapol NX (1.0%)
7	Check
8	PP938 (0.25%) + Tween 80 (1.0%)
9	PP938 (0.5%) + Tween 80 (1.0%)

An attempt was made before treatment to select plants at a uniform stage of inflorescence development. Only plants at Stages B or C were chosen before random application of the treatments.

B. Cultivar, Flower Position, Flower Abortion and Yield Responses to Chemical Bud Pruners

In May, 1971, the following treatments were randomly applied to strawberry selections IA26-6215, 'Midway', 'Surecrop' and 'Badgerbelle':

Treatment No.	Material
1	JF2777 (0.25%) + Lissapol NX (1.0%)
2	JF2777 (0.50%) + Lissapol NX (1.0%)
3	JF2777 (1.00%) + Lissapol NX (1.0%)
4	---------- Lissapol NX (1.0%)
5	DNOC (Elgetol) (0.25%)
6	DNOC (Elgetol) (0.12%)
7	"Off-Shoot-O" (5.0%)
8	"Off-Shoot-O" (10.0%)
9	Control

Because of the differences in dates of apparent full bloom applications to IA26-6215 and 'Surecrop' were made four days prior to 'Midway' and 'Badgerbelle'. An attempt was made to time applications to the third day after apparent full bloom. The experiment was designed as a factorial to evaluate main effects and interactions. Components of linear and quadratic response in interactions were also obtained.

All fruits were harvested in a single picking of entire clusters from 15 plants of the respective varieties when

primary fruits reached the sound overripe stage. Data were obtained for mean and total fruit weights of primary, secondary, tertiary and quaternary fruit positions within inflorescences. Individual fruits were graded at the time of harvest as usable or unusable using a rating from one to five as follows:

Rating	Stage of maturity
1	green
2	½ green
3	¼ green
4	ripe
5	sound overripe

Fully green fruit were considered unusable. Grades 2-5 were considered usable fruit for purposes of evaluating potential concentration of ripening. Counts of aborted flowers, usable and unusable fruits by flower position in inflorescences were also obtained.

C. Morphological Effects and Rates of Action of Chemical Bud Pruners on Stigma, Style and Anther Tissue of Strawberry Flowers

In January, 1973, intact 'Surecrop' flower buds were selected for application of chemical bud pruners at intervals of 2, 4, 8, 36 and 72 hours prior to comparative examination for injury to stigma, style and anther tissue. An attempt was made to select for some uniformity in flower development by choosing only partially opened buds in which petals were loosely folded over the stigmatic surfaces. This stage is commonly termed the "white bud" stage and is comparable to

Stage B in primary flower buds as outlined in the preliminary tests. "Off-Shoot-O", JF2777 and JF3457 were applied at rates of 5.0%, 0.8% + 0.5% Lissapol NX, and 0.8% + 0.5% Lissapol NX in water, respectively. An untreated control and Lissapol NX (0.5%) applied four hours prior to viewing were also examined. Application of the pruning emulsion consisted of placing one drop on individual buds from an eyedropper held just above the loosely clasping petals at appropriate time intervals.

Flowers were left on the plants until one hour prior to examination in the JEOLCO JSM-U3 Scanning Electron Microscope at 5KV. To reduce desiccation, detached flower pedicels were kept in tap water within a crisper for transportation to the microscope. Preparation of a specimen consisted of careful removal of the corolla with a forceps, and pedicel trimming with a razor; the bud was then immediately glued upright to a small brass stand normally used to hold specimens for viewing in the SEM. A rapid drying black cement designed for use in radio tube repair was found to provide an excellent means for attachment to the holder. A small amount of cement was placed on the holder and the base of the bud was immediately held against the cement. Sufficient hardening occurred within 3-5 seconds. The completed specimen and holder were then aerosol sprayed for one second with a light coating of #94 Polaron Conducting Film[1] to improve conductance. Potential detrimental

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[1]Cationic S.N. isopropanol plus Arcton 11/12 (50:50). Obtained from Ted Pella Co., Tustin, Calif.

effects of the film were not observed on the untreated control flower, either under a dissecting microscope or in the SEM. Total time elapsed in preparation and photographing a specimen never exceeded 4 minutes.

D. Evaluations of Rapid Objective Measures of Maturity in Chemically Pruned Cultivars

In May, 1972, chemical bud pruning compounds JF2777 and JF3457 were applied 3 days after apparent full bloom to field plots of strawberry selection 26-6215, 'Midway', 'Surecrop', and 'Badgerbelle' at the following rates:

Treatment No.	Material
1	JF2777 (0.25%)
2	JF2777 (0.50%)
3	JF2777 (1.00%)
4	JF2777 (2.00%)
5	JF3457 (0.40%)
6	JF3457 (0.80%)
7	JF3457 (1.60%)
8	Control

Except for the untreated control, all treatments included 1.0% Lissapol NX as the surfactant. Spray applications were made to randomly assigned plots; single harvests of entire fruit clusters were made on each clone as primary fruit reached the apparent sound over-ripe stage. After capping, entire clusters of fruit were assigned by coded treatment to 3 replications of each cultivar - treatment combination in approximately 100 gram lots each of primary, secondary, and tertiary fruits. Mean fresh fruit weights were obtained at

the time of separation into lots by fruit position within inflorescences. Sample lots were then placed into a freezer at -5° C and held until subsequent determination of soluble and total solids, total acidity, pH, ascorbic acid and color of the thawed and blended lots.

Color was measured by the Hunter Color and Color Difference Meter (CDM) on 30 gram fruit samples from each lot in 1 x 3 inch square glass vials approximately five minutes after blending using a plate with a 3/4 inch x 1 1/2 inch opening. For standardization an NBS (National Bureau of Standards) red color plate (L = 26.1, a = 30.9, b = 13.5) obtained from Hunterlab, Inc. was used. Soluble solids were determined with an Abbe refractometer. Total solids were measured on 5 gram samples after drying for 24 hours at 70° C. Total acidity as citric acid was obtained by calculation from titration of 10 gram samples with 0.1N NaOH to an end point of pH 7.0. A 10 gram sample diluted to 50 ml with distilled water was used for pH determinations. Ascorbic acid was determined by the method of Morell (58) on 25 grams of blended fruit using a Spectronic 20 spectrophotometer at 520 mμ after standardization with L-ascorbic acid.

To reduce errors from post-thawing oxidation of fruit, all analyses were performed on random groups of 10 lots within inflorescences before thawing of other groups. Approximately 1 1/2 hours elapsed from initiation of thawing to termination of analyses on a 10 lot group. Each analysis was treated as a

separate experiment with appropriate factorial analysis. Main effects and interactions were tested for significance using the error mean square.

To evaluate the same objective measures of maturity without the complicating effects of chemical pruner , 100 plants each of 'Midway' and 'Surecrop' were planted in four inch pots and placed in the greenhouse in January, 1973. Harvests of fruit were initiated in March at intervals of approximately three days. At each picking all fruit of usable size (3/4 inch or larger) was removed and assigned by cultivar and stage of maturity into large lots of acceptable (ripe), color inception ("pink"), mature green ("white") and immature ("green") grades. Fruit was washed, capped and immediately randomly assigned to treatments. Treatments consisted of mixtures of predetermined percentages of fruit by weight from each grade based on approximate ranges of each obtained by Moore and Brown (57) in once-over field harvests at intervals in the picking season with 'Surecrop' and 'Tennessee Beauty'.

Percentages of each grade by weight in the fruit mixtures are shown in Table 1. Three replications of 100 g of each treatment were made up; samples were then placed in a freezer at -5° C and held until all mixtures were obtained before laboratory analyses were performed. Attempts were made to grade fruit by color without regard to fruit position in inflorescences to duplicate as closely as possible the situation which would occur in once-over harvesting and grading in

Table 1. Percentages of fruit of 'Surecrop' and 'Midway' by grades (stage of maturity) in predetermined mixtures for evaluation of objective measures of maturity on entire fruit clusters

Treatment	Percent by weight			
	Acceptable ("ripe")	Color Inception ("pink")	Mature Green ("white")	Immature ("green")
1	20	16	16	48
2	25	15	15	45
3	30	14	14	42
4	35	13	13	39
5	40	12	12	36
6	45	11	11	33
7	50	10	10	30
8	55	9	9	27
9	60	8	8	24
10	65	7	7	21
11	70	6	6	18
12	75	5	5	15
13	80	4	4	12

the field. Thus, mean fruit weight was not considered as a variable in this study.

CDM "L", "a", "b" values, percent soluble solids, pH, percent total acids, ascorbic acid and percent total solids were determined by the same procedures described previously.

Each variable was analyzed as a separate experiment. Main effects and interactions were tested for significance using the error mean square.

IV. RESULTS

A. Preliminary Screening of Some Potential Pruning Chemicals and Surfactants on Strawberries

1. Test I

Fairly low ambient temperatures (40° - 45°) in the greenhouse during and immediately following treatment apparently contributed to the spread of root rot in the potted plants. Most of the plants were lost within a period of 3-7 days after treatment. The low temperatures may also have contributed to the high levels of injury observed in the treated plants. No data on ripening rates or fruit yields were obtained. Initial observations indicated, however, that all chemical treatments were effective within a period of 36 to 48 hours in achieving flower kill on exposed or partially open flowers. Flower kill or pruning was apparent in initial browning of stylar tissue followed by a browning and drying of associated receptacle tissue. Treatments 1 thru 4, all containing Lissapol NX, appeared to be most active and rapid in inducing pruning. Flower kill observed in Treatment 4 (Lissapol only) did not differ from the treatments in which JF2777 was present, in the amount or degree of flower kill. This suggested the possibility of a phytotoxic effect from the wetting agent. The combinations of JF2777 with JF2197 were also effective in flower pruning however, indicating that some additional factor such as low temperatures may have contributed to the observed

effects. No quantitative differences in flower pruning were established due to subsequent plant losses.

2. Test II

Visual observations on plants 48 hours after treatment indicated the following initial effects:

Treatment 1 Initial pedicel injury and flower kill on exposed flowers, subsequent loss of entire inflorescences, apparently due primarily to peduncle injury to vascular tissue at the base of the inflorescence.

Treatment 2 Initial pedicel injury, some leaflet burn in axils where spray accumulation occurred, flower kill on exposed flowers.

Treatment 3 80% flower pruning on exposed and partially open flowers (9 of 12 visible flowers pruned at initial observation), no apparent leaf injury.

Treatment 4 50% flower pruning on exposed flowers (5 to 10 visible flowers), no apparent leaf injury.

Treatment 5 55% flower pruning on 'Surecrop' (6 of 11 flowers), moderate leaf injury where accumulation of spray material occurred, all exposed flowers in "Midway" pruned.

Treatment 6 10% flower pruning, partial injury on 2 additional flowers, no apparent leaf injury.

Treatment 7 Normal development.

Treatment 8 Loss of entire inflorescence on both cultivars,

moderate ('Surecrop') to heavy ('Midway') leaf injury.

Treatment 9 15% flower pruning on exposed flowers, no leaf injury.

Treatment 10 40% flower pruning (4 of 10 flowers) exposed, some leaf injury in axils where accumulation occurred.

Treatment 11 Normal development.

Treatment 12 Normal development.

From these observations and later observations on recovery of plants from injury, it appeared that optimum rates of JF2777 probably would range from 0.4 - 0.8% in combination with 0.5 - 1.0% wetting agent.

3. Test III

Observations on plants generally concurred with those from the previous test. Approximately 72 hours after treatment, injury to plants was noted for each cultivar and treatment as follows:

'Surecrop'

Treatment 1 Some calyx scorch, pedicels of several smaller late flowers injured to point of flower kill, minor injury to young, emerging leaves.

Treatment 2 Loss of 4 of 5 inflorescences, minor injury to crown of plant, inflorescences lost primarily due to injury at base of inflorescence.

Treatment 3 Moderate injury to younger, emerging leaves,

minor scorch in older leaflet axils, complete primary flower pruning, some loss of secondaries and tertiaries.

Treatment 4 Loss of all inflorescences, moderate to severe leaf injury, severe leaf curl on younger leaves, 2 of 5 plants killed.

Treatment 5 Loss of 2 of 5 inflorescences, some scorch and curl on younger leaves, pruning of all primaries and some secondaries and tertiaries.

Treatment 6 Slight calyx tip burn, some browning of stigmas and styles at flower tip, subsequent fruit development apparently normal.

Treatment 7 Normal development.

Treatment 8 Slight calyx tip scorch, slight scorch on younger leaflets, partial primary flower pruning.

Treatment 9 Moderate injury to leaves and inflorescences, especially at base, pruning of some older flowers.

'Midway'

Treatment 1 Slight pedicel browning on older flowers, minor scorch on younger leaves and calyx tips, all primaries and some secondaries killed.

Treatment 2 Loss of all inflorescences, injury to younger leaves, crowns moderately injured.

Treatment 3 Loss of several secondary and tertiary flowers, complete pruning on primaries, slight injury at

base of inflorescences, very slight scorch in leaflet axils.

Treatment 4 Loss of all younger flowers and leaves, several older flowers partially destroyed, most primaries pruned, severe pedicel injury on surviving flowers.

Treatment 5 Severe calyx burn, numerous younger flowers pruned, older flowers (primaries) surviving.

Treatment 6 Slight calyx tip browning, some stigma and style browning but flowers surviving, no leaf injury.

Treatment 7 Normal development.

Treatment 8 Slight injury to calyx tips and younger leaves, a few primaries pruned.

Treatment 9 Moderate injury to calyx tips and younger leaves, some primaries pruned.

Some pedicel injury was noted, apparently from pruning chemical runoff from buds. In most cases, flower buds with pedicel injury surviving to set fruit also developed normally, despite the injury to pedicels. Vascular tissue in those pedicels examined under a dissecting microscope appeared to be uninjured.

Fruit ripeness at harvest was rated as follows: 1) overripe, 2) ripe, 3) ¼ green, 4) ½ green, 5) green. Ripe, ¼ green and ½ green fruits were considered as usable fruit, overripe and green as unusable in tabulating results for each treatment in a once-over harvest.

Due to substantial losses in 'Midway' fruit numbers, data were not analyzed statistically. Losses to Botrytis fruit rot were especially severe in this cultivar before the single harvest of inflorescences was achieved. In Tables 2, 3, and 4 the number and weight of fruits for primary, secondary and tertiary positions in inflorescences and usable plus non-usable fruit weights are tabulated for 'Surecrop'. Treatments which produced either very severe or complete inflorescence pruning were not included in the analyses. Fruit rot was not a problem in 'Surecrop'.

Substantial pruning of primary and secondary flowers was obtained with both PP938 treatments and "Off-Shoot-O". As expected, the amount of pruning and degree of injury to foliage appeared to be correlated with increasing concentrations of the chemical pruner. Mean fruit weight by position in the inflorescence was not significantly affected in most cases with exceptions in secondary fruits (Lissapol treated) and tertiary fruits (0.25% PP938). The reduced fruit numbers were, however, reflected in lower total yields by fruit position. Appreciable reductions in yield were observed in "Off-Shoot-O" treatments at all flower positions. Substantial reduction in total yields were also observed in the JF2777 and PP938 treatments (Table 3). Separating yield into the various components illustrates the effect of flower pruning on changes in yield by different combinations of fruit position within inflorescences. It is apparent from these data that the bulk

Table 2. Effects of chemical bud pruners on fruit numbers, mean fruit weight and total yield by flower position in the strawberry cultivar 'Surecrop'[1]

No.	Treatments		Primary Fruit		
	Rate (v/v)	Rate (v/v)	No. of fruits	Mean fruit weight (g)	Total yield (g)
1	JF2777 (0.5%) + Lissapol NX	(1.0%)	3	13.4a	40.2
3	JF2777 (0.5%) + JF2197	(1.0%)	-	--	--
5	"Off-Shoot-O"	(5.0%)	2	12.3b	24.6
6	Lissapol NX	(1.0%)	6	13.1a	78.5
7	Check		6	13.5a	81.6
8	PP938 (0.25%) + Tween 80	(1.0%)	4	14.1a	56.5
9	PP938 (0.5%) + Tween 80	(1.0%)	4	12.8a	51.2

[1]Means followed by the same letter are not different at 5% level of significance, Duncan's Multiple Range Test.

Secondary Fruit			Tertiary Fruit		
No. of fruits	Mean fruit weight (g)	Total yield (g)	No. of fruits	Mean fruit weight (g)	Total yield (g)
11	7.9a	86.9	19	5.1a	96.9
8	8.3a	66.4	18	5.4a	97.2
6	8.0a	48.0	11	5.0a	55.1
11	7.8b	85.8	22	5.4a	118.8
12	8.1a	97.2	21	5.3a	111.3
11	8.2a	90.2	22	4.9b	107.8
9	8.0a	72.1	18	5.3a	95.4

Table 3. Components of yield by flower position in the strawberry cultivar 'Surecrop' after treatment with chemical bud pruners[a]

No.	Treatments	Flower Positions in Inflorescence						
		P+S(g)	% of total	P+T(g)	% of total	S+T(g)	% of total	P+S+T(g)
1	JF2777 (0.5%) + Lissapol NX (1.0%)	127.1	57	137.1	61	183.8	82	224.0
3	JF2777 (0.5%) + JF2197 (1.0%)	66.4[b]	41	97.2[b]	59	163.6[b]	100	--
5	"Off-Shoot-O" (5.0%)	72.6	57	79.7	62	103.1	81	127.7
6	Lissapol NX (1.0%)	164.3	58	197.3	70	204.6	72	283.1
7	Check	178.8	62	192.9	66	208.5	72	290.1
8	PP938 (0.25%) + Tween 80 (1.0%)	146.7	58	164.3	64	198.0	78	254.5
9	PP938 (0.5%) + Tween 80 (1.0%)	123.3	56	146.6	67	167.5	77	218.7

[a]Flower (fruit) positions are denoted as follows: P = primary, S = secondary, T = tertiary.

[b]Yields for secondary (S) and tertiary (T) positions only, no primaries present.

of total yield is derived from secondary and tertiary fruit in this cultivar. Although pruning of primary flowers reduces total yield significantly, it appears that this reduction is partially offset by increases in yields of secondary and especially tertiary fruits as a function of total yield.

A primary question arising from these data is the effect of bud pruners on the concentration of ripening or yields of usable fruit. Total usable and unusable fruit weights and usable weight as a percentage of total yield are shown in Table 4. Large reductions in usable fruit yields were apparent using 0.5% PP938 or JF2777. The partial promotion of concentrated ripening is noted in the reduced yields of unusable fruit in chemical pruner treatments. Although total yield of usable fruit does not appreciably differ from the check when 0.25% JF2777 is used, it is of interest to note the sizable increase in percent usable fruit obtained.

Table 4. Effects of chemical bud pruners on usable and unusable fruit weights and percent usable fruit in the strawberry cultivar 'Surecrop'

No.	Treatments	Usable fruit weight (g)	Unusable fruit weight (g)	Percent usable
1	JF2777 (0.5%) + Lissapol NX (1.0%)	185.9	38.1	83
3	JF2777 (0.5%) + JF2197 (1.0%)	122.7[a]	40.9[a]	75
5	"Off-Shoot-O" (5.0%)	95.8	31.9	75
6	Lissapol NX (1.0%)	203.8	79.3	72
7	Check	211.7	78.4	73
8	PP938 (0.25%) + Tween 80 (1.0%)	213.8	40.7	84
9	PP938 (0.5%) + Tween 80 (1.0%)	172.8	45.9	79

[a]No primary fruits present, weights of secondary and tertiaries only.

B. Cultivar, Flower Position, Flower Abortion and Yield Responses to Chemical Bud Pruners

Mean numbers of usable fruits per cluster for the four clones tested did not differ substantially, although 'Surecrop' did have a small but significantly higher number of fruits (Table 5). Unusable or green fruits averaged less than two per cluster although differences between clones were not significant. The higher fruit counts per cluster for 'Surecrop' were also accompanied by a higher mean number of aborted tertiary and quaternary flowers although these differences again were not significant at the 5% level. Numbers of aborted primary and secondary flowers were negligible and were not included in the analyses.

The interaction of cultivar x aborted flowers for mean weight per usable berry although not significant at the 5% level is significant at the 10% level and indicated a possible partial clonal response to chemical pruning (Appendix Table 2). In Fig. 2, mean berry weight and total fruit weight responses by cultivar to increasing numbers of aborted flowers indicate that in 'Surecrop' and IA26-6215, mean berry weight and total fruit weight are generally reduced substantially by increasing numbers of aborted flowers. In 'Badgerbelle' and 'Midway', total usable fruit weight per cluster decreases with 2 aborted flowers but is partially recovered with three aborted flowers. Mean berry weight for the latter cultivars increases with increasing numbers of aborted flowers while decreasing or

Table 5. Strawberry cultivar responses in mean usable and unusable fruit counts per cluster and mean numbers of aborted flowers in tertiary and quaternary positions within inflorescences[1,2,3]

Cultivar	No. of fruits/cluster		No. of aborted flowers	
	Usable	Unusable	Tertiary	Quaternary
IA26-6215	5.91a	1.44	1.83	1.99
'Midway'	5.73a	1.73	1.78	1.68
'Surecrop'	6.19b	1.63	2.29	2.09
'Badgerbelle'	5.76a	1.61	1.74	1.78

[1]Means followed by the same letter do not differ significantly at the 5% level of significance, Duncan's Multiple Range Test.

[2]Data obtained in a once-over harvest of entire clusters.

[3]Usable fruits included firm over-ripe, ripe, ¼ green, and ½ green fruits. Green fruits were classed as unusable.

remaining the same in 'Surecrop' or IA26-6215.

Mean usable berry weight response to treatments are shown in Table 6. Although moderate increases in berry weight were obtained with chemical pruners, only in 'Midway' was this increase significantly greater when compared with the untreated control. With 5.0% "Off-Shoot-O" usable berry weight was significantly higher in 'Midway'. Significant reductions in berry weight with all chemical treatments were obtained in 'Surecrop'. Usable berry weights in IA26-6215, a concentrated ripening clone, were in general not significantly affected

Fig. 2. Trends in strawberry clonal responses to increasing flower abortion in total yield per plant (g) and mean berry weight (g). Curves obtained were derived from 4 points for data obtained over all chemical pruning treatments for each clone.

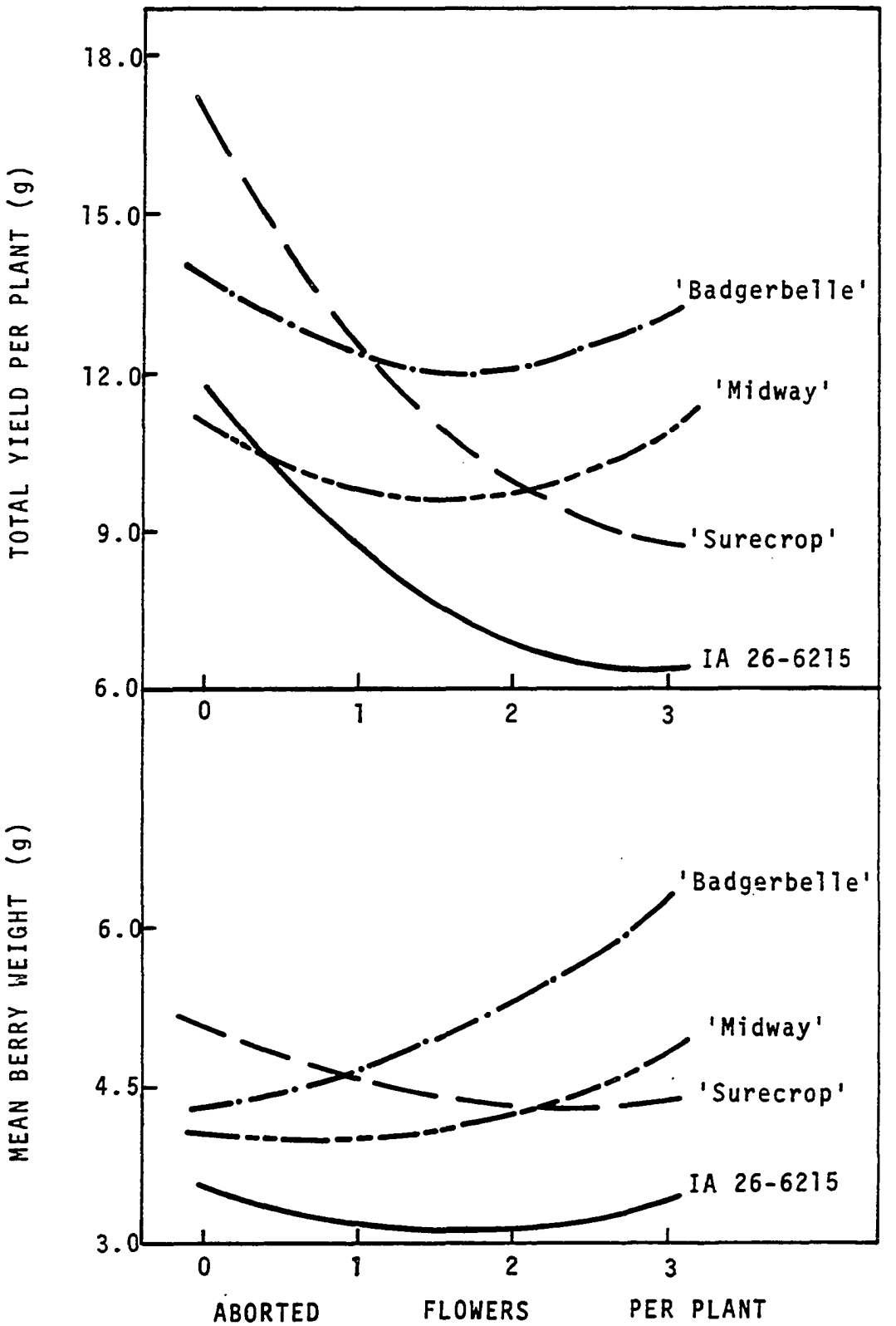

TOTAL YIELD PER PLANT (g)
18.0
15.0
12.0
9.0
6.0
'Badgerbelle'
'Midway'
'Surecrop'
IA 26-6215
0
1
2
3
MEAN BERRY WEIGHT (g)
6.0
4.5
3.0
'Badgerbelle'
'Midway'
'Surecrop'
IA 26-6215
0
1
2
3
ABORTED FLOWERS PER PLANT

Table 6. Influence of chemical bud pruners on mean usable weight per berry (grams) in strawberry cultivars[1,2,3]

Treatment	Rate (v/v)	Cultivar			
		IA26-6215	'Midway'	'Surecrop'	'Badgerbelle'
JF2777 + 1.00% Lissapol	0.25%	2.79ab	3.52abc	3.19de	3.54bc
	0.50%	2.67a	2.56d	1.59g	3.91abc
	1.00%	2.38b	3.01cd	3.95c	2.00d
Lissapol	1.00%	3.19a	3.90ab	2.27fg	4.19ab
DNOC (Elgetol)	0.25%	2.63ab	2.83cd	3.57cd	3.45c
	0.12%	3.11a	3.19abcd	4.76b	4.37a
"Off-Shoot-O"	5.00%	2.74ab	4.04a	3.14de	3.86abc
	10.00%	2.73ab	3.45abc	2.85ef	3.34c
Control	----	2.52ab	3.08cd	6.41a	3.67abc

[1]Means followed by the same letter do not differ significantly at the 5% level of significance, Duncan's Multiple Range Test.

[2]Data obtained in a once-over harvest of entire clusters.

[3]Usable fruit included sound over-ripe, ripe, ¼ green, and ½ green fruit.

although high rates of JF2777 and DNOC reduced fruit weight somewhat. Moderate increases in berry weight in IA26-6215, 'Midway' and 'Badgerbelle' were obtained.

With chemical pruning treatments, unusable or green berry weights were reduced, in most cases significantly (Table 7). In selection IA26-6215, greatest reductions in mean berry weight occurred with higher rates of DNOC and JF2777, although the reverse effect was evident with the 10% rate of "Off-Shoot-O". A similar relationship between chemical rates and berry size occurred in cultivar unusable berry weights, although reductions in berry size when compared with untreated checks were generally greater than in the concentrated ripening selection. Most drastic reductions occurred in 'Surecrop'.

Influences of potential chemical pruners on mean usable berry weight by fruit position in inflorescences and total yields per cluster are listed in Table 8 by clone. Primary fruit weights did not differ significantly in cultivar x treatment interactions (Appendix Table 1). Greatest effects on fruit weight reduction were apparent in tertiary fruits in the three cultivars with only moderate effects apparent in IA26-6215.

Significant increases in mean secondary and tertiary berry weight and total yield per cluster in IA26-6215 as well as in 'Badgerbelle' with Lissapol NX are of interest, although only a moderate increase in secondary berry size in 'Midway'

Table 7. Influence of chemical bud pruners on mean unusable weight per berry (grams) in strawberry cultivars[1,2,3]

Treatment	Rate (v/v)	Cultivar			
		IA26-6215	'Midway'	'Surecrop'	'Badgerbelle'
JF2777 + 1.00% Lissapol	0.25%	2.43ab	2.52ab	2.08e	2.46b
	0.50%	2.12bcd	1.81c	1.33f	2.65b
	1.00%	2.27abc	2.02c	3.13c	1.06d
Lissapol	1.00%	2.10bcd	2.64ab	3.33c	2.49b
DNOC (Elgetol)	0.25%	1.53e	2.80a	1.68ef	1.56c
	0.12%	1.69de	2.24bc	4.80b	2.52b
"Off-Shoot-O"	5.00%	1.87cde	1.92c	2.68d	2.22b
	10.00%	2.47ab	2.75a	2.52d	2.27b
Control	----	2.63a	2.74a	5.55a	3.28a

[1]Means followed by the same letter do not differ significantly at the 5% level of significance, Duncan's Multiple Range Test.

[2]Data obtained in a once-over harvest of entire clusters.

[3]Green fruits were classed as unusable.

Table 8. Influence of chemical bud pruners on usable yields (grams) of primary, secondary, tertiary, and total fruit per plant in strawberry cultivars[1,2,3]

Treatment	Rate (v/v)	Primary	Secondary	Tertiary	Total
		IA26-6215			
JF2777 + 1.00% Lissapol	0.25%	5.73	4.65bc	3.10c	13.48ab
	0.50%	4.72	5.49a	3.31c	13.52ab
	1.00%	4.75	3.02c	3.23c	11.00c
Lissapol	1.00%	4.21	6.30a	3.80ab	14.31a
DNOC (Elgetol)	0.25%	3.92	5.32abc	3.35bc	12.59b
	0.12%	4.74	6.06a	3.22c	14.02ab
"Off-Shoot-O"	5.00%	4.94	4.99abc	2.99c	12.92ab
	10.00%	3.84	5.30abc	4.00a	13.14ab
Control	----	4.76	4.75bc	3.18c	12.69b
		'Surecrop'			
JF2777 + 1.00% Lissapol	0.25%	8.21	8.09b	2.85c	19.15c
	0.50%	8.16	4.69c	4.03ab	16.88d
	1.00%	8.56	7.81b	1.81e	18.18cd
Lissapol	1.00%	8.36	4.34c	4.43a	17.13d
DNOC (Elgetol)	0.25%	7.36	7.42b	2.33d	17.11d
	0.12%	8.18	11.00a	2.20d	21.38b
"Off-Shoot-O"	5.00%	8.38	5.70c	3.62b	17.70cd
	10.00%	8.28	5.22c	3.67b	17.17d
Control	----	9.20	9.93a	4.17a	23.30a

[1]Means followed by the same letter do not differ significantly at the 5% level of significance, Duncan's Multiple Range Test.

[2]Data obtained in a once-over harvest of entire clusters.

[3]Usable fruit included sound over-ripe, ripe, ¼ green, and ½ green fruit.

Primary	Secondary	Tertiary	Total
		'Midway'	
6.35	6.81a	3.48e	16.64bc
6.34	4.65cd	2.40f	13.39e
5.75	5.31bcd	4.63c	15.69c
5.84	6.74ab	4.04d	16.62bc
5.54	4.33d	2.48f	12.35e
6.37	6.27ab	5.86b	18.50ab
6.57	5.91abc	3.52e	16.00c
5.47	6.57ab	3.91de	15.95c
6.34	6.05abc	6.55a	18.94a
		'Badgerbelle'	
6.79	7.25bc	3.91a	17.95b
6.72	7.68bc	2.42cd	16.82bc
6.18	2.12e	2.34d	10.64f
6.27	8.49b	2.66bcd	17.42b
5.98	5.43d	1.83e	13.24e
6.80	10.04a	2.86bc	19.70a
7.00	6.82cd	2.42cd	16.24c
6.90	5.80d	3.95a	16.65bc
7.82	6.31cd	3.09b	17.22bc

and a significant reduction in 'Surecrop' secondary berry weight underscore the inconsistency of response with this material. A somewhat quantitative reduction in berry weight at all fruit positions is apparent with increasing rates of JF2777 with the exception of an increase in tertiary fruit weight in 'Midway' and secondary fruit weights in 'Surecrop'. A similar relationship occurred with increasing rates of DNOC. The higher rate of "Off-Shoot-O", although generally reducing berry weight when compared with untreated controls, did produce moderate but significant increases in tertiary fruit weight in IA26-6215 and 'Badgerbelle'.

All treatments on cultivars reduced total yields of usable fruit although the lowest rates of JF2777, DNOC and "Off-Shoot-O" in general did not significantly reduce yields. Moderate but non-significant increases in total yields were apparent with 0.25% JF2777 and 5.0% "Off-Shoot-O" treatment on IA26-6215. The only significant increase in total usable yield was observed with Lissapol treatment on the same clone.

Visible post-treatment injury to plants in the field with 1.00% JF2777 and the higher rates of "Off-Shoot-O" was evident in necrotic spotting of leaf tissue and petioles in the leaflet axils where spray runoff accumulated. Post-fruiting runnering of plants was not noticeably affected.

C. Morphological Effects and Rates of Action of Chemical Bud Pruners on Stigma, Style and Anther Tissue of Strawberry Flowers

Photomicrographs of injury to reproductive structures of 'Surecrop' flower buds induced by contact chemical pruning agents are shown in Fig. 3-5. In Fig. 3a, initial injury from "Off-Shoot-O" emulsion viewed two hours after treatment is evident in the atrophy of some surface stigmatic cells, although anther tissue does not display apparent injury. After four hours, however, anther surface cells begin to display widespread cellular collapse and membrane breakdown (Fig. 3b). Within eight hours, browning and necrosis of the entire style is complete and anthers display a visible surface browning (Fig. 3c). After eight hours, complete necrosis and increasing desiccation becomes apparent although portions of anthers may not be completely destroyed prior to 36 hours after treatment (Fig. 3d). After 72 hours, destruction of reproductive tissue is complete (Fig. 3e). With JF2777, injury also begins on stigmatic surfaces (Fig. 4a), but proceeds somewhat more slowly down the style (Fig. 4b). Complete collapse of anther epidermal cells does not occur until at least 36 hours after treatment (Fig. 4d). Severe injury and complete bud destruction is apparent after 72 hours (Fig. 4e). Satisfactory micrographs of flowers treated with JF3457, 4 and 36 hours prior to examination under the microscope were not obtained. Results after 2, 8 and 72 hours, however, indicated a similar-

Fig. 3. Scanning electron microscope (SEM) photomicrographs of injury to 'Surecrop' strawberry reproductive tissue by "Off-Shoot-O", a chemical pruning agent, at intervals after treatment. 200 X

a. 2 hours after treatment - atrophy of stigmatic surface cells (arrow). No apparent injury on anther

b. 4 hours after treatment - total cell collapse on stigma surfaces. Pollen grains visible (arrow) apparently due to rupture of anther in specimen preparation

c. 8 hours after treatment - necrosis of entire stigmatic surface and beginning signs of stylar necrosis

d. 36 hours after treatment - severe necrosis and desiccation of stylar tissue is apparent

e. 72 hours after treatment - bud destruction is complete including receptacle tissue (not shown). Associated structure (arrow) is a calyx hair dislodged in sample preparation

f. Control - appearance of normal, untreated stigma and stylar surface

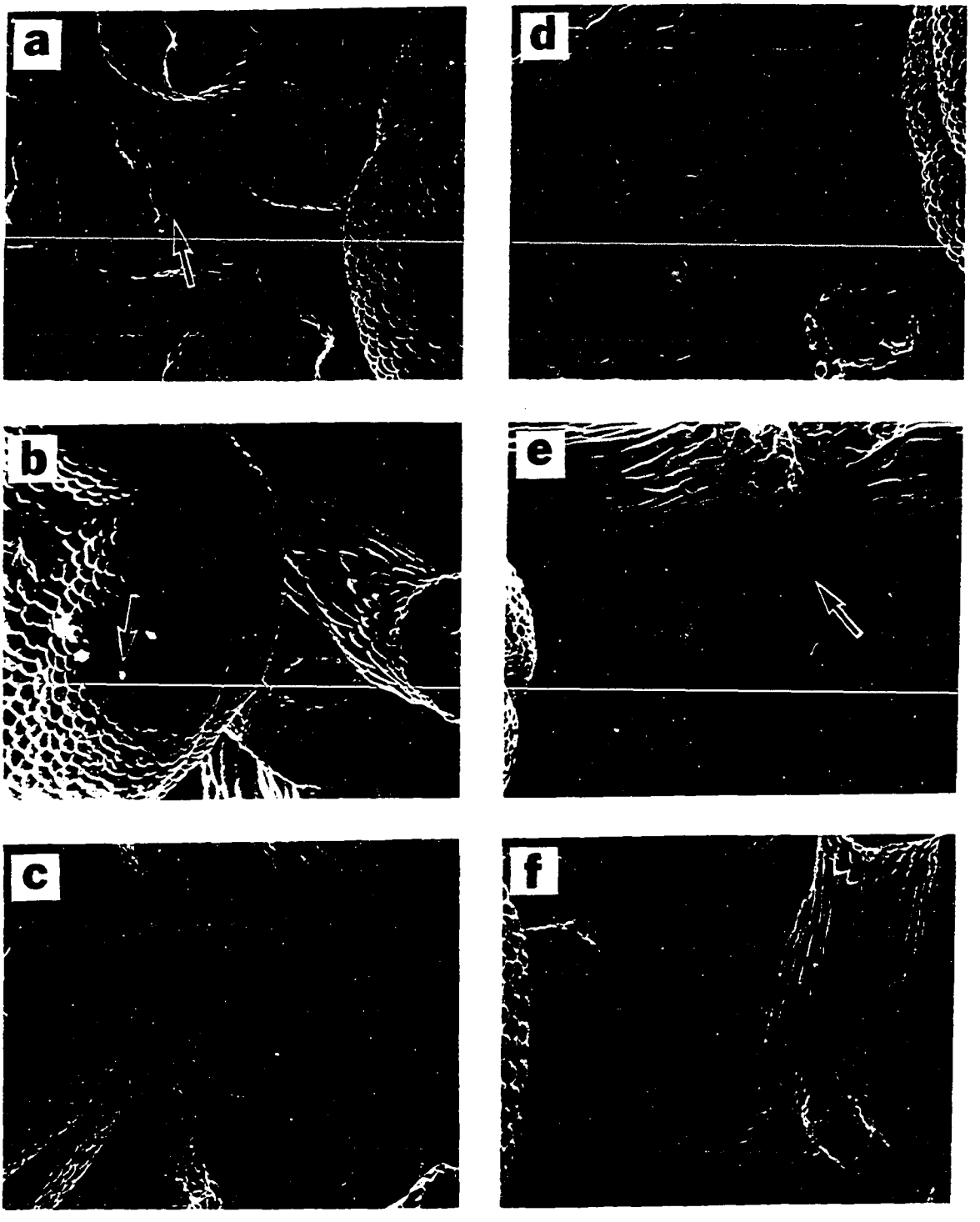

a
d
b
e
c
f

Fig. 4. Scanning electron microscope (SEM) photomicrographs of injury to 'Surecrop' strawberry reproductive tissue by JF2777, an experimental chemical pruning agent, at intervals after treatment. 200X

a. 2 hours after treatment - partial injury to stigmatic surface. No apparent injury to anther tissue

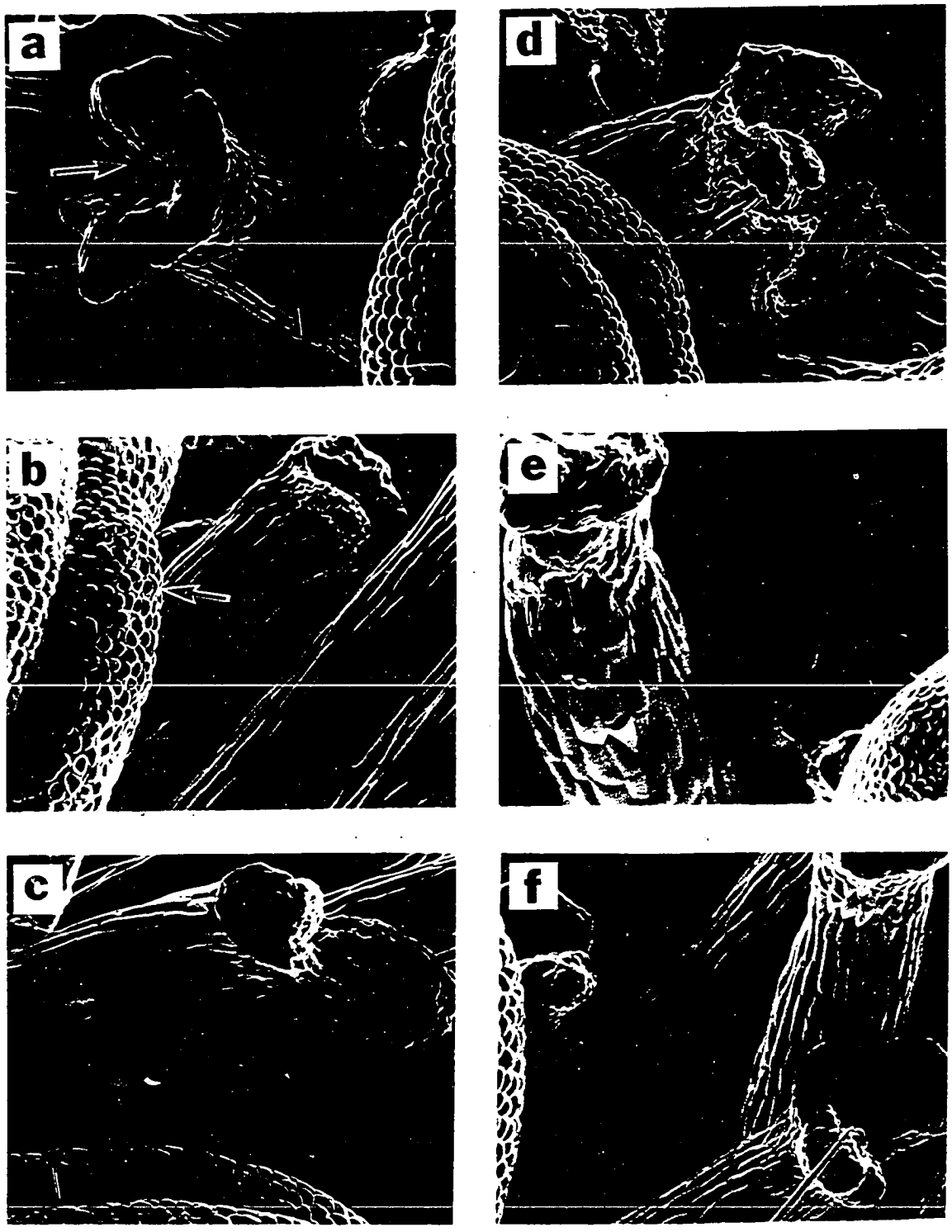
b. 4 hours after treatment - severe injury to stigmatic surfaces and beginning necrosis on style. Partial collapse of anther epidermal cells is visible (arrow)

c. 8 hours after treatment - necrosis of stigmatic and anther surfaces apparent

d. 36 hours after treatment - severe necrosis on stigma and style, collapse of anther tissue

e. 72 hours after treatment - destruction of stigma and style complete, breakdown of anther tissue evident

f. Control - appearance of normal, untreated stigma and stylar surface


a
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f

ity in action to JF2777 in the type and rates of injury. Initial disruption of stigmatic surfaces is apparent in Fig. 5a 2 hours after treatment. At 8 hours, injury is comparable to that observed with JF2777 (Fig. 4c, 5b). Moderate injury is apparent on anthers at 72 hours (Fig. 5e). Lissapol treated flowers display no apparent injury to stigmatic surfaces, although some minor disruption of anther epidermal cells is visible (Fig. 5d). Normal stigmatic and anther surface morphology is visible in the control.

D. Evaluations of Rapid Objective Measures of Maturity in Chemically Pruned Cultivars

Results of statistical analyses of CDM color values L, a, and b, soluble solids, total solids, pH, total acids, ascorbic acid, and mean fresh fruit weight are reported in Appendix Table 5. All main effects and interactions tabulated were significant at the 1% level.

Important interactions of chemical pruning treatments with cultivars, fruit position and variety x fruit positions were plotted to evaluate potential patterns in the data obtained which might indicate their usefulness in characterizing ripening patterns in strawberry clones (Fig. 6-11). In addition, partial correlation coefficients for the 9-variable matrix were obtained to assist in making judgements on which variables could be eliminated due to duplication of information, e.g., either of any two variables with high degrees of

Fig. 5. Scanning electron microscope (SEM) photomicrographs of injury to 'Surecrop' strawberry reproductive tissue by JF3457, an experimental chemical pruning agent and Lissapol NX, a surfactant, at intervals after treatment. 200X

a. 2 hours after treatment - stigmatic surface swelling, no initial signs of disruption. Calyx hair (arrow) dislodged in specimen preparation

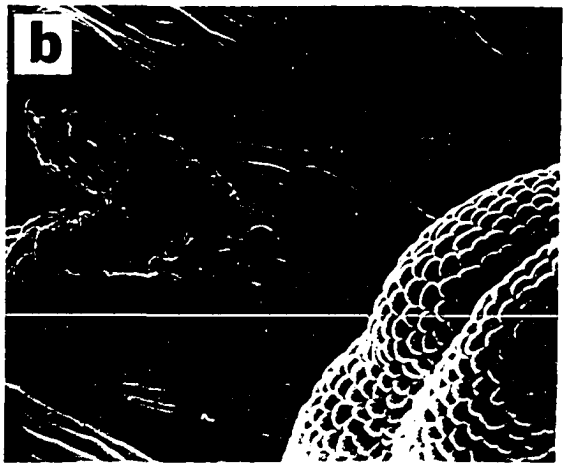
b. 8 hours after treatment - severe injury to stigmatic and stylar tissue, no apparent injury to anthers

c. 72 hours after treatment - severe disruption and necrosis in stigma and stylar tissue, moderate injury to anther surfaces

d. Lissapol NX 4 hours after treatment - no injury to stigmatic surfaces apparent, moderate injury to anther epidermal cells apparent (arrow)

e. Control - appearance of normal, untreated stigma and stylar surfaces


a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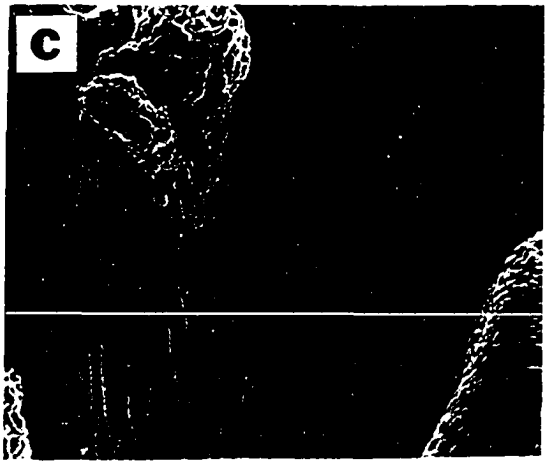
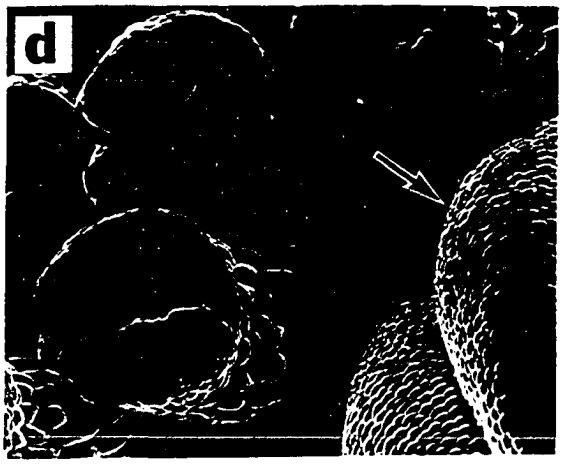

c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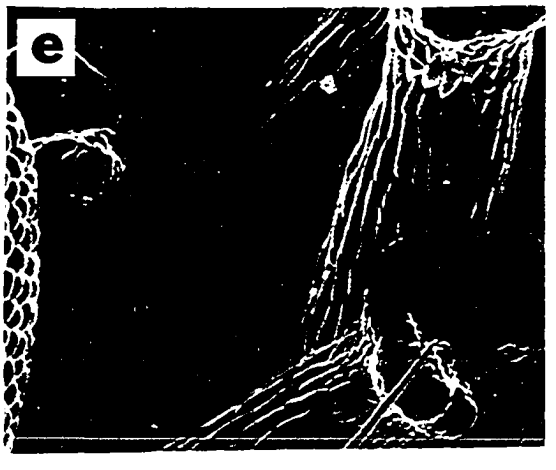
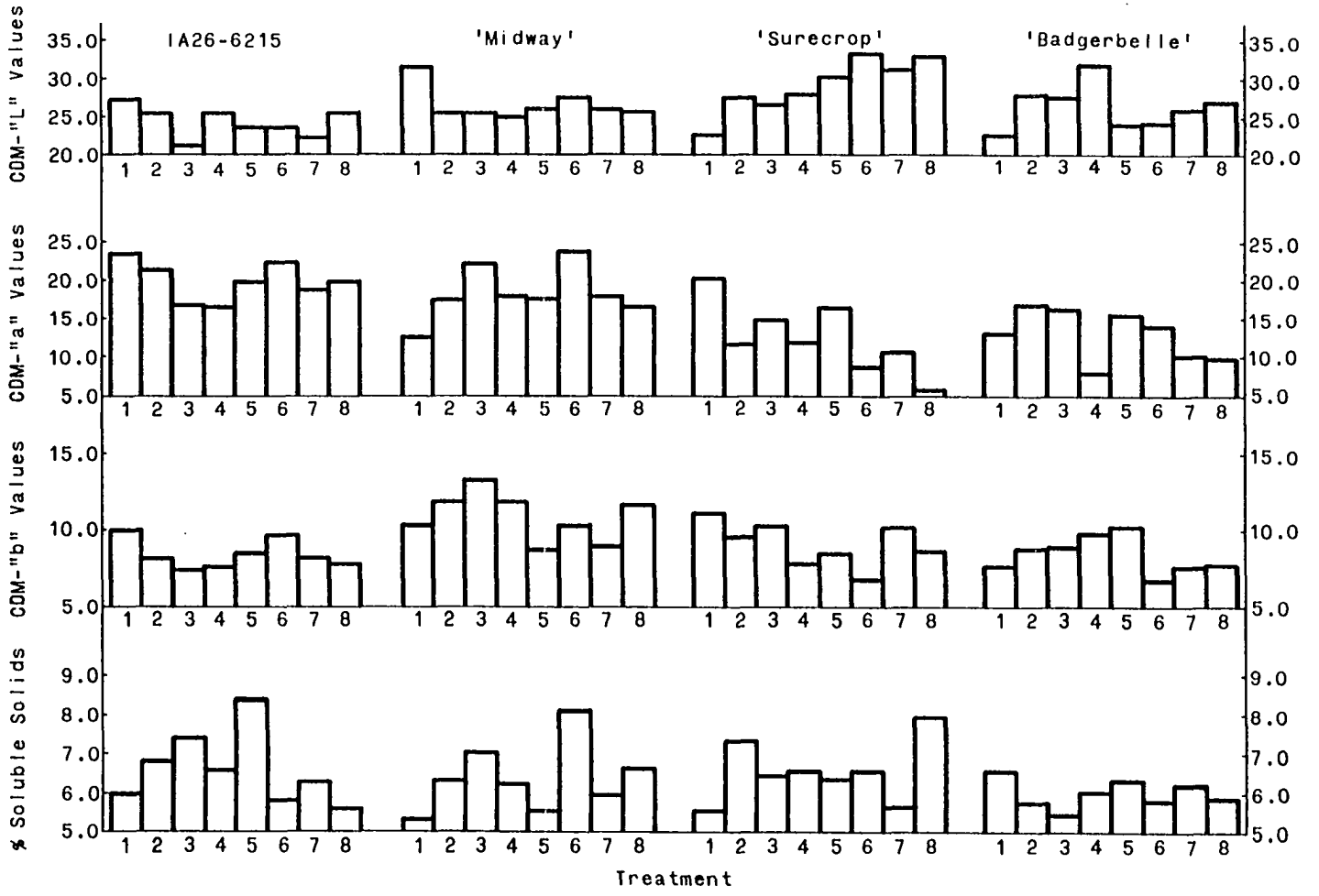

e

Fig. 6. Mean Hunter Color and Color Difference Meter (CDM) "L", "a", "b" values and percent soluble solids in strawberry clones with chemical pruner treatments. Materials and rates tested were as follows:

Treatment	Material[a]	Rate (v/v)
1	JF2777	0.25%
2	do	0.50%
3	do	1.00%
4	do	2.00%
5	JF3457	0.40%
6	do	0.80%
7	do	1.60%
8	Control	-----

[a]1.00% v/v Lissapol NX, a wetting agent, was included with all chemical treatments.


IA26-6215
'Midway'
'Surecrop'
'Badgerbelle'
CDM-"L" Values
CDM-"a" Values
CDM-"b" Values
% Soluble Solids
Treatment

correlation could potentially substitute for each other as an objective measure of maturity patterns. According to Snedecor and Cochran (81), where no variables can be specified as independent or dependent, partial correlation methods are appropriate. Since effects of cultivar, treatment and flower position contributed significantly to the values obtained, partial correlations ($r_{V.T.FP}$) were calculated to provide a measure of correlation holding these factors constant. A sample correlation matrix for "L" values is tabulated in Table 9, and is representative of values obtained with all the variables measured.

A wide range of correlations obtained by calculation are evident, indicating the difficulty in selecting any subset of variables which would suffice as maturity indicators to replace the balance of the variables in predicting or characterizing a particular stage of maturity. For example, significant correlations between mean weight and CDM "L", "a" and "b" values, soluble solids and total acids suggest that any of these variables could be substituted as an index of fruit maturity. On the other hand non-significant correlations between percent total solids and the other variables measured indicate that percent total solids, if they are a good objective measure of maturity, cannot be replaced by another variable.

Cultivar x treatment responses in CDM "L", "a", "b" color values and percent soluble solids are shown in Fig. 6. Data

Table 9. Correlations for a 9-variable matrix of potential maturity indicators based on 9 observations (n = 9)

		CDM values "L"	CDM values "a"	CDM values "b"	Soluble solids	pH	% total acids	Mean weight[a]	% total solids	Ascorbic acid
CDM values	"L"	1.00								
	"a"	-0.95*	1.00							
	"b"	0.72*	-0.54	1.00						
Soluble solids		-0.92*	0.97*	0.58	1.00					
pH		0.12	0.02	0.37	0.06	1.00				
% total acids		0.81*	-0.63	0.95*	-0.56	0.40	1.00			
Mean weight[a]		-0.98*	-0.90*	-0.80*	0.85*	-0.25	-0.88*	1.00		
% total solids		-0.04	-0.03	-0.06	0.00	-0.55	-0.07	0.08	1.00	
Ascorbic acid		0.26	-0.02	0.80*	0.03	0.35	0.66	-0.36	-0.28	1.00

[a]Mean berry weight by flower position within inflorescences.

*Correlations exceeding 0.71 are significant at the 5% level.

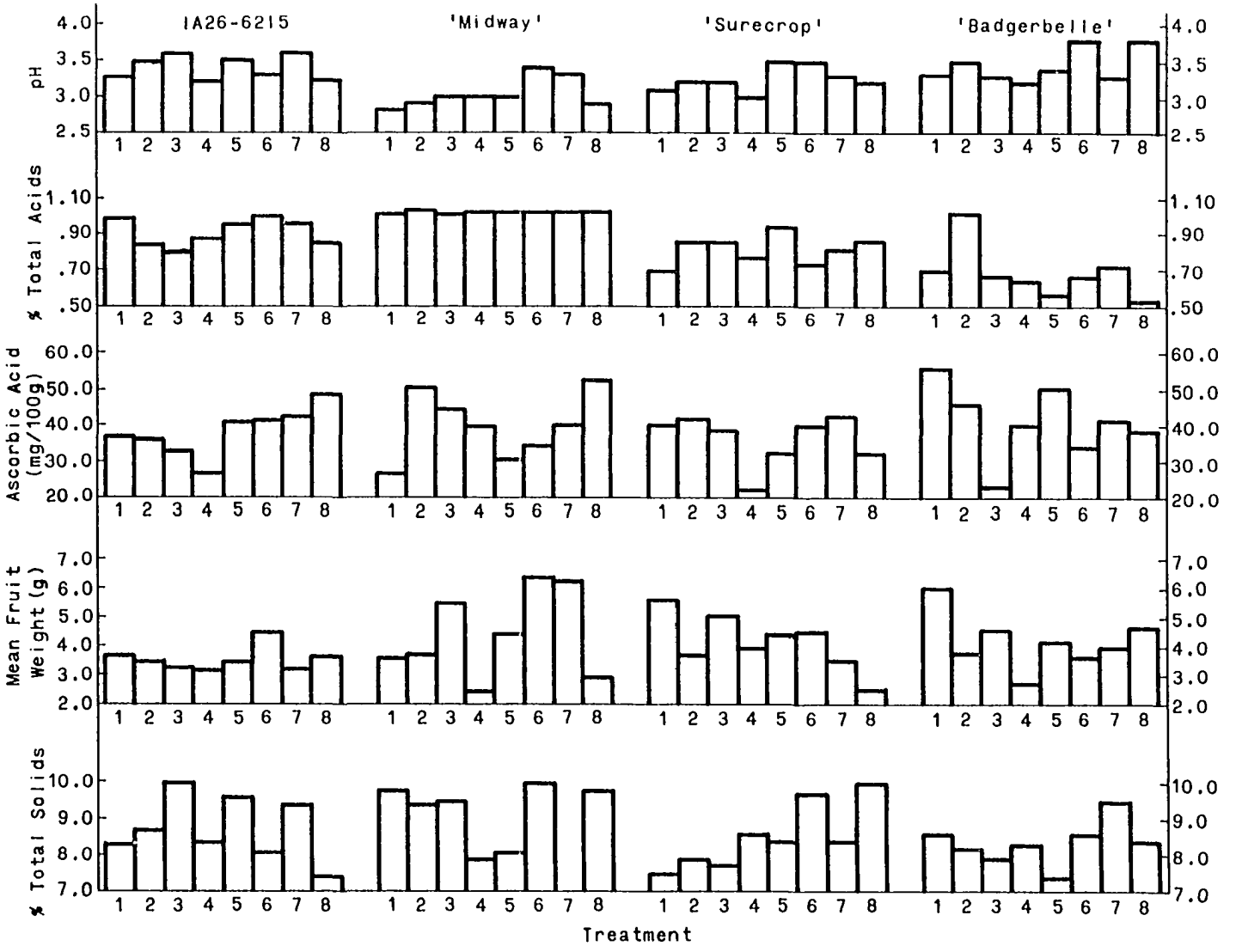
on pH, percent total acids, ascorbic acid, mean fruit weight and percent total solids for the same interaction are displayed in Fig. 7. Higher L (lightness) values denote increasing amounts of colorless (green) fruit. The expected minimal effects of chemical pruners on the concentrated ripening clone are apparent in only moderate differences between the treatments and untreated control. A definite concentration of ripening is apparent in lower "L" values in comparison with the non-concentrated 'Surecrop' or 'Badgerbelle' cultivars. High CDM "a" values on the other hand, demonstrate the higher amounts of red or ripe fruit in IA26-6215 when compared with the non-concentrated ripening 'Badgerbelle. Possible effects of higher rates of JF2777 and JF3457 on reductions in mature, usable fruit are apparent in 'Midway' and 'Surecrop'. Positive increases in CDM "b" values indicate increases in yellow tones but have not generally been accepted as useful in characterization of strawberry fruit color. A significant correlation ($r = 0.72$) with "L" values indicates that this particular variate could potentially be replaced by "L" readings as a measure of color or ripening in fruits.

Significant negative correlation between CDM "L" values and soluble solids and positive correlation with CDM "a" values indicates that this variable could be replaced by either or both color determinations as a method for characterizing maturity in strawberries. Soluble solids in the strawberry increase as fruit maturity increases (18, 80).

Figure 7. Mean pH, percent total acids, ascorbic acid (mg/100 g), fruit weight (g) and percent total solids in strawberry clones with chemical pruner treatments. Materials and rates tested were as follows:

Treatment	Material[a]	Rate (v/v)
1	JF2777	0.25%
2	do	0.50%
3	do	1.00%
4	do	2.00%
5	JF3457	0.40%
6	do	0.80%
7	do	1.60%
8	Control	-----

[a]1.00% v/v Lissapol NX, a wetting agent, was included with all chemical treatments.


IA26-6215
'Midway'
'Surecrop'
'Badgerbelle'
pH
% Total Acids
Ascorbic Acid (mg/100g)
Mean Fruit Weight (g)
% Total Solids
Treatment

The reduction in concentration of ripening in 'Surecrop' is apparent in reduced soluble solids in plants treated with chemical pruners when compared with the untreated check.

Moderate increases in pH and total acidity in IA26-6215 again indicate an increasing effect on concentration of ripening with chemical pruning (Fig. 7). General reductions in concentration of ripening are suggested by lower pH in the cultivars with chemical flower pruning treatments although lower rates of JF3457 appear to promote some maturity and associated higher pH in 'Surecrop' and 'Badgerbelle'. Although total acidity varies for cultivars, the reduced response within cultivar-treatment combinations suggests that this variable may not be useful as a criterion of maturity. Ascorbic acid levels are significantly correlated only with CDM "b" values and thus could possibly be substituted for this variable in characterizing maturity in strawberries. Some question may exist in regard to the reliability of either characteristic as a maturity indicator. Somewhat erratic response is observed in clonal comparisons, although a general reduction in ascorbic acid levels is evident with higher rates of JF2777.

Overall mean fruit weight is affected very little by chemical pruners in IA26-6215 although general increases are apparent in cultivars with chemical treatment. The high rate of JF2777 reduced fruit weight substantially in 'Midway' and 'Badgerbelle' although the decrease was not as great in

'Surecrop'. Total solids tended to increase with increasing rates of JF2777 and were substantially higher for chemical treatments when compared with the IA26-6215 control. Response in increased total solids also occurred with increasing rates of JF3457 in the cultivars although levels were generally the same or lower than in the untreated controls.

Responses for cultivar x fruit position in the inflorescence were generally straight-forward and somewhat predictable (Figs. 8, 9). In several cases, cultivar response was characteristic and distinct, indicating promise for use of that particular variable in characterizing maturity of fruit. CDM "L" values increased linearly as the amount of green or partially green fruit increased downward in the inflorescence, and were distinct for a clone (Fig. 8). CDM "a" values were linear for 'Surecrop' and 'Badgerbelle' although a different pattern of values was obtained for IA26-6215 and 'Midway'. CDM "b" values for chromaticity aid in characterizing pigment "depth" but may not be useful in defining maturity since almost identical values were observed for 'Surecrop' and 'Badgerbelle' and do not correlate well with "L" values observed for these cultivars. Higher soluble solids in more mature primary fruit were evident, decreasing in tertiary fruit. The concentration of ripening in IA26-6215 in comparison with the cultivars is apparent in the minimal differences between soluble solids in primary and tertiary fruit.

pH values for the strawberry clones evaluated fluctuated

Figure 8. Mean Hunter Color and Color Difference Meter (CDM) "L", "a", "b" values and percent soluble solids in strawberry fruits by flower position (primary, 1^{o}, secondary, 2^{o} and tertiary, 3^{o}) within clones.

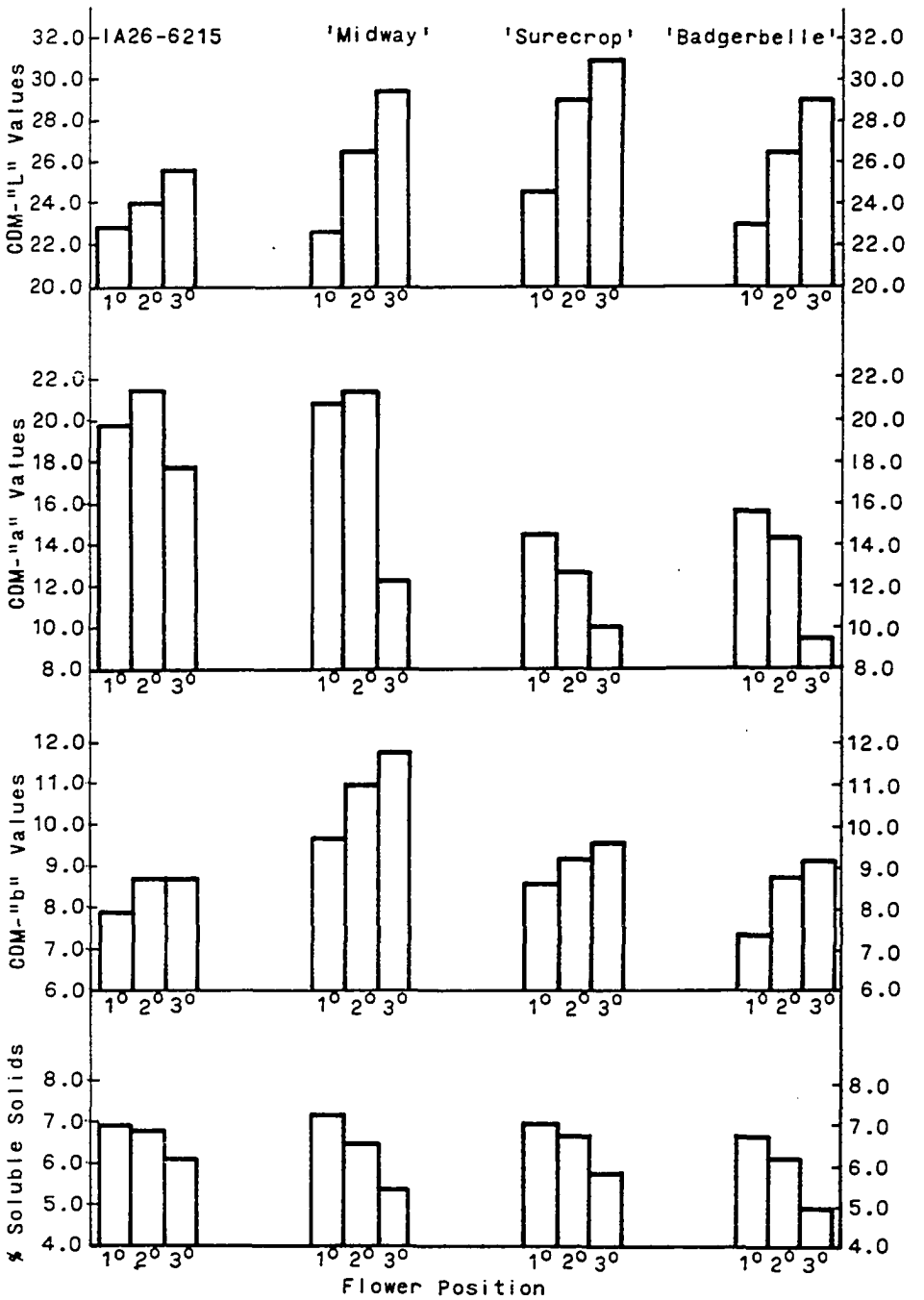
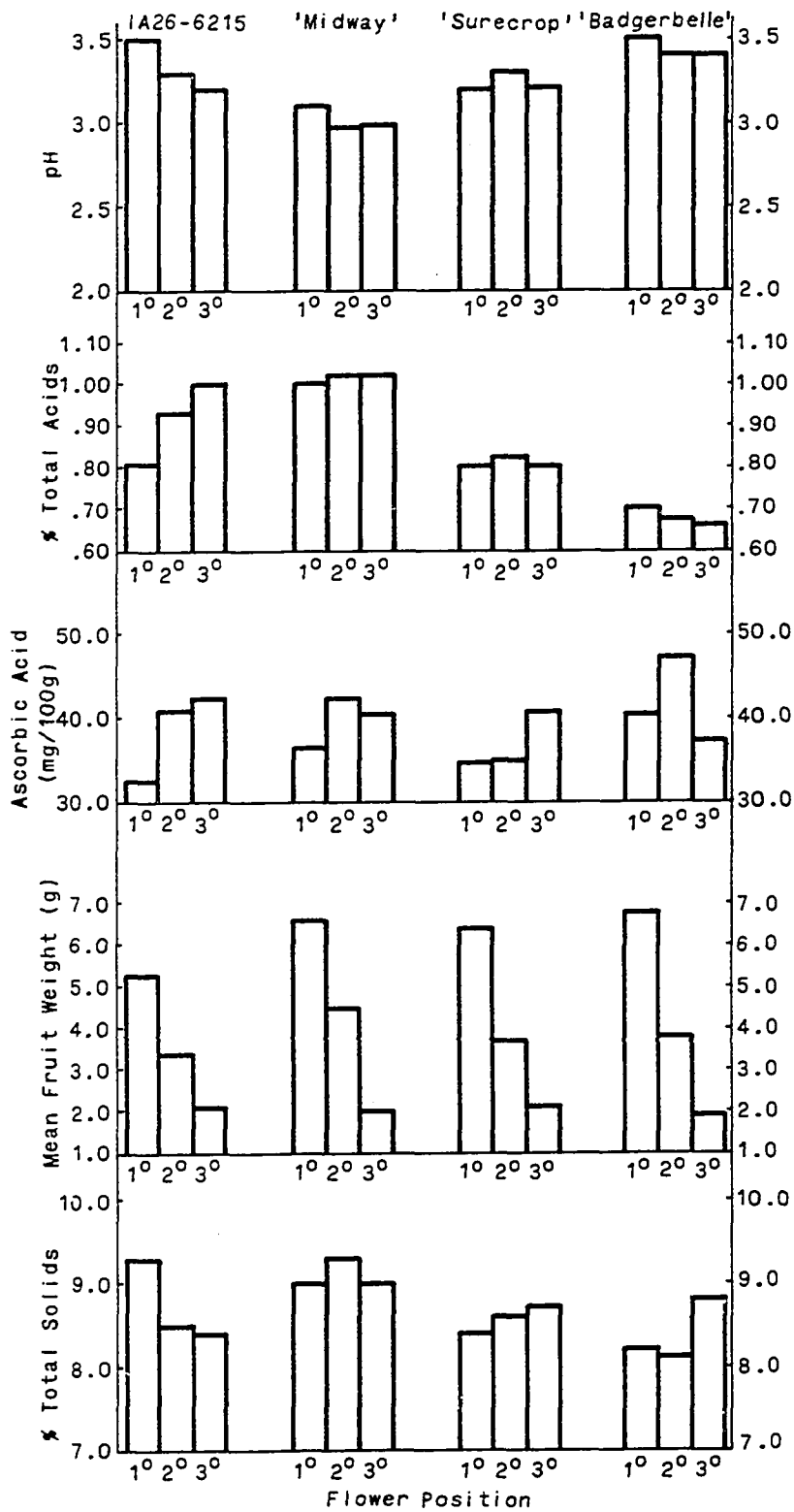

IA26-6215
'Midway'
'Surecrop'
'Badgerbelle'
COM-"L" Values
COM-"a" Values
COM-"b" Values
% Soluble Solids
1° 2° 3°
Flower Position

Figure 9. Mean pH, percent total acids, ascorbic acid (mg/100g), fruit weight (g) and percent total solids in strawberry fruits by flower position (primary, 1^{o}, secondary, 2^{o} and tertiary, 3^{o}) within clones.


IA26-6215
'Midway'
'Surecrop'
'Badgerbelle'
pH
% Total Acids
Ascorbic Acid (mg/100g)
Mean Fruit Weight (g)
% Total Solids
1° 2° 3°
Flower Position

widely by fruit position and did not display a pattern which would suggest usefulness as maturity indicators (Fig. 9). Inconsistent patterns also resulted from total acids determinations. Berry acidity may thus lack usefulness in describing maturity for comparative purposes. The same may be true for ascorbic acid where flower position and degree of ripening may not be directly related to maturity levels in fruit.

Mean fruit weight patterns may be useful in defining maturity when combined with values for other characteristics. Similar values obtained for primary and tertiary values in cultivars raise the question of their direct value, however. Erratic response in total solids by fruit position for the clones examined suggest that the percent total solids probably would not be meaningful in a single determination on blended fruit. Similar levels of total solids for primary and tertiary fruit in 'Midway' underscore the low specificity of this criterion for defining maturity.

Removing cultivar effects from treatment x flower position responses provides additional information for evaluating the potential rapid measurements of maturity used in this test (Figs. 10, 11). A quantitative response in terms of reduced "L" color values is apparent in primary fruit with increasing levels of chemical pruner up to 1.00% JF2777 and 0.80% JF3457 while the highest rates appeared to promote fruit coloration in comparison with the control (Fig. 10). In tertiary fruit, reductions in fruit puree lightness are

Fig. 10. Mean Hunter Color and Color Difference Meter (CDM) "L", "a", "b" values and percent soluble solids by fruit position in strawberry inflorescences with chemical pruner treatments.[a] Materials and rates tested were as follows:

Treatment	Material[b]	Rate (v/v)
1	JF2777	0.25%
2	do	0.50%
3	do	1.00%
4	do	2.00%
5	JF3457	0.40%
6	do	0.80%
7	do	1.60%
8	Control	-----

[a]Means obtained are estimates based on values observed with the four clones tested.

[b]1.00% v/v Lissapol NX, a wetting agent, was included with all chemical treatments.

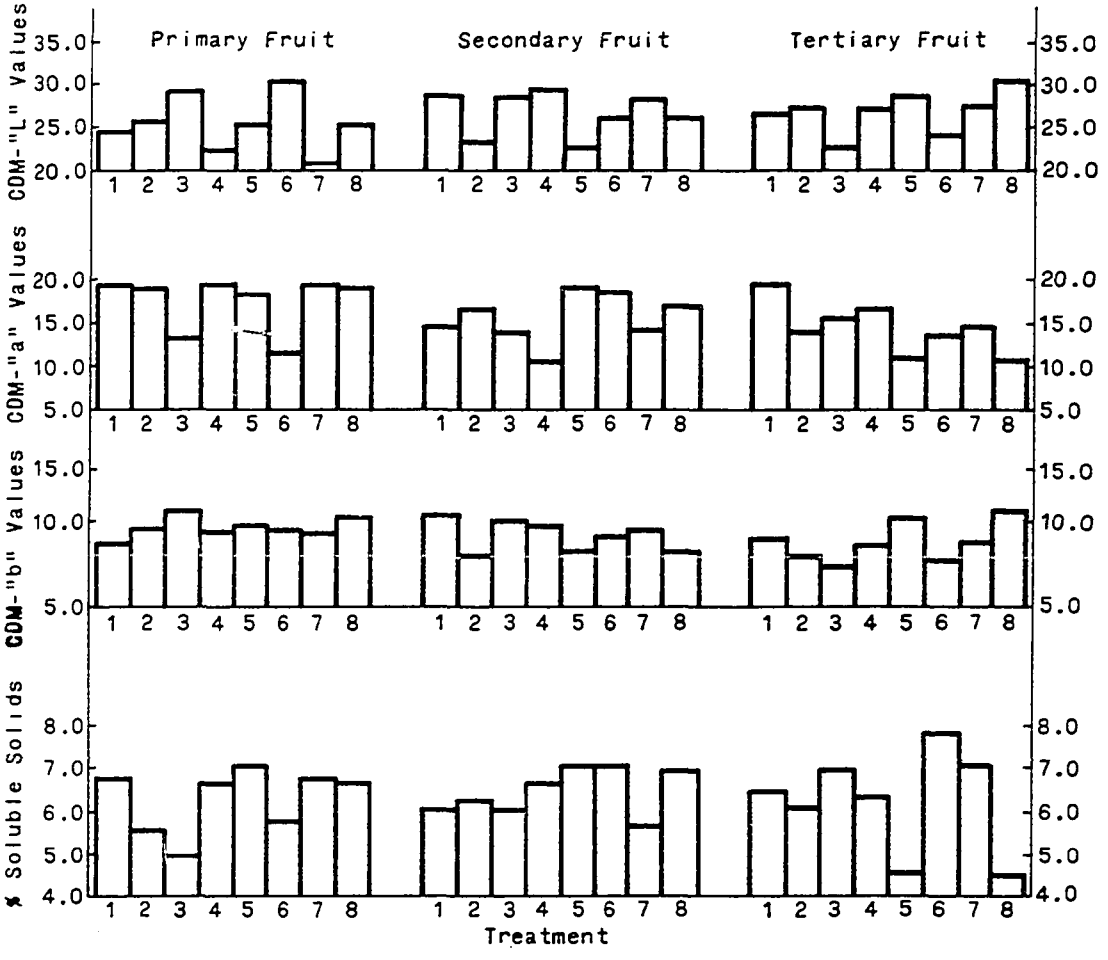
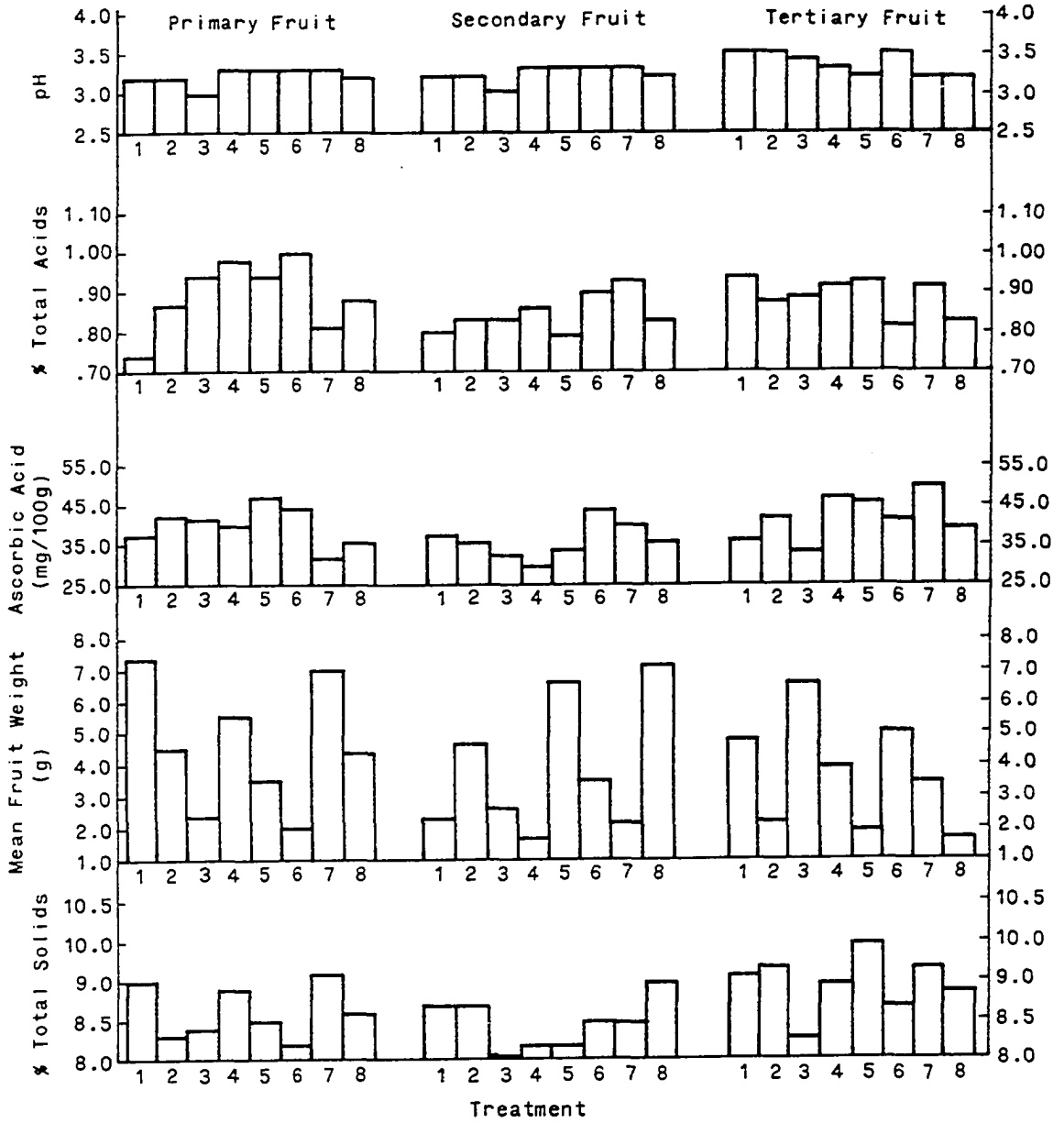

Primary Fruit
Secondary Fruit
Tertiary Fruit
CDM-"L" Values
CDM-"a" Values
CDM-"b" Values
% Soluble Solids
Treatment

Fig. 11. Mean pH, percent total acids, ascorbic acid (mg/100 g), fruit weight (g) and percent total solids by fruit position in strawberry inflorescences with chemical pruner treatments.[a] Materials and rates tested were as follows:

Treatment	Material[b]	Rate (v/v)
1	JF2777	0.25%
2	do	0.50%
3	do	1.00%
4	do	2.00%
5	JF3457	0.40%
6	do	0.80%
7	do	1.60%
8	Control	-----

[a]Means obtained are estimates based on values observed with the four clones tested.

[b]1.00% v/v Lissapol NX, a wetting agent, was included with all chemical treatments.


Primary Fruit
Secondary Fruit
Tertiary Fruit
pH
% Total Acids
Ascorbic Acid (mg/100g)
Mean Fruit Weight (g)
% Total Solids
Treatment

apparent suggesting a general treatment effect on concentration of ripening. Results are erratic with secondary fruit. Conversely, CDM "a" or red values decrease slightly with moderate rates of chemical pruners but indicate little change from the control in primary and secondary fruit while the amount of red fruit generally is increased in tertiary fruit. CDM "b" values fluctuate little from the control and again raise the question of their utility in evaluating fruit ripeness. The high degree of correlation (0.97) between soluble solids and CDM "a" values is apparent in graphs of the data obtained. Trends in both variables are similar for each treatment except for higher rates of JF3457 on tertiary fruit.

Variations in pH readings for fruit position x treatment interactions are slight and stress the need for additional information in relating this criterion to fruit maturity (Fig. 11). Total acids are in general significantly higher for chemical pruner treatments except in secondary fruit. Patterns in ascorbic acid levels are similar.

Substantial increases in mean fruit weight in primary and tertiary fruit with chemical pruner treatments in comparisons with the control are apparent but their validity must be questioned in light of previous results with chemical pruners. Dramatic fruit size increases have never been encountered previously using these materials. Erratic results in percent total solids determinations are also evident in Fig. 11.

The complexity of this type of study, where imposed

cultivar, chemical treatment and flower position effects can all affect results makes interpretation difficult. To supplement this information, the estimations of the same variables on known quantities of fruits at various stages of ripening provided information on those factors involved which are inherently difficult to interpret.

Tabulations of results of the second portion of this study are shown in Tables 10 and 11 by cultivar. Analyses of variance for CDM "L", "a", "b" color values and percent soluble solids are shown in Appendix Table 8. Similar analyses for pH, percent total acids, percent total solids and ascorbic acid levels are listed in Appendix Table 9. Although significant cultivar differences were observed in CDM "b" values, percent soluble solids, pH, percent total solids, percent total acids and ascorbic acid, a glance at the tables for mean cultivar responses by treatment demonstrates the failure to obtain quantitative, linear responses to increasing levels of mature or decreasing levels of green fruit in the treatment mixture (Tables 10 and 11).

Significant differences in treatment effects are evident in CDM "L", "a", "b", percent soluble solids and ascorbic acid levels in both 'Midway' and 'Surecrop'. Neither percent soluble solids nor ascorbic acid, however, appear promising as a quantitative indicator for increasing maturity in fruit mixtures such as those created in this study to attempt to duplicate as closely as possible field mixtures within

Table 10. Mean Hunter color and color difference meter (CDM) "L", "a", "b" values, percent soluble solids, pH, percent total solids and ascorbic acid determinations on samples of 'Midway' strawberry fruit containing varying amounts of mature, "pink", mature green and immature green fruit

Variable	Sample means				
CDM "L"	31.23	32.23	31.67	32.47	29.83
CDM "a"	12.93	14.00	16.83	15.40	18.53
CDM "b"	11.60	11.83	11.60	11.46	11.30
% soluble solids	4.57	4.80	5.37	4.97	5.33
pH	3.57	3.53	3.51	3.56	3.57
% total acids	0.81	0.80	0.88	0.83	0.85
% total solids	7.96	7.41	7.82	7.56	7.78
Ascorbic acid (mg/100g)	47.33	47.56	53.77	47.30	42.73
	Fruit sample composition (% of each grade present)				
% Acceptable (mature)	20	25	30	35	40
% Color inception (pink)	16	15	14	13	12
% Mature green (white)	16	15	14	13	12
% Immature (green)	48	45	42	39	36

28.07	29.27	30.17	30.23	27.47	26.77	25.03	24.70
18.56	17.10	17.27	18.60	20.53	19.53	21.73	22.40
10.83	11.27	10.70	11.37	11.17	11.30	11.50	11.07
5.10	4.87	5.10	5.57	5.00	6.13	5.27	5.33
3.56	3.49	3.63	3.49	3.53	3.57	3.54	3.60
0.81	0.86	0.79	0.84	0.78	0.84	0.84	0.79
7.82	7.36	7.61	7.44	7.40	7.98	7.49	7.54
47.46	47.87	41.80	41.33	44.83	60.53	65.63	69.03

45	50	55	60	65	70	75	80
11	10	9	8	7	6	5	4
11	10	9	8	7	6	5	4
33	30	27	24	21	18	15	12

Table 11. Mean Hunter color and color difference meter (CDM) "L", "a", "b" values, percent soluble solids, pH, percent total solids and ascorbic acid determinations on samples of 'Surecrop' strawberry fruit containing varying amounts of mature, "pink", mature green and immature green fruit

Variable	Sample means				
CDM "L"	33.07	33.67	32.83	31.57	28.77
CDM "a"	14.26	11.43	14.83	13.80	16.77
CDM "b"	10.90	10.80	10.67	10.16	10.00
% soluble solids	5.67	5.30	5.80	6.16	6.06
pH	3.50	3.45	3.41	3.48	3.43
% total acids	1.03	1.08	1.10	1.05	1.02
% total solids	7.87	7.53	7.71	8.43	8.26
Ascorbic acid (mg/100g)	66.63	73.63	71.60	57.56	66.50
	Fruit sample composition (% of each grade present)				
% Acceptable (mature)	20	25	30	35	40
% Color inception (pink)	16	15	14	13	12
% Mature green (white)	16	15	14	13	12
% Immature (green)	48	45	42	39	36

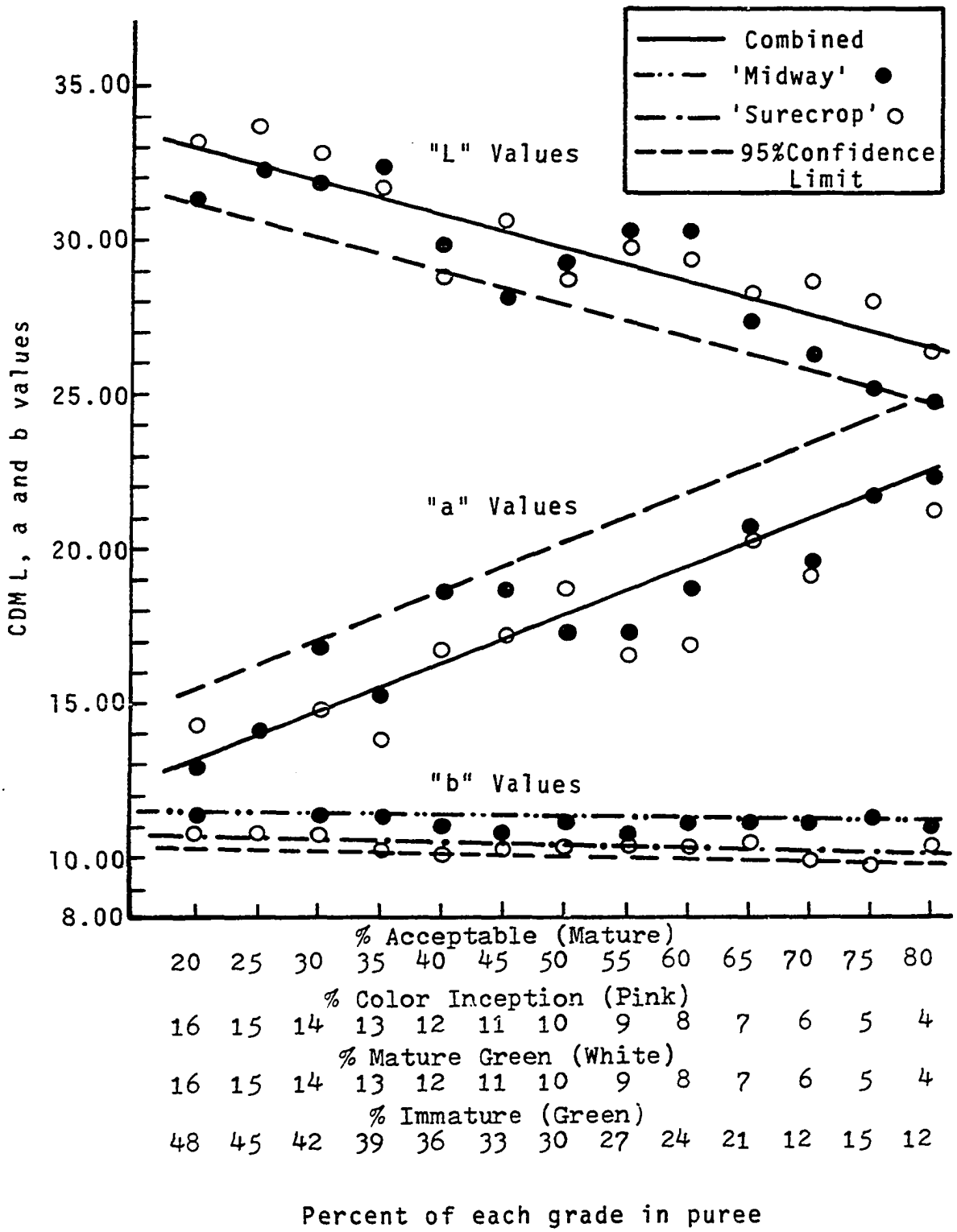
30.53	28.77	29.90	29.40	28.20	27.63	28.00	26.46
17.10	18.67	16.50	16.97	20.37	19.10	26.53	21.16
10.40	10.47	10.30	10.40	10.47	9.97	9.93	10.23
6.20	5.60	6.10	6.27	6.17	6.83	6.87	7.17
3.48	3.41	3.43	3.47	3.44	3.51	3.47	3.46
1.00	1.07	1.05	1.01	1.00	0.98	1.03	1.05
8.24	7.84	8.20	7.96	7.63	8.74	8.65	8.81
70.13	72.93	67.47	51.63	49.53	63.80	71.43	73.76

45	50	55	60	65	70	75	80
11	10	9	8	7	6	5	4
11	10	9	8	7	6	5	4
33	30	27	24	21	18	15	12

individual fruit clusters. Although general increases in both soluble solids and ascorbic acid content are apparent with increasing amounts of mature fruit, substantial and significant deviations from a linear response are apparent and suggest potential difficulties in using these criteria as quantitative indicators of fruit maturity, at least in this particular study.

Fruit color determinations, i.e., CDM "L", "a" and "b" values appear to offer the greatest promise as potential rapid objective measures of concentration of ripening in mixtures of fruit at different stages of maturity within a cluster. Linear regressions for CDM "L", "a", and "b" values on fruit sample composition are shown in Fig. 12. A significant negative correlation ($r = -0.75$) between CDM "L" and "a" values indicates the interrelationship of these measurements in defining strawberry puree color. CDM "b" values differed significantly at the 5% level for treatments; highly significant differences between cultivars are apparent (Appendix Table 8). As expected, in CDM "b" values no quantitative response to increasing levels of mature fruit or decreasing levels of immature fruit was obtained; the range of "b" values obtained for each cultivar was, however, characteristic for that cultivar and fluctuated within a fairly narrow range.

Fig. 12. Responses of Hunter color and color difference meter (CDM) "L", "a", "b" color values to increasing amounts of acceptable ("ripe") fruit and decreasing amounts of fruit at color inception ("pink"), mature green ("white"), and immature ("green") stages of maturity in pureed mixtures of 'Surecrop' and 'Midway' fruit.


Combined
'Midway'
'Surecrop'
95%Confidence Limit
"L" Values
"a" Values
"b" Values
CDM L, a and b values
35.00
30.00
25.00
20.00
15.00
10.00
8.00
% Acceptable (Mature)
20 25 30 35 40 45 50 55 60 65 70 75 80
% Color Inception (Pink)
16 15 14 13 12 11 10 9 8 7 6 5 4
% Mature Green (White)
16 15 14 13 12 11 10 9 8 7 6 5 4
% Immature (Green)
48 45 42 39 36 33 30 27 24 21 12 15 12
Percent of each grade in puree

V. DISCUSSION AND CONCLUSIONS

Preliminary greenhouse results indicated that response to chemical pruners is related to concentration of the chemical used within a relatively narrow range. With 'Surecrop', 0.5% PP938 or the emulsifiable concentrate, JF2777, effectively produced flower thinning with minimal injury to vegetative tissue. The inconsistencies observed in mean tertiary fruit, in terms of a reduction in comparison with the higher rate of the same material were considered to be primarily a reflection of the small sample size used. The 10% increase in usable fruit in 'Surecrop' after chemical thinning (Table 4) with PP938 and JF2777 gave some promise for promotion of concentrated ripening, at least in this particular cultivar, although sizeable reductions in total fruit yields did occur with the same materials. In instances where losses to overripe fruit in unpruned inflorescences could be substantial when once-over harvests with maximum yield of fruit are attempted, enhanced concentration of ripening might aid in offsetting these reductions in total yield.

Determining the components of yield by flower position (Table 2) demonstrated that secondary and tertiary fruits contribute the highest percentages of fruit by weight to total yield, substantiating Janick and Eggert's (44) contention that pruning of flowers should be limited to either primary or tertiary flowers on an inflorescence to obtain concentration

of ripening while minimizing reductions in usable yields. From the data obtained in the preliminary work it appeared that severe pruning of tertiary flowers would reduce yields of fruit drastically. Although data on the contribution of quaternary fruits to total yield were not obtained, it seemed possible that pruning of primary, quaternary or both flower positions within inflorescences would promote maximum concentration of ripening with minimal reductions in yield. Since primary fruit may contribute up to 40% of the total usable fruit weight, however, primary fruit was not considered to be expendable in this study. Efforts were made to prevent or reduce losses of primary fruit in applying chemical treatments.

At the 10.0% rate in the greenhouse, "Off-Shoot-O" treatments usually resulted in severe injury to leaf petioles and fruit pedicels, occasionally resulting in death of the entire plant. Rates of 5.0% or lower did not produce consistent flower thinning. These observations corroborated reports by Cathey et al. (16) and also McDowell et al. (54) using various plant materials in which high humidity or low temperatures enhanced injury obtained with methyl decanoate (16, 54). In addition, plant researchers have frequently reported the lack of consistency in greenhouse and field results when plant responses to chemical treatment are compared. In most instances higher rates of a chemical are required in the field to obtain results comparable to those observed in greenhouse tests. For these reasons, both the 5.0% and 10.0% rates were included in

the subsequent field test for comparative purposes. As an additional comparison DNOC (Elgetol) was included because of its demonstrated usefulness in thinning pome fruits. Initial injury to flowers with Lissapol NX noted in the earliest preliminary screening of potential chemical pruners could not be duplicated in subsequent greenhouse tests; in the field, significant increases in usable berry size in IA26-6215 and in 'Badgerbelle' with this surfactant again demonstrated a modifying effect on plant response. Further tests are needed.

In the field, non-significant differences in the number of unusable fruits per cluster and in the numbers of aborted tertiary and quaternary fruits by clone reported in Table 5 at first suggested a non-specific response by cultivar or clone to chemical pruning. The relationship between higher numbers of aborted flowers and higher numbers of usable fruits per cluster however suggests at least a potential promotion of concentrated ripening. In addition, reduced berry weight in green, unusable fruit evident in cultivar x treatment response indicates potential increases in usable fruit size if reduced competition from smaller unusable fruits contributed to larger fruit size in earlier developing fruits. The opposite effect was observed.

Although clonal response varied, general reductions in usable fruit size were also obtained with chemical pruner treatments (Table 6), and are reflected in the reduced total yields of usable fruit (Table 8). Since usable fruit size in

'Surecrop' with chemical pruner treatments is comparable to that observed in the three other clones, higher total yields probably reflect the higher numbers of usable fruits per cluster in this clone.

High rates of natural abortion of late flowers in the concentrated ripening clone IA26-6215 have previously been reported (82). Although moderate but significant increases in secondary fruit size are evident with chemical pruning treatments, the potential for increasing total yields of usable fruit appear to be limited, as results in reduced total yields indicate. This potential for increases in usable fruit yields by abortion of late flowers does not appear to be present in the commercial cultivars tested. 'Surecrop' has been reported to be one of the commercial cultivars with highest yields in once-over harvests (57). The inherent mechanism for whatever concentration of ripening is present in this cultivar thus is probably not related to the natural abortion of flowers, since the greatest reduction in usable berry weight, particularly in secondary fruits, occurred in this cultivar with increased abortion of flowers.

Abbott and Webb's (1) observation that achene number in individual fruits is directly related to subsequent fruit size development raises the question of possible partial achene abortion in flowers as a factor affecting fruit size in this experiment. Greenhouse tests with either PP938 or "Off-Shoot-O" did not indicate any partial pruning effects on individual

berries, nor were fruits sprayed 2 or 3 days after fertilization of flowers affected by the rates used. Incomplete coverage with sprays in the field could contribute, however, to partial pistil abortion. Since harvested fruit shape on treated plants was normal for a clone, it appears most likely that differences due to incomplete coverage, if they occurred, would be reflected in differences in the numbers of fruits aborted.

Timing of pruning or thinning sprays is critical in most fruit crops (17, 27), and may be even more critical in the strawberry where sequential flower development plays an important role in subsequent fruit development. Preliminary greenhouse tests with JF2777 and "Off-Shoot-O" indicated the effectiveness of these materials in pruning at moderately low rates when applications were made at or just prior to the "white bud" stage, when sepals are partially open with the petals showing. Prior to this stage, flowers are generally partially enclosed in the leaf sheaths around the plant crown or are protected by the canopy of leaves above the plant. Optimum timing for late flower pruning in the field thus appeared to occur during the period 2-4 days after "full bloom" of primary flowers. A reduction in the number of tertiary flowers pruned could possibly be achieved by an application several days after this period.

The promotion of significant increases in secondary fruit weight and total fruit weight in IA26-6215 and 'Badgerbelle'

and moderate fruit weight increase in 'Midway' secondary fruit with the wetting agent Lissapol NX again raised the question of potential pruning effects with this chemical. For this reason, a Lissapol treatment was included in an evaluation of external morphological effects and rates of action of chemical bud pruners on reproductive tissue in the strawberry. Scanning electron microscope (SEM) photomicrographs provided an effective, rapid means for evaluating these effects. Partial injury to anther surfaces was detected (Fig. 5) 4 hours after treatment with Lissapol. Rates and patterns of injury using "Off-Shoot-O" for thinning of flowers in the 'Surecrop' strawberry parallel results obtained in similar studies on azaleas and chrysanthemum (62, 63, 92). Initial browning and minor cell breakdown becomes quickly apparent, usually within 15-30 minutes after application. Since protective structures are not operative on partially opened strawberry flowers and trichomes or extensive cuticle are not present on pistils, penetration and cell breakdown occurs rapidly. The cuticle on anthers may retard penetration somewhat since anthers are not visibly affected until at least 4-8 hours after necrosis of the pistil is apparent.

Although their mode of action appears to be similar, compounds JF2777 and JF3457 do not display the rapidly apparent browning of stigma surfaces visible with "Off-Shoot-O". Injury becomes evident within 8-24 hours after treatment, even though epidermal cell disruption apparently occurs before this time. Injury to anthers if often not visible to the eye prior to 36-

48 hours after treatment. At rates below 0.80% v/v in preliminary work it often appeared that desiccation and necrosis in anthers treated with JF2777 and JF3457 may actually have been caused by girdling of the filament, thereby shutting off the water supply to the anthers. Immature anthers would probably be most susceptible to this particular mode of pruning.

It was apparent from the start of the investigations into effects of chemical pruners in the strawberry that a certain degree of complexity would result in a single evaluation of so many variables. The sequential maturity in the strawberry inevitably complicates any attempts to evaluate biochemical or physiological events occurring in the development of flowers or fruits. Despite these difficulties, some indications of the potential value of the variables examined for comparative or prediction purposes have been obtained.

CDM "L" and "a" values appear to be useful for rapid, objective measurement of sample lightness and color (Figs. 6, 8). Even though chemical pruner treatment effects were superimposed upon clonal effects, clonal differences were apparent, indicating that these differences are great enough to provide a characteristic measure for each cultivar or selection. The lack of significant amounts of yellow pigment in strawberries has been cited by Shah and Worthington (74) and others (32, 35) as a primary reason for the insignificant differences often observed in measurements in CDM "b" values on strawberry fruit. Although significant differences are observed in "b" values

when fruits from different positions in the inflorescence are examined, it appears unlikely that these differences would be apparent in blended lots of fruit from entire inflorescences. Such rapid evaluations would potentially be of use in objectively categorizing the status of ripening in a clone in the field at any given time in its ripening period and for comparative studies of rates of ripening in different clones. The minimization of variation obtained in blending fruit (88) should be a definite advantage in instances where rapid evaluations are desirable or the numbers of sample clusters available are limited.

The examination of changes in soluble and total solids by Culpepper et al. (18) on fruit of different strawberry cultivars at different stages of maturity demonstrated that soluble solids consistently show greater differences than total solids. Similar results are observed where chemical treatment effects are superimposed upon clonal effects (Figs. 6, 7). The high degree of positive correlation between soluble solids determinations, total acids and ascorbic acid plus the significant negative correlation with fruit weight strongly suggests the potential of soluble solids determinations for replacing those variables as a measure of maturity.

Size grading of once-over mechanically harvested fruit has been tested as a means for separation of unripe fruit[1].

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[1]Moore, J. R., University of Arkansas, Fayetteville, Arkansas. Personal communication, 1972.

Although a certain amount of error is evident in this procedure, progress has been reported and indicates some potential for use of fruit weight or fruit size as an aid in defining maturity in a given clone. Since sorting and weighing are required however, the advantages gained by blending of fruits within individual clusters would be lost. An overall cluster value for fruit size or weight would probably be of little use in characterizing maturity.

Determinations of pH by fruit position in inflorescences vary only slightly and appear in this instance to be of negligible value in describing clonal differences in ripening (Figs. 9, 11). Percent total acids, expressed as citric acid, may be of greater value. Substantial clonal differences are apparent where values by flower or fruit position are obtained (Fig. 9), although only slight differences between fruit from different positions within inflorescences are evident. Again, where comparative determinations are made on entire clusters, the ability to obtain specific clonal values would be of greatest interest.

Olliver's examination of ascorbic acid levels in developing strawberries (64) initially suggested the potential use of this variable as a maturity indicator. Erratic responses observed in this study (Figs. 7, 11) however, verify results reported by other workers (12, 25) where differences in soil type, amounts of sunlight or season of ripening significantly affected vitamin C levels. Similarities in fruiting behavior

in pH, total solids and other characteristics in presently available cultivars reflect the current trends toward a narrowed gene base in Fragaria (20), and could also be a factor in the somewhat similar ascorbic acid levels encountered in analyses of currently available clones. Although they are erratic for different treatments, overall mean levels for ascorbic acid appear to be similar for the different clones, and thus might provide little additional information of use in comparisons of ripening patterns.

The primary objective in this study was to examine and evaluate the potential use of simple and rapid objective measures of maturity in the strawberry for clonal comparisons or prediction of concentrated ripening patterns. Response to chemical pruner treatments were of interest only where response patterns based on previous observations could be predicted. Small sample size (3 observations per cultivar/ treatment/flower position) was required due to the complexity of the experiment and undoubtedly contributed to somewhat erratic results obtained. For this reason a second evaluation of the variables was made on samples in which known quantities of fruit at acceptable (ripe); color inception ("pink"), mature green and immature green stages were present to provide additional information.

The failure to observe consistent quantitative, linear responses in mean pH, percent total acids, percent total and soluble solids and ascorbic acid determinations indicates the

limitations of these variables as measures of maturity in puree mixtures of strawberry fruit at various stages of maturity.

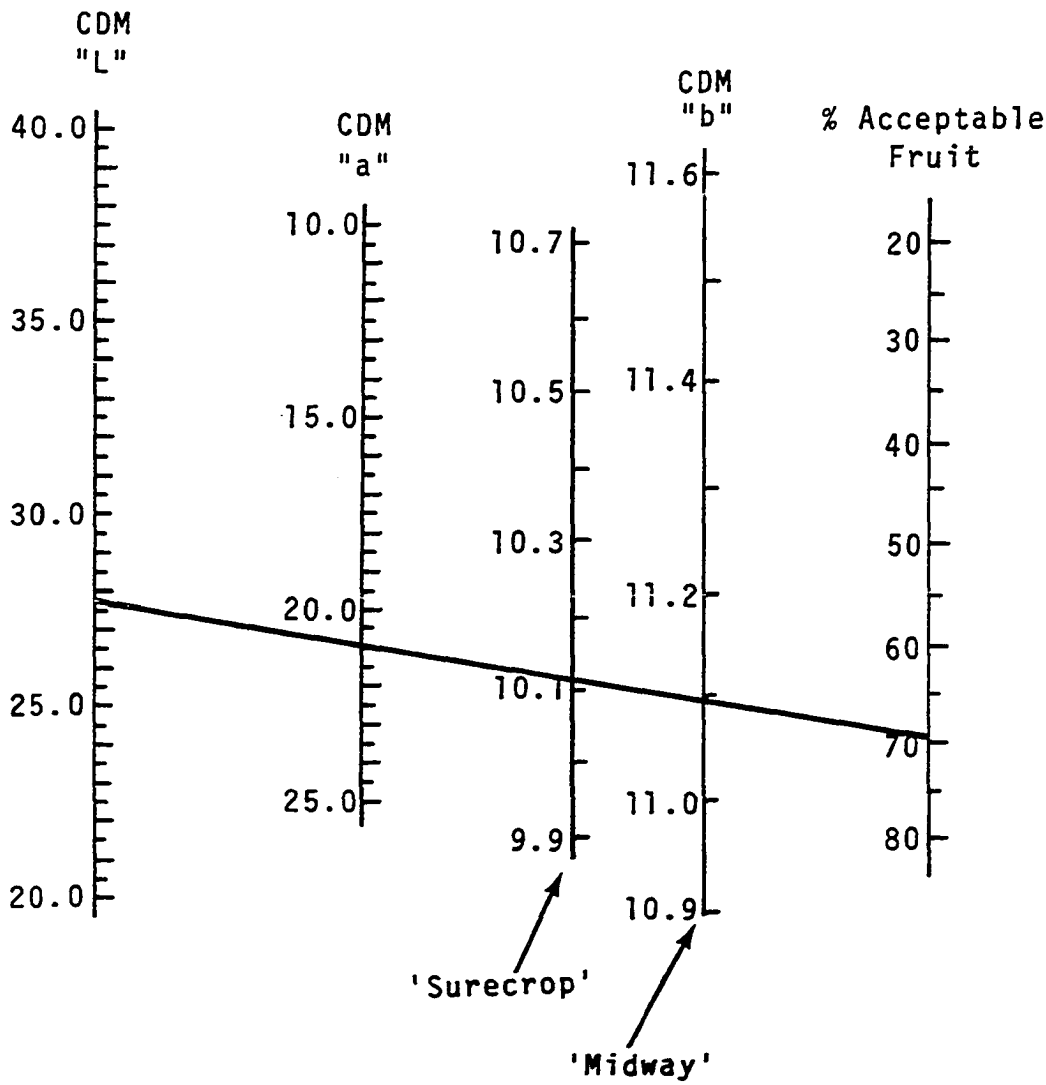
Within the limits of error specified in Fig. 12, however, it appears that CDM "L", "a", and "b" values could potentially be used as a rapid means for objectively defining the status of maturity in a given strawberry clone. The use of color as an indicator of maturity and ripeness in tomato fruits and juice and in peaches has been thoroughly evaluated (47, 48). In tomatoes, CDM "a" and "b" values, usually expressed as the a/b ratio are reported to be necessary and adequate in characterizing tomato juice color (48). In the same study, CDM "L" values were reported to suffice for characterization of color in frozen lima beans. With canned applesauce all three color dimensions were necessary to determine U.S. grades of color. The same requirement may exist in the characterization of strawberry puree where blends of fruit at varying stages of maturity are included. In the absence of further definitive field data on the contribution of varying amounts of immature, mature green or fruit at the "pink" stages to changes in puree color values obtained with the CDM it appears that the CDM "b" values must be included in specifying the status of maturity for a clone. The inability to obtain significantly different regression lines for "L" and "a" values in 'Midway' and 'Surecrop" necessitates the inclusion of the "b" values obtained for each cultivar if color specifications are to be used for

comparative purposes.

Kramer and Twigg (48) suggest the use of nomographs for the interpretation of objective measures of color in terms of grade scores or other quality criteria. A sample nomograph for the characterization of the status of maturity in cluster or once-over harvest sampling in 'Midway' and 'Surecrop' is shown in Fig. 13.

According to Sims and Comin (77) it would be possible to very accurately determine maturity of peaches by using objective color measurements in conjunction with a soluble solids - acids ratio. Rood (72), however, has reported that this ratio varies by season and would thus require correlation of these criteria for each season. Similar seasonal influences on soluble solids and acids have been reported in strawberry fruit (18, 80), and may not be related quantitatively or directly to color development. Since the ultimate criterion for picking maturity in the strawberry is fruit color, it appears that objective color measurement offers the greatest promise for rapid characterization of concentration of ripening. It must be kept in mind, of course, that these conclusions are based on initial data from a limited number of clones. A thorough field evaluation of a larger number of clones is required to compare season of ripening and rates of ripening in fruit cluster sampling. Further testing appears to be warranted by these initial evaluations.

Fig. 13. A sample nomograph for determining concentration of ripening in 'Midway' and 'Surecrop' fruit using Hunter color and color difference meter (CDM) "L", "a", "b" color value determinations on usable pureed fruit from entire fruit clusters.


CDM
"L"
40.0
35.0
30.0
25.0
20.0
CDM
"a"
10.0
15.0
20.0
25.0
CDM
"b"
11.6
11.4
11.2
11.0
10.9
10.7
10.5
10.3
10.1
9.9
% Acceptable
Fruit
20
30
40
50
60
70
80
'Surecrop'
'Midway'

VI. BIBLIOGRAPHY

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APPENDIX: STATISTICAL ANALYSES

Field Experiment I

Table 1. Analyses of variance for usable primary, secondary and tertiary fruit weights

Source	d.f.	M.S.	"F"
Primary fruit			
Total	230		
Cultivar	3	93.81	0.10
Treatment	8	520.93	0.80
Aborted fruits			
Linear	1	402.11	0.57
Quadratic	1	226,34	0.32
Cultivar x treatment	24	528.49	0.75
Cultivar x aborted fruits			
Linear	3	446.90	0.70
Quadratic	3	541.52	0.77
Treatment x aborted fruits			
Quadratic	8	337.77	0.48
Error	171	701.62	
Secondary fruit			
Total	230		
Cultivar	3	17,626.00	11.00**
Treatment	8	5,780.62	3.60**
Aborted fruits			
Linear	1	1,200.31	0.75
Quadratic	1	700.24	0.44
Cultivar x treatment	24	4,493.33	2.80**
Cultivar x aborted fruits			
Linear	3	1,118.26	0.69
Quadratic	3	744.16	0.46
Treatment x aborted fruits			
Quadratic	8	2,088.01	1.30
Error	171	1,603.90	
Tertiary fruit			
Total	217		
Cultivar x treatment	24	3,965.44	2.13**
Cultivar x aborted fruits			
Linear	3	276.05	0.14
Quadratic	3	1,749.80	0.94
Treatment x aborted fruits			
Linear	8	3,325.04	1.72
Quadratic	8	3,531.32	1.90
Error	171	1,863.52	

**Significant at $\alpha = 0.01$.

Field Experiment I

Table 2. Least squares analyses of variance for total usable fruit weight per plant, usable fruit count per plant and mean fruit weight per usable berry

Source	d.f.	M.S.	"F"
Total usable fruit weight/plant			
Total	635		
Cultivar	3	131.68	7.63**
Treatment	8	78.01	4.52**
Aborted flowers	1	1.78	0.10
Cultivar x treatment	24	75.77	4.39**
Cultivar x aborted flowers	3	22.76	1.32
Treatment x aborted flowers	8	18.70	1.08
Error	588	17.27	
Usable fruit count/plant			
Total	635		
Cultivar	3	3.56	6.67**
Treatment	8	0.73	1.36
Aborted flowers	1	0.07	0.13
Cultivar x treatment	24	0.72	1.34
Cultivar x aborted flowers	3	0.65	1.21
Treatment x aborted flowers	8	0.99	1.86
Error	588	0.53	
Mean weight/usable berry			
Total	635		
Cultivar	3	19.26	6.59**
Treatment	8	7.93	2.71**
Aborted flowers	1	0.47	0.16
Cultivar x treatment	24	10.30	3.53**
Cultivar x aborted flowers	3	6.28	2.15
Treatment x aborted flowers	8	1.34	0.46
Error	588	2.92	

**Significant at $\alpha = 0.01$.

Field Experiment I

Table 3. Least squares analyses of variance for total unusable fruit weight per plant, unusable fruit count per plant and mean fruit weight per unusable berry

Source	d.f.	M.S.	"F"
Total unusable fruit weight/plant			
Total	424		
Cultivar	3	12.40	3.15*
Treatment	8	6.62	1.68
Aborted flowers	1	7.91	2.01
Cultivar x treatment	24	5.92	1.51
Cultivar x aborted flowers	3	7.95	2.02
Treatment x aborted flowers	8	1.27	0.32
Error	377		
Unusable fruit count/plant			
Total	424		
Cultivar	3	0.73	0.98
Treatment	8	0.39	0.53
Aborted flowers	1	1.48	2.00
Cultivar x treatment	24	0.94	1.26
Cultivar x aborted flowers	3	1.01	1.36
Treatment x aborted flowers	8	0.19	0.26
Error	377	0.74	
Mean weight/unusable berry			
Total	424		
Cultivar	3	7.60	4.65**
Treatment	8	4.96	3.03**
Aborted flowers	1	10.92	6.67*
Cultivar x treatment	24	3.76	2.30**
Cultivar x aborted flowers	3	1.57	0.96
Treatment x aborted flowers	8	1.09	0.66
Error	377	1.64	

*Significant at $\alpha = 0.05$.

**Significant at $\alpha = 0.01$.

Field Experiment I

Table 4. Analyses of variance for total and mean usable fruit weight per plant (primary + secondary + tertiary fruit)

Source	d.f.	M.S.	"F"
Total usable	466		
Cultivar x treatment	24	22,884.71	4.97**
Cultivar x aborted fruits			
Linear	3	10,616.30	2.32
Quadratic	3	3,433.76	0.75
Treatment x aborted fruits			
Linear	8	3,902.76	0.85
Quadratic	8	4,074.91	0.88
Error	420	4,604.61	
Mean usable	466		
Cultivar x treatment	24	423.11	1.09
Cultivar x aborted fruit			
Linear	3	1,238.00	3.22*
Quadratic	3	463.09	1.19
Treatment x aborted fruits			
Linear	8	297.77	0.77
Quadratic	8	83.06	0.21
Error	420	388.70	

*Significant at $\alpha = 0.05$.

**Significant at $\alpha = 0.01$.

Table 5. Analyses of variance for Hunter color and color difference meter (CDM) "L", "a", and "b" color values in strawberry fruit **

Source	d.f.	M.S. "L"	"F" "L"	M.S. "a"	"F" "a"	M.S. "b"	"F" "b"
Total	287						
Cultivar	3	241.83	238.69	972.17	1429.80	89.84	525.96
Treatment	7	23.92	23.61	129.05	189.80	10.25	60.02
Cultivar x treatment	21	73.16	72.21	104.62	153.86	16.83	98.54
Flower position	2	794.83	784.47	882.40	1297.78	56.72	332.07
Cultivar x flower position	6	26.65	26.31	78.05	114.79	2.84	16.62
Treatment x flower position	14	18.01	17.78	13.74	20.21	4.88	28.59
Cultivar x treatment x flower position	42	18.23	17.99	28.87	42.47	2.42	14.18
Error	192	1.01		0.68		0.17	

**Unless otherwise specified, all "F" values were significant at $\alpha = 0.01$.

Table 6. Analyses of variance for percent soluble solids, pH and percent total acid determinations in strawberry fruit **

Source	d.f.	M.S.	"F"	M.S.	"F"	M.S.	"F"
		% soluble solids		pH		% total acids	
Total	287						
Cultivar	3	5.94	63.97	2.40	296.92	2.55	765.26
Treatment	7	3.13	33.69	0.58	71.44	0.96	28.86
Cultivar x treatment	21	6.32	68.05	0.25	30.87	0.88	26.32
Flower position	2	50.21	540.97	0.40	49.39	0.14	41.35
Cultivar x flower position	6	1.50	16.21	0.11	13.39	0.82	24.73
Treatment x flower position	14	5.13	55.29	0.50	6.16	0.27	8.23
Cultivar x treatment x flower position	42	2.90	31.29	0.36	4.46	0.57	17.17
Error	192			0.81		0.33	

**Unless otherwise specified, all "F" values were significant at $\alpha = 0.01$.

Table 7. Analyses of variance for ascorbic acid, mean fruit weight and percent total solids in strawberry fruit **

Source	d.f.	M.S.	"F"	M.S.	"F"	M.S.	"F"	
		Ascorbic acid		Mean fruit weight		% total solids		
Total	287							
Cultivar	3	313.96	20.51	7.76	96.40	7.21	33.58	
Treatment	7	598.24	39.08	14.41	179.04	2.92	13.58	
Cultivar x treatment	21	668.75	43.69	8.01	99.58	7.18	33.46	
Flower position	2	886.74	57.93	436.08	5419.25	0.19	0.88	n.s.
Cultivar x flower position	6	357.56	23.36	4.43	55.11	3.31	15.41	
Treatment x flower position	14	179.78	11.74	2.48	30.77	1.52	7.08	
Cultivar x treatment x flower position	42	204.61	13.37	1.74	21.64	2.04	9.48	
Error	192	15.31		0.80		0.21		

**Unless otherwise specified, all "F" values were significant at $\alpha = 0.01$.

Table 8. Analyses of variance for Hunter color and color difference meter (CDM) "L", "a", "b" color values and percent soluble solids in strawberry fruit

Source	d.f.	M.S.	"F"
"L"			
Total	77		
Cultivar	1	10.56	3.36
Treatment	12	33.08	10.53**
Cultivar x treatment	12	2.71	0.86
Error	52	3.14	
"a"			
Total	77		
Cultivar	1	4.06	0.61
Treatment	12	61.85	9.20**
Cultivar x treatment	12	6.00	0.89
Error	52	6.72	
"b"			
Total	77		
Cultivar	1	17.46	89.23**
Treatment	12	0.39	1.99*
Cultivar x treatment	12	0.19	0.97
Error	52	0.20	
% soluble solids			
Total	77		
Cultivar	1	18.90	84.07**
Treatment	12	1.06	4.73**
Cultivar x treatment	12	0.25	1.13
Error	52	0.22	

*Significant at $\alpha = 0.05$.

**Significant at $\alpha = 0.01$.

Table 9. Analyses of variance for pH, percent total acids, percent total solids and ascorbic acid determinations in strawberry fruit

Source	d.f.	M.S.	"F"
pH			
Total	77		
Cultivar	1	0.166	47.13**
Treatment	12	0.005	1.47
Cultivar x treatment	12	0.003	0.80
Error	52	0.004	
% total acids			
Total	77		
Cultivar	1	0.860	143.05**
Treatment	12	0.004	0.67
Cultivar x treatment	12	0.002	0.36
Error	52	0.006	
% total solids			
Total	77		
Cultivar	1	5.19	22.44**
Treatment	12	0.42	1.81
Cultivar x treatment	12	0.27	1.17
Error	52	0.23	
Ascorbic acid			
Total	77		
Cultivar	1	4589.26	66.91**
Treatment	12	323.37	4.72**
Cultivar x treatment	12	122.07	1.78
Error	52	68.59	

**Significant at $\alpha = 0.01$.