CHEMICAL PINCHING OF *CHRYSANTHEMUM X MORIFOLIUM* RAMAT. WITH UNDECANOL

by

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Dissertation submitted to the Graduate Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

Horticulture

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July, 1983

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Dedication

To my wife, for believing I could do it and for her constant support throughout.

Acknowledgements

I am especially indebted to Dr. A. J. Lewis, III, my committee chairman, for his support and assistance throughout my graduate program. His guidance, encouragement, and patience are deeply appreciated. Drs. Robert Wright, Richard Lindstrom, C. L. McCombs, and David Orcutt have provided invaluable contributions to the completion of this manuscript and I am deeply grateful to them for their encouragement and friendship throughout my graduate experience.

Appreciation is expressed to and and to for their help in the statistical analysis of these data.

A special thanks goes to ; without her typing and editing speed and accuracy the completion of this manuscript would not have been possible.

My deepest appreciation is extended to my wife, , and to my children, , for their encouragement and belief in me. Without their emotional support and love, this degree would probably not have been attained.

Lastly, acknowledgement must be made to the horticulture graduate students, staff, and other faculty for their support. Their friendship throughout my graduate studies will never be forgotten.

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Introduction

The potted chrysanthemum (*Chrysanthemum* x *morifolium* Ramat.) is the largest selling flowering pot crop grown in the United States. The number of pots sold increased from 19 million in 1972 to 28.4 million in 1980 while the wholesale value more than doubled from 30.6 million dollars to 68.3 million (3). Steady future expansion of production and sales has been predicted.

Several costly and time consuming cultural practices are inherent in potted chrysanthemum production including photoperiodic lighting and shading, pinching, chemical height control, disbudding, and precise temperature control. One of the most costly and labor intensive cultural practices is manual pinching, a specialized form of pruning to induce lateral bud development and branch elongation. Pinching may account for up to 30 percent of the total production cost (2).

The majority of chrysanthemum cultivars exhibit strong apical dominance requiring the removal of the apical meristem by manual pinching to produce branched, symmetrical plants with multiple flowers per plant. In addition to being costly and laborious, manual pinching can result in the spread of pathogens and can also result in loss of more plant tissue than desired (35).

Chemical pinching is a potential alternative to manual pinching and could have decided cost and labor advantages over manual pinching. In some plant species, apical dominance can be overcome by growth retardants which halt growth of the terminal bud, induce redistribution of growth hormones, and thus promote branching. Such chemicals have not, however, been successfully used commercially for pinching chrysanthemum. A second, and more promising approach, has been the simulation of a manual pinch with growth inhibitors which selectively kill the apical meristem without appreciable phytotoxic injury to other plant parts. The principle of selective phytotoxicity is critical to the success of chemical pinching agents for chrysanthemum. Unlike nursery crops, which may be several years in production and often develop new foliage that masks any phytotoxic injury to subapical portions of the plant, chrysanthemum is in production only 8-12 weeks. Any damage produced on subapical leaves may be evident at sale and potentially reduces plant value.

Numerous chemical pinching substances have been used experimentally on a wide variety of plants, including C. x morifolium, with varying degrees of success. Response varies among cultivars, and is strongly concentration dependent. Environmental conditions preceding, during, and following application; method of application; and interactions with endogenous and exogenous substances have also been implicated in plant response.

To date, no growth inhibitor has been successfully used commercially on chrysanthemum. The objectives of this research were to investigate the effectiveness of an experimental growth inhibitor, undecanol, as a pinching agent for C. x morifolium and to establish conditions under which the chemical might be used in commercial production. The study was comprised of three major sections: 1) the establishment of an effective but nonphytotoxic concentration range along with an investigation of cultivar response; 2) the effect of environmental factors on pinching response and phytotoxicity; and 3) the effect of time of application on pinching response, phytotoxicity, time to flower, yield, and plant quality under standard commercial conditions.

Literature Review

The inhibitory effect exerted by the apical meristem on the development of lateral buds is a widespread phenomenon throughout the plant kingdom, with all higher plants exhibiting apical dominance to some degree. Auxin, alone or in interactions with other plant growth hormones such as cytokinin or ethylene, hypothetically controls the inhibition of lateral shoots by the apex in most plants; the role of these hormones in nutrient mobilization has also been implicated (28, 35). Although the physiology and biochemical activity involved in apical dominance is debated even today, removal of the apical meristem generally results in elongation and development of axillary buds (28). Most *Chrysanthemum* x *morifolium* cultivars exhibit strong apical dominance and manual removal of the apical meristem is a necessary and common commercial practice in the production of multi-flowered uniform plants (2, 28, 35, 46). Because of the high labor cost associated with this practice and the potential for spread of pathogens such as chrysanthemum bacterial blight and stunt virus (35), the use of chemicals for this purpose is not only of academic interest but is justified because of its potential commercial application.

Chemical pinching is a specialized form of pruning resulting from the chemical alteration of hormonal activity in the apical meristem (as with growth retardants), or selective wounding or killing of the apical meristem without damage to axillary buds, leaves, or stems (as with growth inhibitors) (28, 35).

Since Schoene and Hoffman (40) first reported in 1949 that apical dominance in tomato could be overcome with maleic hydrazide (MH) sprays, there has been a persistent interest in chemical pinching. Research has involved numerous horticultural crops and chemical pinching agents with varying degrees of success. Beach and Leopold (6) reported 1000 ppm MH sprays resulted in more lateral breaks per plant than manual pinching in 3 chrysanthemum cultivars. Quality of plants was unaffected as was the number of flowers and time to flower. The authors hypothesized anti-auxin activity as the mode of action in increased branching. Masterlerz and Campbell (29) later reported that while pinching could be achieved with MH, a lack of uniformity in chrysanthemum response severely limited its potential in commercial production. A reduction in yield (height and fresh weight), delayed flowering, abnormal vegetative and floral growth, and differences in cultivar response were noted. Because of the lack of uniformity, MH was not recommended as a pinching agent for chrysanthemum. This research was further corroborated by Powell and Andreasen (37). Shanks (43) later reported that MH sprays inhibited terminal growth of both chrysanthemum and carnation and induced branching, but overall growth and flowering were suppressed. He noted that slight changes in numerous environmental factors apparently interacted with the chemical to produce different responses. Variability in response among chrysanthemum cultivars was also reported.

TIBA (2,3,5-triiodobenzoic acid), an anti-auxin, has also been used to reduce or eliminate apical dominance in several crops (15, 35). Abscission of the apical bud has been reported (21), but in most cases

TIBA applications resulted in the partial inhibition of apical dominance, increased branching at lower internodes, decreased plant height and delayed maturity (5, 15, 23). The use of TIBA on ornamental crops is not recommended currently.

Salicylate derivatives have been reported to kill the apical meristem of soybeans and stimulate lateral branching under greenhouse conditions (18). Total yield (seed number and seed and pod weight) was increased but the effectiveness of these compounds under field conditions has not been demonstrated. Use of salicylates on floricultural crops has not been reported.

Morphactins have been reported to induce changes in growth of many plant species, including the enhancement of lateral branch development in both decapitated and nondecapitated plants. Kahn (24) reported induced branching in several intact woody and semiwoody ornamental species. Other researchers reported similar results with azalea (43) and chrysanthemum (49, 50). However, differences in cultivar response were again reported, especially chrysanthemum phytotoxicity.

Ethephon (Ethrel™, Amchem Products, Inc., Ambler, PA), alone and in combination with other chemicals, has been reported to induce lateral branch development in several plant species. Shanks (42) reported that over a 4 month period terminal growth was reduced and lateral shoot development increased in Hibiscus chinensis after treatment with low concentrations of ethephon. Ethephon in combination with fatty acid esters also enhanced lateral branch development in chrysanthemum but delayed flowering. Manual pinching plus ethephon foliar sprays reportedly increased the number of lateral branches on azalea (43).

Dikegulac-sodium (Atrinal™, Hoffmann-La Roche, Inc., Nutley, NJ), another growth retardant, has been reported an effective pinching agent for Rhododendron sp. Treated plants developed more lateral branches than hand-pruned controls (8, 17, 19, 26, 48). However, Arzee et al. (4) reported that dikegulac-sodium applied as a foliar spray to C. x morifolium, Helianthus sp., and Zinnia sp. resulted in severe prolonged chlorosis, malformed vegetative and floral parts, yield reduction, and suppressed lateral branch development, results which are supported by preliminary research of the author (unpublished data).

P293 (Uniroyal Chemical, Bethany, CT) (2,3-dihydro-5,6-diphenyl-1,4-oxathiin) has been used experimentally as a chemical disbudding agent for chrysanthemum with varying degrees of success (13, 32, 33, 36). Interest has also been shown in this compound as a potential pinching agent for chrysanthemum and azalea. Cathey (13) reported that P293 was effective at killing apical tissue without damage to vegetative lateral buds, but pinching and phytotoxicity were inconsistent and dependent, at least to some extent, on timing of application, concentration, and cultivar. He concluded that the physiological condition of the plant, as affected by age, environment, and genome, determined the relative consistency and effectiveness of the chemical. Kofranek and Accati (25) reported P293 effective in pinching azalea and increasing lateral shoot development. However, changes in relative humidity at the time of application resulted in marked differences in response. Sytsema

(48) reported fairly consistent branching in azalea with P293; Purohit and Shanks (38) reported increased branching and consistent pinching in 1 chrysanthemum cultivar. However, other researchers have reported inconsistent pinch and flowering response to P293 probably due to differences in physiological age of plant tissue, timing of application, and the relatively narrow nonphytotoxic concentration range (13, 32, 33). P293 has been withdrawn for experimental testing and its commercial potential is doubtful.

Certain fatty acids (C_8-C_{14} compounds) and fatty acid esters have been reported effective at killing meristematic tissue of _Nicotiana tabacum_ (51, 52). Mature tissue was not damaged and the compounds, especially methyl caprate (C_{10}), produced results within 30-60 minutes of application. Cathey et al. (15) reported C_8-C_{12} fatty acids and C_8-C_{10} fatty alcohols effective at selectively killing the terminal meristems of a wide variety of plants without damage to axillary buds, foliage, or stem tissue. Plants chemically pinched with these compounds consistently developed more lateral branches than did manually pinched plants. Plant species tested included marigold, coleus, tomato, chrysanthemum, carnation, and azalea among others. The authors noted, however, that plant response to these pinching compounds was again highly dependent on the physiological age of the tissue. Cultivar differences were also reported as were differences in phytotoxic response purportedly due to environmental conditions including temperature, light, and air movement at time of application.

Since the study by Cathey et al. (15), chemical pinching research has concentrated primarily on the use of fatty acids and fatty acid esters. Cathey et al. (16) reported that HAN, a C_{10}-C_{13} compound, effectively aborted lateral buds and pinched the apical meristem of several C. x morifolium cultivars. This response was, however, nonselective in that all actively growing tissue was affected. Response variability was reported in a narrow concentration range and was dependent upon the physiological age of the plant tissue, light, and relative humidity. McDowell (31) reported that methyl nononoate (Emgard™, Emery Industries, Cincinnati, OH) and methyl octonate + methyl deconoate (Off-Shoot-O™, Procter and Gamble, Cincinnati, OH) effectively pinched azalea. However, age of plant tissue and temperature at time of application were critical in preventing phytotoxicity at effective pinching concentrations. Other researchers reported similar findings relative to the applicability of Emgard and Off-Shoot-O as chemical pinching agents for azalea (7, 8, 9, 14, 17, 39, 46).

Studies on azalea, chrysanthemum, and other plant species have stressed the importance of environmental factors and cultivar differences in plant response to fatty acids, fatty acid esters, and other chemicals (20, 22, 27, 31, 41, 47). Cathey (11) reported that concentrations required to pinch some cultivars seriously injured more susceptible cultivars. Sanderson and Martin (39) reported variation in response to both Emgard and Off-Shoot-O due to variety, concentration, relative humidity, temperature, plant age, and growth stage in azalea and chrysanthemum. Cathey (10, 12) reported that although many plant species could be effectively pinched with fatty acids, cultivar response was highly variable possibly due to differences in bud and leaf morphology among cultivars. He also stressed the importance of considering the interaction of these compounds with environmental conditions such as temperature and air movement at the time of application. Shanks (43) reported that azalea and chrysanthemum were highly responsive to fatty acids and fatty acid esters although response varied among chrysanthemum cultivars even at low concentrations. He too stressed the interaction of these compounds with light, temperature, and relative humidity. McDowell (31) reported that C_8-C_{10} fatty acid esters effectively pinched C. x morifolium but phytotoxic damage occurred within a narrow concentration range possibly due to the succulent nature of chrysanthemum. Each cultivar tested appeared to react differently although genetically related lines reacted similarly. Brabson and Lindstrom (7) and Carr and Lindstrom (9), working with azalea, reported environmental factors such as temperature, air movement, and relative humidity affected plant response to Off-Shoot-O but that light had no effect. Pretreatment low-temperature-conditioning was the single most important factor in determining response of azalea to methyl deconoate. Sill and Nelson (45) hypothesized that reproductive tissue was less susceptible to methyl deconoate because of the presence of bud scales and thick cuticle layers. Based on this hypothesis, the authors concluded that lower pretreatment temperatures made the plants more sensitive to the pinching agent by inducing a reduction in metabolic activity thus delaying development of these protective reproductive structures.

Undecanol (TipNip™, Armak Co., Chicago, IL) is a recently introduced experimental chemical for pinching chrysanthemum. It is a C_{11} fatty alcohol designed to selectively kill the apical meristem and thus simulate a manual pinch (1). Its specific mode of action is not known although it is probably similar to that of C_8-C_{12} fatty acids and fatty acid esters. Direct contact with actively dividing cells results in either disruption of the cell membrane or penetration to the cytoplasm and nucleus where metabolic activity is altered (34, 45, 53). Evidence for an exact mode of action remains inconclusive.

Shanks and Purohit (44) reported undecanol at 0.8 to 1.2% a.i. effective in pinching some chrysanthemum cultivars without serious injury to leaves or stems. Undecanol pinched plants produced more lateral branches and flowers than manually pinched plants and time to flower was not affected. However, effective pinching concentration varied with plant tissue age. McDaniel and Graddy (30) corroborated these results and noted no differences in cultivar response. Timing of application relative to short day treatment and time of year did affect response.

In summary, numerous chemical pinching agents have been tested on a wide variety of horticultural crops, especially azalea and chrysanthemum. While some success with azalea has been attained and commercially employed, success with chrysanthemum has been much more elusive. Cultivar, chemical concentration, environmental conditions, and physiological age of the plant have been strongly implicated in plant response and appear to interact with chemical agents and with each other. These factors, and their variation or lack of control in the literature cited, may well account for the inconsistencies reported in plant response. The need for a chemical pinching agent for chrysanthemum continues to exist. Undecanol has shown potential and is the most promising chemical to date, but considerable research remains in determining the effect of the many variables which interact with undecanol in determining its effectiveness and/or phytotoxicity.

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Cultivar Response of Chrysanthemum to Undecanol

Abstract. Concentrations between 5000 and 15000 mg/liter undecanol were effective in pinching most varieties of chrysanthemum (*Chrysanthemum* x *morifolium* Ramat.) tested. Subapical phytotoxicity increased with increasing concentrations and was generally more variable among cultivars than was the pinch response. Concentrations effective in pinching resulted in plants comparable (number of branches and height) to manually pinched plants. Microscopic examination of shoot apices revealed no gross morphological differences that could account for cultivar variability in pinch and subapical phytotoxicity.

Chrysanthemum is the largest selling flowering potted plant in the U.S. largely due to its superior keeping quality and year-round availability (3). Many costly and labor intensive cultural practices are inherent in production. Among these is pinching, a specialized form of pruning required to overcome apical dominance and to produce a well branched plant with multiple flowers per plant (2). In addition to being costly and time consuming, manual pinching can also result in the spread of pathogens and the loss of more plant tissue than desired (20).

Chemical pinching is a potential alternative to manual pinching and could have decided cost and labor advantages in chrysanthemum production. Many chemical pinching agents have been used experimentally on floricultural crops, however, wide differences are reported in species and cultivar response, concentration effect, optimal environmental conditions, and methods and timing of application. Results with maleic hydrazide (MH) (6, 15, 21), morphactins (12, 27), ethephon (23), 2,3,5-triiodobenzoic acid (5), dikegulac-sodium (4, 11, 14), 2,3-dihydro-5,6-diphenyl-1,4-oxathiin (10, 13, 17, 18, 22) and C_8-C_{14} fatty acids and fatty acid esters (7, 8, 9) on chrysanthemum and other horticultural crops have been rather inconsistent. Variations in cultivar response to fairly narrow concentration ranges have been reported for each of these chemicals and to date none has gained commercial acceptance excepting Off-Shoot-O™ (Procter and Gamble, Cincinnati, OH) and Artinal™ (Hoffmann-LaRoche, Inc., Nutley, NJ) for use on azalea (26).

Recent research involving chemical pinching of floricultural crops has concentrated primarily on fatty acids and fatty acid esters. Cathey (8, 9) reported C_8-C_{14} compounds effective in chemically pinching chrysanthemum, however, cultivars differed in their response with 1.5 to 3.0% a.i. required to kill apical buds. Phytotoxicity also varied among cultivars, some being much more susceptible than others. Other researchers have reported similar results with other horticultural crops (7, 25, 26).

Undecanol (TipNip™, Armak Co., Chicago, IL), a C_{11} fatty alcohol, is an experimental chemical for pinching chrysanthemum (1). The chemical is designed to selectively kill the apical meristem and thus simulate a manual pinch. Results reported to date have been inconclusive, especially regarding cultivar and concentration response. Shanks and

Purohit (24) reported variation in the pinching and phytotoxic response of 9 chrysanthemum cultivars within a relatively narrow concentration range of 0.8-1.0% a.i. McDaniel and Graddy (16), however, reported no variations among 4 cultivars within a concentration range of 1.0-1.5%. However, they did suggest pretesting because other cultivars may be more or less susceptible to undecanol pinching and/or phytotoxicity.

The objectives of this study were to investigate cultivar variability with regard to the effectiveness of undecanol as a chemical pinching agent for chrysanthemum and to determine effective nonphytotoxic concentrations.

Materials and Methods

Rooted cuttings of 9 chrysanthemum cultivars (Amber Concord, Candlelight, Circus, Fiesta, Free Spirit, Yellow Fuji Mefo, Illini Trophy, Sunburst Spirit, and Torch) were potted 1 cutting per pot on August 31, 1981 in 10.2 cm plastic pots filled with a peat-lite artificial medium (Pro-Mix™, Premier Peat Moss Corp., New York, NY). All plants were greenhouse grown under prevailing irradiance in a glass greenhouse (17°C minimum night temperature) equipped with fan-and-pad cooling. Long-day (LD) conditions were provided for 2 weeks commencing at potting by night interruption (2200-0200) low-level incandescent lighting. Plants were fertilized weekly with water soluble 20N-8.7P-16.7K fertilizer (Peters 20-20-20™, W. R. Grace and Co., Allentown, PA) at 600 ppm N.

Concentration and cultivar response. On September 14, plants were manually pinched (control) or sprayed with undecanol at 5000, 10000, 15000, or 20000 mg/liter a.i. These concentrations were chosen based on previous research (16, 24) and on earlier studies by the author (unpublished data). Foliar sprays were applied as a fine mist using a hand-held air-pressurized (80 psi) sprayer. A sufficient volume of spray material was applied to wet the entire foliage and run-off the apical bud. To assure turgidity, plants were watered 4 to 6 hours before spraying. Nine single plant replicates per cultivar per concentration were arranged in a completely randomized design.

Two days after treatment, the number of plants with necrotic apices and phytotoxicity to subapical plant parts were recorded. Subapical phytotoxicity was defined as any injury or abnormal growth occurring below the shoot apex. Although the extent and severity of subapical phytotoxicity varied, no attempt was made to quantify injury since virtually any phytotoxicity is unacceptable in the finished plant. Twelve weeks after treatment, phytotoxicity was again recorded along with height (pot rim to top of tallest flower) and the number of branches exceeding 5 cm in length. Pinch and phytotoxicity data were analyzed by a x^2-test and counts separated by a 2-sample test of proportions. Other data were analyzed by analysis of variance and means separated by Duncan's multiple range test where appropriate.

Morphological study. On October 10, 1981, 3 terminal stems per cultivar were randomly selected from a separate group of plants grown under the conditions described previously. The apices were excised immediately above the first reflexed leaf. Microscopic observations were made regarding relative pubescence, position and angle of immature leaves subtending the apical meristem, and relative tightness of the leaves enclosing the apex.

Results and Discussion

Concentration and cultivar response. Data taken 2 days after treatment demonstrated the ineffectiveness of undecanol in pinching at concentrations of 5000 mg/liter (Table 1). Concentrations of 10000 mg/liter resulted in 100% pinching in 7 of the 9 cultivars tested; over 50% of the 2 remaining cultivars were pinched at this concentration. Concentrations above 10000 mg/liter produced 100% pinching in all cultivars, however, phytotoxicity increased markedly in most cultivars with increasing concentrations. At 10000 mg/liter only 2 cultivars showed extensive phytotoxicity.

Pinching is in itself a phytotoxic response to the chemical, therefore, it is not unexpected to find a tendency for increased phytotoxicity to subapical plant parts with increasing pinching percentages. These data suggest, however, that cultivars vary more in their phytotoxic response than in their pinching response. Thus, cultivars chosen for chemical pinching may need to be selected based on their susceptibility to phytotoxic injury as well as pinching response. These data generally corroborate previous research (16, 24) and suggest concentrations between 5000 and 15000 mg/liter are effective in pinching most chrysanthemum cultivars. Further research is needed to better define the effective concentration range.

Table 1. Pinch (necrotic apices) and phytotoxic response of chrysanthemum 2 days after treatment with foliar applications of undecanol.

Cultivar	Undecanol (mg/liter)							
	5000		10000		15000		20000	
	Pinch	Phyt.	Pinch	Phyt.	Pinch	Phyt.	Pinch	Phyt.
Amber Concord	0a[z]	0[z]	6a	0a	9	6bc	9	9b
Candlelight	0a	0	9b	2ab	9	7bc	9	9b
Circus	0a	0	8b	0a	9	0a	9	2a
Fiesta	4b	0	9b	5b	9	4ab	9	8b
Free Spirit	4b	0	9b	1ab	9	9c	9	9b
Yellow Fuji Mefo	0a	0	9b	1ab	9	7bc	9	9b
Illini Trophy	1ab	0	9b	0a	9	3ab	9	9b
Sunburst Spirit	1ab	0	9b	4b	9	9c	9	9b
Torch	3ab	0	9b	1ab	9	3ab	9	7b

[z]Number of plants out of 9 pinched or exhibiting subapical phytotoxicity. Cultivars followed by the same letter within columns are not significantly different based on χ^2 analysis and a 2-sample test of proportions, 5% level.

Phytotoxicity counts generally declined by the end of the experiment (12 weeks) (Table 2). New vegetative growth can mask the initial phytotoxicity somewhat. Thus, minor phytotoxicity resulting from chemical pinching may be acceptable in some varieties.

Concentrations effective in pinching also resulted in as many branches as manual pinching (Table 2). Chemical pinching in 3 cultivars (Amber Concord, Fiesta, and Illini Trophy) actually produced more branches than manual pinching. In many cultivars, use of intermediate levels of undecanol resulted in more branches than use of higher levels. This is attributed to the increased phytotoxicity to lateral buds when concentrations were increased. Pinching should result in 3 to 4 branches in order to be commercially acceptable (2).

Minimum concentrations effective in achieving a 100% pinch did not alter height of any cultivar compared to the manually pinched controls (Table 2). Higher concentrations reduced height possibly due to their associated phytotoxicity. Thus it appears that chemical pinching can be used to produce plants which closely resemble plants produced by conventional manual pinching.

Morphological study. Microscopic observations of the apices of the 9 cultivars revealed no gross morphological differences that might account for differences in cultivar response. Although the arrangement of immature leaves subtending the apex varied somewhat (Figure 1), no relationship between gross morphology and pinching/phytotoxicity could be established. Morphological factors have been reported to influence the effectiveness of fatty acids and fatty alcohols. Sill and Nelson

Table 2. Final phytotoxic response, branching, and height of chrysanthemum 12 weeks after treatment with foliar applications of undecanol.

Undecanol (mg/liter)	Cultivar								
	Amber Concord	Candlelight	Circus	Fiesta	Free Spirit	Yellow Fuji Mefo	Illini Trophy	Sunburst Spirit	Torch
	Phytotoxicity[z]								
manual pinch (control)	0a	0a	0a	0a	0a	0a	0a	0a	0a
5000	0a	0a	0a	0a	0a	0a	0a	0a	0a
10000	0a	1a	0a	0a	1a	0a	0a	1a	0a
15000	0a	1a	0a	0a	1a	5b	1a	7b	0a
20000	2a	7b	1a	1a	9b	7b	3a	9b	1a
	Branches[y]								
manual pinch (control)	4.0b	8.1a	5.8a	4.0c	6.0a	3.4ab	3.2b	6.9ab	5.7a
5000	7.3a	5.8ab	1.0c	5.4abc	3.8b	0.0c	0.8c	4.2c	3.1b
10000	7.6a	5.6ab	4.6ab	5.6ab	6.7a	4.4a	4.4a	7.7a	6.7a
15000	6.8a	5.4ab	3.8b	4.2bc	5.2ab	3.8ab	3.4ab	5.3bc	7.3a
20000	5.1b	3.5b	4.7ab	5.7a	3.8b	3.0b	4.1ab	4.8bc	6.4a
	Height (cm)[y]								
manual pinch (control)	27.6a	24.7b	23.5b	26.3a	21.8b	38.0b	23.8ab	26.2b	19.0b
5000	28.2a	28.7a	27.6a	25.7a	24.6a	42.8a	24.2ab	29.6a	21.2a
10000	25.7ab	24.2b	22.5b	24.8a	21.5b	36.6b	24.4ab	25.2b	19.4ab
15000	23.6b	24.2b	22.1b	24.6a	22.2b	36.4b	22.4ab	22.1c	18.2b
20000	23.1b	23.7b	19.5c	21.3b	21.6b	35.4b	21.5a	22.6c	19.0b

[z]Number of plants out of 9 exhibiting subapical phytotoxicity. Treatments followed by the same letter within columns are not significantly different based on x^2 analysis and a 2-sample test of proportions, 5% level.

[y]Means of 9 plants; those followed by the same letter within columns are not significantly different based on Duncan's multiple range test, 5% level.

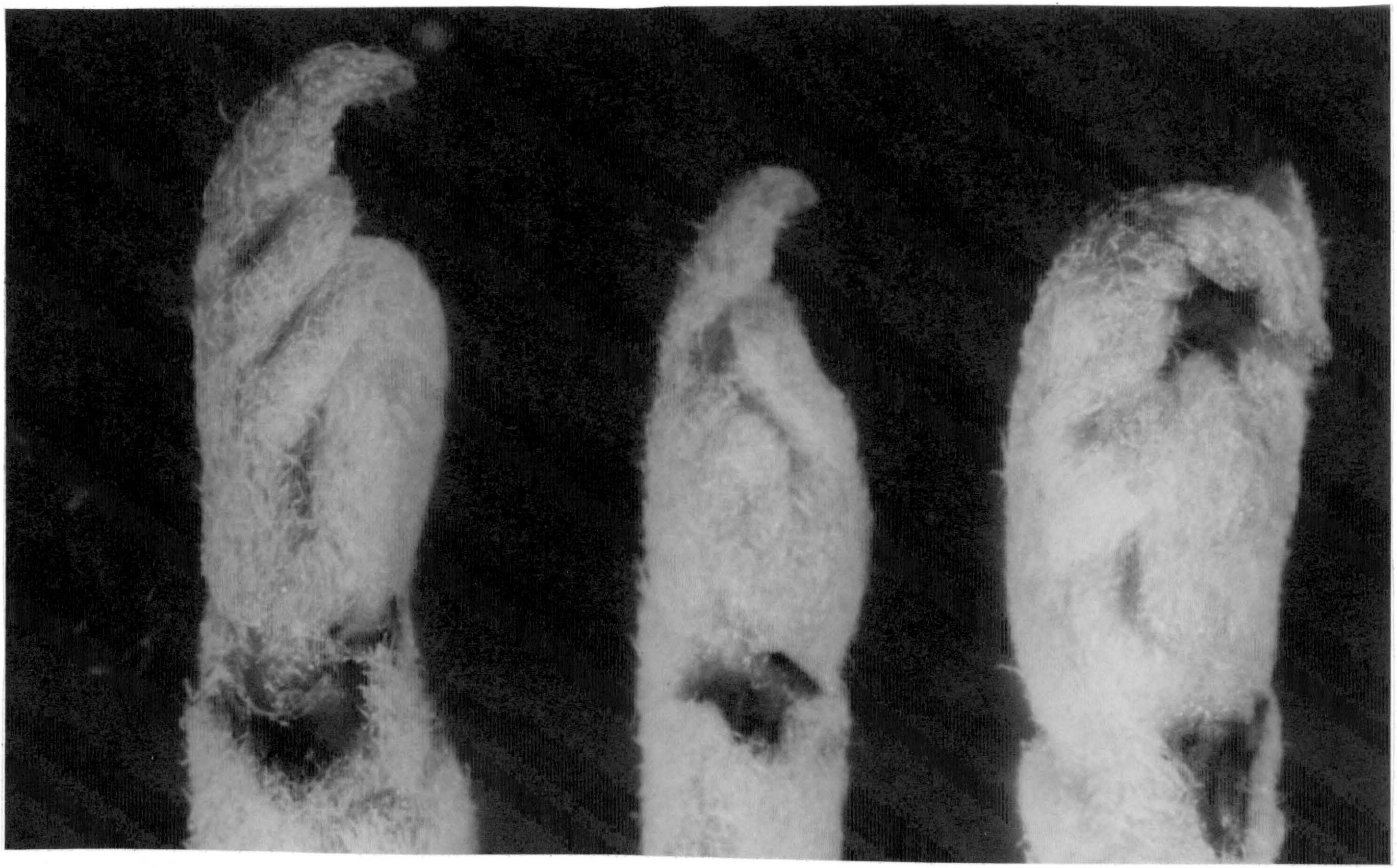

Fig. 1. Shoot apices of chrysanthemum cvs Fiesta, Torch, and Yellow Fuji Mefo (left to right) with reflexed leaves removed.

reported more trichomes per unit area of leaf surface, within the enclosing sheath of leaves covering azalea buds, decreased the effectiveness of methyl decanoate. However, Uhring (28) reported that methyl decanoate entered the terminal meristem of chrysanthemum through the epidermal cells and trichomes. Thus plants with a larger number of trichomes might be more susceptible to damage. Breece et al. (7) and Nelson and Poteet (19) reported that azalea flower buds were not as easily killed as vegetative buds due to the increased thickness of cuticle and the presence of bud scales. They suggested that cultivar differences in response to the chemical agents were due partially to the morphology. Further research should be conducted to investigate the effect of anatomy in chemical pinching of chrysanthemum with undecanol.

These data suggest that chemical pinching of certain chrysanthemum cultivars with undecanol can be used to produce plants comparable to those produced by manual pinching. Cultivars vary somewhat in their response and effective concentration but subapical phytotoxicity appears more variable. Further research is needed to more accurately define effective concentration ranges and to investigate factors influencing cultivar response.

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Influence of Environmental Factors on Chemical Pinching of Chrysanthemum with Undecanol

Abstract. The effect of environmental variables (air temperature, air flow, relative humidity, and light) on chemical pinching of chrysanthemum (_Chrysanthemum x morifolium_ Ramat.) with undecanol was investigated. Studies were conducted in a growth chamber and under greenhouse conditions. In general, conditions which favored more rapid drying tended to decrease the number of plants pinched and reduce the number of plants showing subapical phytotoxicity. Air temperature was the single most highly correlated environmental variable with both pinching and phytotoxicity in the greenhouse. Prediction equations for pinching and phytotoxicity were developed.

Pinching is one of the most costly and labor intensive cultural practices in potted chrysanthemum production (2). Chemical pinching has been successfully adapted to commercial azalea production (17) and is a potential alternative to manual pinching in chrysanthemum.

Response to plant growth regulators is dependent upon many factors including the environmental conditions preceding, during, and following application (3, 4, 15). The effectiveness of chemical pinching agents like undecanol is dependent on the rate of drying of the chemical (3, 4, 5, 14) and thus interrelated with many environmental factors. Light

(7, 10, 16), relative humidity (8, 11, 16), air movement (6, 7), and temperature (6, 7, 13) have all been implicated in the effectiveness of these compounds. No single factor has been determined most critical; all combine to determine the microclimate surrounding the plant and are interrelated in their effect.

Environment has been reported especially critical with fatty acids and fatty acid esters (5, 6) because direct contact and penetration of the apical tissue is necessary to insure pinching (18). Should the chemical dry or evaporate too quickly, effective pinching may not be achieved; should the chemical remain in contact with tissue (bud, leaf, and/or stem) for too long a time, excessive or undesirable phytotoxicity may occur.

Undecanol (TipNip™, Armak Co., Chicago, IL), a C_{11} fatty alcohol, is an experimental pinching agent for chrysanthemum (1). Its mode of action is likely similar to that of the C_8-C_{14} compounds such as methyl nononoate (Emgard™, Emery Industries, Cincinnati, OH) and methyl octonate + methyl decanoate (Off-Shoot-O™, Procter and Gamble, Cincinnati, OH). While variation in chrysanthemum response to undecanol due to seasonal variations has been reported (12), no data has been reported on the effect of individual environmental variables. This research was initiated to investigate the effect of environmental conditions on plant response to undecanol and to establish conditions for optimal pinching with minimal phytotoxicity to leaves, stems, and/or axillary buds. Relative humidity, air temperature, air flow, and light levels were considered.

Materials and Methods

Rooted cuttings of chrysanthemum cvs Fiesta, Sunburst Spirit, and Yellow Fuji Mefo were planted March 15, 1982 in 10.2 cm plastic pots filled with a peat-lite artificial medium (Pro-Mix™, Premier Peat Moss Corp., New York, NY). All plants were grown under prevailing irradiance in a glass greenhouse (17°C night temperature, 20°C day temperature). Long day (LD) conditions were provided by night interruption (2200-0200) low-level incandescent lighting. Plants were fertilized weekly with water soluble 20N-8.7P-16.7K fertilizer (Peters 20-20-20™, W. R. Grace and Co., Allentown, PA) at 600 ppm N.

Growth chamber study. On March 30 to April 2, 1982 plants of each cultivar were randomly selected and moved into a walk-in growth chamber measuring 1.3 m x 2.3 m x 2.1 m (Percival Co., Boone, IA). Light in the chamber was provided by a bank of cool-white fluorescent lamps (Westinghouse F96T12/CWX/HO). Photosynthetically active radiation (PAR) was measured at plant height using a LI185 light meter (Lambda Instrument Corp., Lincoln, NE) with a quantum sensor. Air temperature (AT) and air flow (AF) were measured with a 100 VT air flow meter (Datametrics, Inc., Wilmington, MA). Relative humidity (RH) was measured with a sling psychrometer.

All plants were thoroughly watered 1 hour prior to treatment to insure turgidity, and were acclimated in the chamber 30 minutes prior to treatment and remained in the chamber 30 minutes after treatment before being returned to the greenhouse. Treatment consisted of undecanol foliar sprays of 10000 mg/liter applied to runoff with a hand-held pressurized (80 psi) sprayer under varying combinations of environmental conditions.

Standard chamber conditions selected for AT, RH, PAR, and AF were $21 \pm 1^{\circ}C$, $60 \pm 5\%$, 300 $\mu E\ m^{-2} sec^{-1}$ and 0.5 m sec^{-1} respectively. One environmental factor was varied while the others were held constant at standard conditions. AT used were 15, 21, 27, and $33^{\circ}C$; RH 30, 60, and 90%; PAR 150, 300, and 450 $\mu E\ m^{-2} sec^{-1}$; and AF 0.5, 1.0, and 1.5 m sec^{-1}.

Nine plants per cultivar were treated at each combination of environmental variables and the experimental design within the chamber completely randomized. Number of plants pinched and number showing phytotoxicity to remaining plant parts were recorded. Data were analyzed using x^2 procedures where appropriate.

<u>Greenhouse study</u>. 'Yellow Fuji Mefo' plants were randomly selected and treated under prevailing environmental conditions in the greenhouse during the period March 30 to April 7, 1982. An attempt was made to treat the plants over a widely varying set of environmental conditions. AT varied between $15\text{-}34^{\circ}C$, RH 17-90%, PAR 100-1200 $\mu E\ m^{-2} sec^{-1}$, and AF 0.0-4.0 m sec^{-1} (Appendix I). Environmental conditions were measured with the same instrumentation described for the growth chamber study.

Plants were treated each time with undecanol foliar sprays of 7500, 10000, and 12500 mg/liter applied to runoff as described previously. A completely randomized design with 3 replications per concentration was used each time and there were 3 plants per replication. The percentage of plants pinched and those showing subapical phytotoxicity were recorded. Data were analyzed by correlation and regression procedures. Stepwise regression was used to develop prediction models for pinching and phytotoxicity; entry and stay significance levels were set at 15%.

Results

Growth Chamber Studies

Air temperature. Pinching was unaffected by AT in 'Fiesta' and 'Sunburst Spirit' (Table 1). 'Yellow Fuji Mefo' was effectively pinched at AT of 15°C only; higher temperatures resulted in significantly fewer plants pinched. Subapical phytotoxicity was observed at all AT with 'Yellow Fuji Mefo'. No phytotoxicity occurred in the other 2 cultivars excepting 'Sunburst Spirit' at the lowest AT (15°C).

Relative humidity. Pinching was generally unaffected by RH in 'Fiesta' and 'Sunburst Spirit' (Table 2). The number of plants pinched in 'Yellow Fuji Mefo' decreased with increasing RH, the number pinched at 90% significantly less than that at 30%. Subapical phytotoxicity of 'Fiesta' and 'Sunburst Spirit' generally increased with increasing RH. Subapical phytotoxicity of 'Yellow Fuji Mefo' was nearly 100% at all RH levels.

Air flow. AF had no effect on pinching in 'Fiesta' and 'Sunburst Spirit' (Table 3). The number of plants pinched in 'Yellow Fuji Mefo' tended to decline slightly with increasing AF rates. Subapical phytotoxicity was more variable among cultivars than pinching. Phytotoxicity was observed in nearly 100% of 'Yellow Fuji Mefo' at all AF

Table 1. Influence of air temperature on pinch (necrotic apices) and phytotoxic response of 3 chrysanthemum cultivars to 10000 mg/liter undecanol foliar sprays.

Air temperature (^oC)	Cultivar					
	Fiesta		Sunburst Spirit		Yellow Fuji Mefo	
	Pinch	Phyto.	Pinch	Phyto.	Pinch	Phyto.
15	8a[z]	0a[z]	9a	0a	9b	9b
21	9a	0a	8a	0a	1a	0a
27	8a	0a	7a	0a	0a	0a
33	9a	0a	9a	0a	1a	0a

[z]Number of plants out of 9 pinched or exhibiting subapical phytotoxicity. Treatments followed by the same letter within columns were not significantly different based on a x^2 test and 2-sample test of proportions, 5% level.

Table 2. Influence of relative humidity on pinch (necrotic apices) and phytotoxic response of 3 chrysanthemum cultivars to 10000 mg/liter undecanol foliar sprays.

Relative humidity (%)	Cultivar					
	Fiesta		Sunburst Spirit		Yellow Fuji Mefo	
	Pinch	Phyto.	Pinch	Phyto.	Pinch	Phyto.
30	7a[z]	0a[z]	8a	1a	5b	9a
60	9a	0a	7a	4b	2ab	9a
90	9a	2a	9a	3ab	0a	8a

[z]Number of plants out of 9 pinched or exhibiting subapical phytotoxicity. Treatments followed by the same letter within columns were not significantly different based on a χ^2 test and 2-sample test of proportions, 5% level.

Table 3. Influence of air flow on pinch (necrotic apices) and phytotoxic response of 3 chrysanthemum cultivars to 10000 mg/liter undecanol foliar sprays.

Air flow ($m\ sec^{-1}$)	Cultivar					
	Fiesta		Sunburst Spirit		Yellow Fuji Mefo	
	Pinch	Phyto.	Pinch	Phyto.	Pinch	Phyto.
0.5	9a[z]	2a[z]	9a	9c	9a	9a
1.0	9a	1a	9a	6b	7a	9a
1.5	9a	0a	9a	1a	6a	8a

[z]Number of plants out of 9 pinched or exhibiting subapical phytotoxicity. Treatments followed by the same letter within columns were not significantly different based on a x^2 test and 2-sample test of proportions, 5% level.

rates. Phytotoxicity was low at all AF rates in 'Fiesta', but tended to decline further with increasing AF rates. Phytotoxicity of 'Sunburst Spirit' was greatly affected by AF; 100% of the plants showed injury at 0.5 m sec^{-1} but the number declined significantly at 1.5 m sec^{-1} to almost 0.

Light. PAR had little effect on the pinch response of 'Fiesta' and 'Sunburst Spirit' to undecanol; pinching was achieved in nearly 100% of both cultivars at all PAR levels (Table 4). PAR had no effect on pinch response of 'Yellow Fuji Mefo' and acceptable pinching was not obtained at any PAR level. Subapical phytotoxicity significantly declined in 'Fiesta' and 'Sunburst Spirit' at PAR levels from 150 to 300 $\mu E\ m^{-2}\ sec^{-1}$. PAR had no effect on phytotoxicity of 'Yellow Fuji Mefo'; all plants showed injury at all PAR levels.

Greenhouse Study

Simple linear correlations between pinch or phytotoxicity and concentration, AT, AF, RH, and PAR showed AT to be the single variable most highly correlated with both pinch and phytotoxic response (Table 5). PAR was also highly correlated with pinch but is itself highly correlated with AT (r = 0.689, significant at 0.01%). The best models developed were: pinch (%) = 564.86 + $(6.06 \times 10^{-3}) \times AT^3 - (132.85 \times AT^{\frac{1}{2}}) + (5.00 \times 10^{-3}) \times$ concentration [R^2 = .35, significant at 1%]; and phytotoxicity (%) = 131.17 - $(2.76 \times AT) - (21.98 \times AF^{\frac{1}{2}})$ [R^2 = .22, significant at 5%].

Table 4. Influence of light (PAR) on pinch (necrotic apices) and phytotoxic response of 3 chrysanthemum cultivars to 10000 mg/liter undecanol foliar sprays.

PAR ($\mu E\ m^{-2}\ sec^{-1}$)	Cultivar					
	Fiesta		Sunburst Spirit		Yellow Fuji Mefo	
	Pinch	Phyto.	Pinch	Phyto.	Pinch	Phyto.
150	9a[z]	5b[z]	9a	7b	1a	9a
300	9a	0a	9a	4a	0a	9a
450	9a	0a	9a	3a	1a	9a

[z]Number of plants out of 9 pinched or exhibiting subapical phytotoxicity. Treatments followed by the same letter within columns were not significantly different based on a x^2 test and 2-sample test of proportions, 5% level.

Table 5. Simple linear correlation coefficients (r) between pinch and phytotoxic response of chrysanthemum 'Yellow Fuji Mefo' to undecanol concentration and several environmental factors.

	Concentration	Environmental factors			
		Air temperature	Air flow	Relative humidity	PAR
pinch	0.222	-0.342	-0.232	-0.557	-0.338
significance	0.195	0.041	0.173	0.747	0.044
phytotoxicity	0.205	-0.364	-0.203	-0.029	-0.264
significance	0.195	0.029	0.234	0.866	0.119

Discussion

Pinch response to undecanol under chamber conditions was similar in 'Fiesta' and 'Sunburst Spirit' under most environmental conditions; over 75% of the cuttings treated were pinched under any set of conditions. 'Yellow Fuji Mefo' was quite dissimilar in its response however. The number of plants pinched under any set of environmental conditions never exceeded the number pinched in either of the 2 other cultivars. In general, lower AT and RH tended to increase the number of plants pinched in 'Yellow Fuji Mefo' although higher AF rates tended to insignificantly reduce pinching, and PAR had no effect.

Subapical phytotoxicity resulting from undecanol was more variable than the pinch response. In general, 'Fiesta' and 'Sunburst Spirit' again responded in a somewhat similar manner, although phytotoxicity was consistently greater under nearly all environmental conditions in 'Sunburst Spirit' compared to 'Fiesta'. In general, conditions which tended to increase the rate of drying (higher AT, lower RH, and higher AF) resulted in fewer plants showing phytotoxic injury, the effect dramatically illustrated in 'Sunburst Spirit' when AT increased from 15 to 21^{o}C and AF rates increased from 0.5 to 1.5 m sec^{-1}. Conditions favoring rapid drying tend to decrease contact time and to increase the potential for evaporation and volatilization of the chemical. Higher light levels also significantly reduced phytotoxicity.

The number of plants showing phytotoxicity in 'Yellow Fuji Mefo' totaled nearly 100% under all chamber conditions.

These data are generally in agreement with previous research indicating environmental variables as a major factor in plant response to chemical pinching agents (5, 9, 13, 14, 15, 17). The effectiveness of pinching agents has been reported dependent on the rate of drying (3, 4, 5, 14). Effective pinching with least phytotoxicity was generally obtained under chamber conditions which promoted rapid drying. Changes in environmental conditions, notably temperature, would also affect the metabolic activity of the plant which may also alter plant response.

Analyses of the greenhouse data suggest AT as the single most important environmental variable in the pinch response although concentration was significant in the model developed. Both concentration and AT contribute to the model and suggest pinching increases as a function of both variables. With the phytotoxic response, AT was also the single most important environmental variable but AF also entered the model. Both AF and AT contribute negatively to the model and suggest phytotoxicity decreases with increasing AF and AT.

In reality, however, it is unlikely that any single environmental variable exerts an overriding effect on either the pinch or phytotoxic response to undecanol because all are interrelated. Furthermore, subapical phytotoxicity does not appear to be necessarily a function of pinching with all cultivars. 'Yellow Fuji Mefo', which showed the poorest overall pinch response in the chamber, also consistently showed the highest phytotoxicity. Pinching and phytotoxicity appear to be more a function of concentration than environmental conditions with this cultivar.

Many factors besides environment affect chrysanthemum response to undecanol, notably concentration and cultivar. It would appear that certain cultivars are better candidates for chemical pinching than others. Further research is needed to identify these cultivars with particular attention to those least susceptible to subapical phytotoxicity.

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Effect of Timing of Application on Chemical Pinching of Chrysanthemum with Undecanol

Abstract. Undecanol foliar sprays of 7500 mg/liter were nearly 100% effective in chemically pinching chrysanthemum (*Chrysanthemum* x *morifolium* Ramat.) cvs Fiesta and Sunburst Spirit with minimal phytotoxicity when applied 9 to 18 days after planting. Pinching was significantly reduced in plants treated prior to 9 days or later than 18 days. Manually pinched plants were generally taller than chemically pinched plants treated the same day. Chemically pinched plants generally produced more branches than manually pinched plants. Day of treatment did not affect flowering of chemically pinched plants, however, chemically pinched plants tended to flower later than manually pinched plants. Finished plants pinched chemically were comparable to those produced by manual pinching.

Despite its potential, chemical pinching of floricultural crops has not been successfully adopted commercially except with Off-Shoot-O™ (Procter and Gamble, Cincinnati, OH) and Atrinal™ (Hoffmann-La Roche, Nutley, NJ) for azaleas (15). Experimental use of various compounds on potted chrysanthemum, a crop that traditionally requires costly manual pinching to produce branched and well shaped plants, has resulted in highly variable plant response. Species and cultivar differences (3, 12), environmental factors (6, 7, 9), concentration (3, 4, 9, 10), and timing of application relative to the physiological age of the plant (4, 5, 6, 10, 13) have all been implicated in response variability.

Undecanol (TipNip™, Armak Co., Chicago, IL), a C_{11} fatty alcohol, is an experimental pinching agent for chrysanthemum (1). It is similar to fatty acids and fatty acid esters in that contact with and penetration of the apical tissue destroys the shoot meristem and simulates manual pinching.

Previous research with azalea has shown plants treated with fatty acids and fatty acid esters must be in an actively growing, vegetative state for the chemical to be effective (4, 5, 6, 10, 13, 14, 16). Azalea reproductive buds were not as easily killed as vegetative buds due to increased thickness of the cuticle and bud scales surrounding the reproductive tissue (14). Uhring (16) reported that methyl decanoate, acting on the nuclear membrane of meristematic chrysanthemum cells, resulted in progressive stages of cell destruction. Highly specialized cells, lacking protoplasts, were not as greatly affected as the meristematic cells which had dense protoplasts.

Similar but inconsistent results have been reported for chrysanthemum treated with undecanol. Shanks and Purohit (13) noted that increasing concentrations of undecanol were required to pinch chrysanthemum treated 20, 25, or 30 days after propagation. McDaniel and Graddy (8) treated plants with undecanol at 1.0, 1.25, and 1.5% a.i. 4, 7, 10, and 13 days following the start of short days (SD); all concentrations tested resulted in complete pinching on the 4th day, but by day 10 no concentration tested was effective in pinching all plants. However, these results were inconsistent with preliminary data in which no uniform pinch was reported on the 5th SD at any concentration tested, but plants were 100% pinched at all concentrations on days 10 and 15. The authors concluded that this was a result of seasonal variation in cultivar response which might necessitate adjustments in undecanol concentration or timing of treatment.

The purpose of this study was to determine the time (day) at which cuttings should be treated for effective pinching with minimal sub-apical phytotoxicity and to investigate effect of timing on factors subsequently affecting plant quality.

Materials and Methods

Rooted cuttings of chrysanthemum cvs Fiesta and Sunburst Spirit were planted one cutting per pot on May 26, 1982 in 10.2 cm plastic pots filled with a peat-lite artificial medium (Pro-Mix™, Premier Peat Moss Corp., New York, NY). All plants were grown under prevailing irradiance in a glass greenhouse (17°C night temperature). Plants were fertilized weekly with water soluble 20N-8.7P-16.7K fertilizer (Peters 20-20-20™, W. R. Grace and Co., Allentown, PA) at 600 ppm N. Short day (SD) conditions were provided using black cloth (2000-0800) beginning June 2, 1982, 1 week after planting.

Chemical pinch dates (treatments) were: 0 days (day of planting), 3 days, 6 days, 9 days, 12 days (recommended manual pinch date), 15 days, 18 days, and 21 days. Treatment dates were randomly assigned within cultivars and plants manually pinched (control) or sprayed with undecanol at 7500, 10000, or 12500 mg/liter a.i. Foliar sprays were applied as a fine mist using a hand-held air-pressurized (80 psi) sprayer. A sufficient volume of spray material was applied to wet the entire foliage to runoff. To assure turgidity, plants were watered 4 to 6 hours before spraying. There were 3 plants per concentration/date combination per cv and 3 replications per treatment in a completely randomized design.

Data on pinching, phytotoxicity, number of branches, days to flower, height, and dry weight were recorded. Data were analyzed by analysis of variance or χ^2 where appropriate.

Results and Discussion

Undecanol foliar sprays of 7500 mg/liter were 100% effective at pinching 'Fiesta' when applied between days 9 and 18 from potting and were nearly as effective in 'Sunburst Spirit' when applied over the same time period (Fig. 1); the number of plants pinched was significantly less in both cultivars when treated less than 6 days or more than 18 days from planting. Cuttings treated less than 6 days from planting may not have been actively growing or fully turgid. Plants treated more than 18 days from planting would have initiated reproductive tissue less susceptible to chemical growth inhibitors than vegetative tissue (4, 6, 10). No subapical phytotoxicity occurred in 'Fiesta' between days 9 and 18, but phytotoxicity increased slightly in 'Sunburst Spirit' at days 15 and 18 (data not shown).

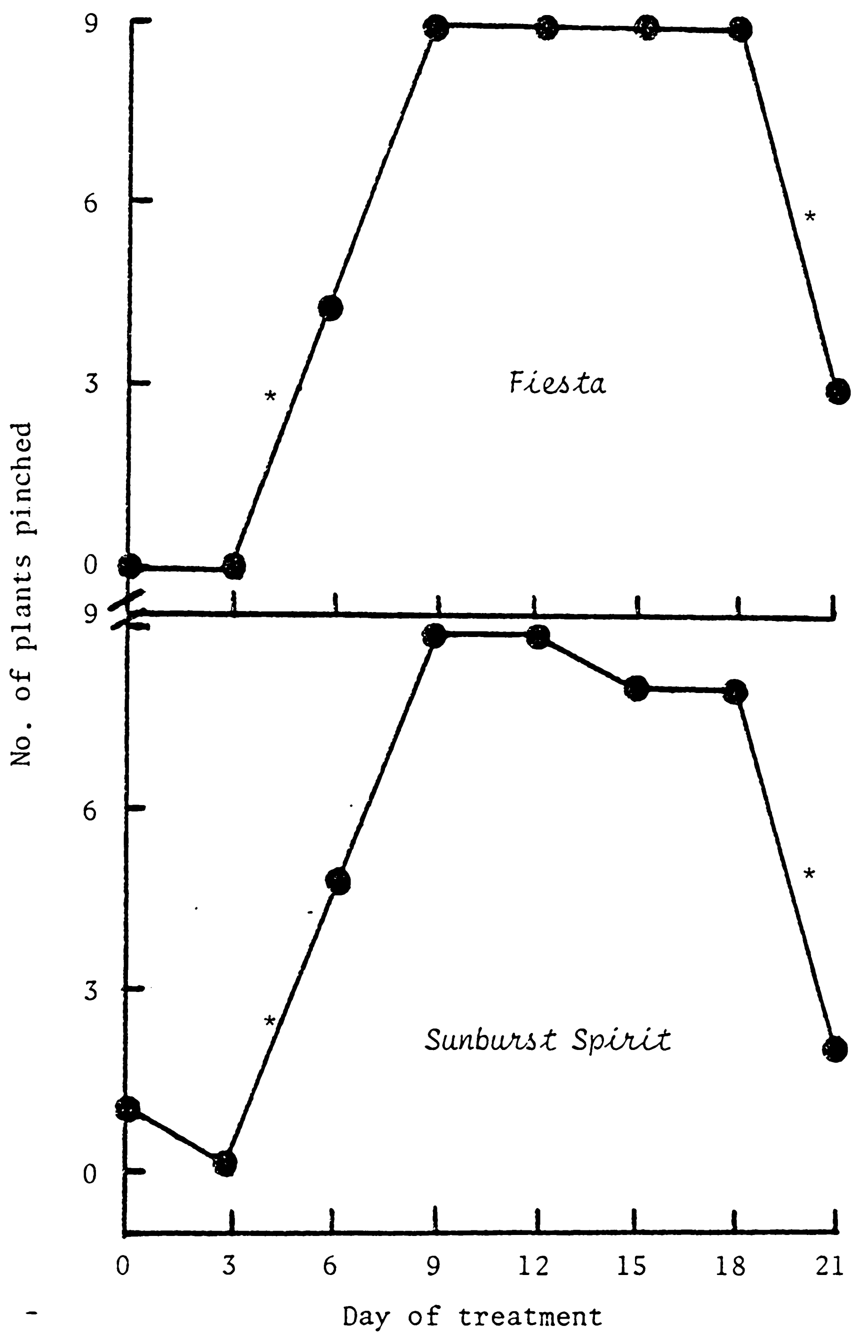

Fig. 1. Influence of time of application on the pinch response of chrysanthemum cvs Fiesta and Sunburst Spirit to 7500 mg/liter foliar sprays of undecanol. (* = number of plants within cultivars were significantly different based on x^2 test and 2-sample test of proportions, 5% level.)

Higher concentrations of undecanol were as or more effective than 7500 mg/liter in pinching regardless of the time of application but significantly increased phytotoxicity in 'Sunburst Spirit' (data not shown).

These results generally agree with previous reports indicating actively growing, vegetative tissue is more susceptible to chemical pinching than reproductive tissue (4, 6, 10), and that higher concentrations are needed for effective pinching with increasing age (5, 6, 9, 13). More importantly, however, they indicate that effective pinching can be obtained in some cultivars at nonphytotoxic (subapical) concentrations when applied several days before or after the commercially recommended manual pinch date. Thus it would appear that within limits, the timing element is not as critical as concentration and environmental variables in determining pinch response (3, 4, 6, 9, 10).

Plant height was greatest at day 12 (recommended pinch date) in both manually and chemical pinched plants of both cultivars and significantly decreased when pinching was done prior to or after that date (Table 1). Manually pinched plants were generally taller than chemically pinched plants treated the same day; this is probably due in 'Fiesta' to the fact that chemically pinched plants either produced more branches and thus growth (height) was distributed among more stems. No growth retarding activity has been attributed to undecanol.

The number of branches produced when pinched on day 18 was significantly greater than the number obtained on earlier pinch dates excepting 'Sunburst Spirit' when chemically pinched. Plants at day

Table 1. Effect of chemical (7500 mg/liter undecanol) vs manual pinching on height, number of branches, dry weight, and days to flower of chrysanthemum cvs Fiesta and Sunburst Spirit as affected by day of treatment (time of application).

Day of treatment[z]	Cultivar					
	Fiesta			Sunburst Spirit		
	Manual		Chemical	Manual		Chemical
			Height (cm)			
9	28.2c[y]		28.2b	31.7b		30.5b
12	35.1a	*	32.2a	36.3a		35.6a
15	31.3b	*	28.7b	32.2b	*	30.2b
18	29.8bc	*	28.3b	31.0b	*	29.4b
			No. of branches			
9	4.5b[y]		5.5b	6.1b		6.3a
12	4.3b	*	5.8b	7.3ab	*	5.2a
15	4.8b		6.0b	6.5b		6.5a
18	8.0a		7.8a	8.1a		7.0a
			Dry weight (g)			
9	10.1ab[y]		7.8b	11.7ab	*	9.7a
12	8.5b		9.6ab	10.6b		10.4a
15	9.4b		8.2b	9.9b		9.3a
18	11.6a		11.6a	13.3a		11.3a
			Days to flower			
9	54.7b[y]		56.7a	60.3c	*	62.6a
12	56.7ab	*	59.0a	64.3a		64.4a
15	58.5a		56.3a	62.5ab		63.1a
18	58.0a		57.3a	60.7bc		63.3a

[z]Days from planting. Day 12 = commercially recommended manual pinch date.

[y]Means within columns followed by the same letter are not significantly different based on Duncan's multiple range test, 5% level.

*Significant difference between manual and chemical treatment within days and cultivars based on *t*-test, 5% level.

18 were older and had more nodes from which potential branches could arise. The tendency for chemically pinched plants to produce more branches than manually pinched plants (cv Fiesta) may be due to the fact that chemical pinching results in less tissue loss than does manual pinching (11) and thus more nodes may remain on the chemically pinched plant. This effect was not observed in 'Sunburst Spirit' in which subapical phytotoxicity was more extensive but has been reported for other cultivars (13). In all treatments, however, the number of branches produced exceeded the minimum commercially desired number of 3 to 4 (2).

Dry weight varied considerably among cultivars and treatments. Although the dry weight of manually pinched plants of 'Sunburst Spirit' was significantly greater than chemically pinched plants at day 9, no clear trends in the data are apparent.

Days to flower among chemically pinched plants did not differ when treatments were applied between days 9 and 18, although some differences were observed among manually pinched plants. Chemical pinching delayed flowering compared to plants manually pinched the same day in 'Fiesta' and 'Sunburst Spirit' on days 9 and 12 respectively. Certain pinching agents have been reported to slightly delay flowering (12).

These data suggest that certain chrysanthemum cultivars can be effectively pinched chemically to produce a finished plant similar to one produced by manual pinching. The actual date of chemical pinching appears to be no more critical than for manually pinched plants, although it should be considered with respect to cultivar response group and cultural/production procedures employed. The response to the chemical is influenced, however, by a number of factors, many of which are interrelated and affect not only the pinch response but propensity for subapical phytotoxicity. Some cultivars appear much better suited to chemical pinching than others. Further research is needed to identify these cultivars and to investigate means of controlling variability.

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Conclusions

Successful chemical pinching of chrysanthemum has remained a commercially elusive goal for more than three decades. While the potential advantages of chemical pinching are many, variability in response to chemical pinching agents remains the single most important obstacle to commercial use.

Undecanol represents probably the most promising of numerous chemical pinching agents tried experimentally. However, cultivars vary in their response and concentrations effective in pinching one cultivar may be ineffective for others. The potential for accompanying subapical phytotoxicity also remains a serious problem and appears even more variable among cultivars than pinching. While new growth produced can potentially mask some phytotoxic injury, some foliage injury resulting from chemical pinching agents often remains on the finished plant reducing its aesthetic appeal and thus its value.

Various factors aside from concentration and cultivar affect plant response, notably environmental factors. The situation is confounded further, however, because many of these factors are interrelated. While it appears that conditions which favor more rapid drying of the chemical tend to decrease pinching percentage in some cultivars and reduce the potential for subapical phytotoxicity, there is some evidence that changes in environmental parameters during treatment may not affect all cultivars uniformily. Where chemical pinching can be achieved without subapical phytotoxicity, resulting plants differ little from those produced by manual pinching; cultural/production procedures do not appear to require alteration to accommodate chemical pinching.

Certain cultivars appear better candidates for chemical pinching than others. Further research is needed to identify these cultivars and investigate means of minimizing subapical phytotoxicity. Until this is accomplished or chemical pinching agents developed which effectively pinch without subapical phytotoxicity, the commercial use of pinching agents in chrysanthemum production is unlikely. Given the problem of subapical phytotoxicity, inhibition of the apical meristem with growth regulators (thus promoting lateral shoot development) rather than the selective phytotoxicity approach (with chemicals like undecanol) holds more promise.

Appendices

Appendix I. Greenhouse environmental conditions at time of treatment of chrysanthemum cv Yellow Fuji Mefo with undecanol foliar sprays.

Air temperature (^{o}C)	Relative humidity (%)	Air flow ($m\ sec^{-1}$)	PAR ($\mu E\ m^{-2}\ sec^{-1}$)
22	29	4.0	350
26	25	0.2	1050
26	25	0.2	850
26	25	0.2	150
15	40	0.2	350
27	90	0.1	500
27	17	0.3	1000
26	34	0.2	700
34	38	0.05	1050
25	40	0.1	500
25	28	0.2	1200
17	28	0.0	650
17	28	0.4	100
17	28	0.0	100
21	75	0.0	350

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Chemical Pinching of *Chrysanthemum* x *morifolium* Ramat. with Undecanol

by

Jerry Lawrence Garner

(ABSTRACT)

Concentrations between 5000 and 15000 mg/liter undecanol applied as foliar sprays were effective in pinching most varieties of chrysanthemum tested. Cultivars varied in their response. Subapical phytotoxicity increased with increasing concentrations and was generally more variable among cultivars than was the pinch response. Concentrations effective in pinching without subapical phytotoxicity resulted in plants similar to manually pinched plants with respect to height and number of branches.

Studies conducted in the growth chamber and greenhouse indicate environmental factors exert a major influence on plant response to undecanol. In general, conditions which favor more rapid drying tended to decrease the number of plants pinched and reduce the number of plants showing subapical phytotoxicity. Comparing air temperature, air flow, relative humidity, and light (PAR), temperature was the single most highly correlated environmental variable with both pinching and phytotoxicity in the greenhouse study. Many of these variables are, however, highly interrelated with one another so that a change in one results in a change in others. Prediction equations using concentration and environmental variables were developed for pinching and phytotoxicity.

Undecanol foliar sprays of 7500 mg/liter were nearly 100% effective in pinching two cultivars with minimal phytotoxicity when applied 9 to 18 days after planting. Pinching was significantly reduced in plants treated prior to 9 or later than 18 days after planting. Manually pinched plants were generally taller than chemically pinched plants treated the same day. Chemically pinched plants generally produced more branches than manually pinched plants. Day of treatment did not affect flowering of chemically pinched plants; however, chemically pinched plants tended to flower slightly later than manually pinched plants. Finished plants pinched chemically were comparable to those produced by manual pinching.