Reformation of specialty cut flower production for *Celosia cristata*

Cameron Zuck, University of Minnesota (Landscape Design and Planning, Department of Landscape Architecture)

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EXECUTIVE SUMMARY

Celosia cristata is an interesting and increasingly popular crop in specialty cut flower production. With origins of dry, temperate climates in Africa and Asia, this herbaceous annual plant is now distributed and cultivated worldwide. *C. cristata* has a wide variety of cultivars available on the market including the 'Chief Series' and the 'Bombay'. To become a more sustainable and energy-efficient crop in the future, one potential change in production is an overall increase on growth efficiency. By evaluating the current practices and traits of *C. cristata,* a new ideotype is

proposed that addresses possible genetic improvements that can create a more sustainable production of *C. cristata.*

I. INTRODUCTION

A. Study Species.

Celosias are eye-catching flowers that come in many different colors and forms. The unique inflorescence of *Celosia cristata* have been compared to a rooster comb, a brain and elegant ribbon; whichever way they are described, they are sure to strike the attention of anyone who catches a glimpse (Cornell 2006). *Celosia* are versatile plants that have been used as herbal remedies, as ornamental annuals in the garden and as cut and dry flowers. *Celosia cristata* is still considered fairly unknown to consumers in specialty cut flower production and has potential to grow (Gilman and Howe 1999). Since *C. celosia* is a temperate climate species, field production is restricted in location and time. In northern climates, the growing season is shortened and greenhouse production is common as a result (McKinley and Wright 2010). Through investigating the characteristics and history of production of *Celosia cristata*, a comprehensive analysis of current production practices can be made and improvements can be made. By extending the growing season through the use of high tunnels or novel cultivars are more tolerant, the production of *C. cristata* can become sustainable and economically efficient.

B. Taxonomic Classification and Geographic Distribution in the Wild.

Celosia cristata is an herbaceous annual plant, a member of the Amaranthaceae. The Amaranthaceae includes herbs, annuals or perennials being most abundant in the tropics, subtropics and warm-temperate regions (USDA 2006; Cornell 2006). *Celosia cristata* L. in some cases is considered a species separate from *Celosia argentea L.*, but can also be treated as a varietas of the species, denoted as *Celosia argentea* L. var. *cristata* Kuntze. Therefore synonyms include *C. argentea* L., C. *argentea* L. var. *cristata* Kuntze as well as *C. margaritacea* L. Common names are Crested Cockscomb, Cockscomb and Woolflower (FNA; USDA 2006). There are many cultivars available differing in color, overall size and growth habits. Since *C.*

cristata is also a annual plant many cultivars are specifically for this including ‘Jewel Box’ Mix, ‘Amigo’ Series, ‘Sparkler’ Series, ‘Prestige Scarlet’, ‘Toreador’. Cultivars that have been bred specifically for cut flower production are the ‘Chief’ series, ‘Bombay’ series and ‘Spring Green’ (Cornell 2006). The ‘Chief’ series are characterized as tall plants with long stems, which is good for drying and cutting purposes. The ‘Bombay Fiora’ cultivar is also notable with a bicolor inflorescence (Cornell 2006; Barash 2006).

Celosia cristata is a branching; erect annual, 15 to 90 cm in height and 15 to 30 cm in spread. It has alternate, oval to lance-shaped leaves, 5 to 12 cm long that are medium green in color. The inflorescence is terminal with broad, showy fan-shaped heads (Foster and Chongxi 1992; Cornell 2006) . Colors for inflorescences are white, pink, red, violet, orange, and yellow. The bloom time for Celosia cristata ranges from mid-summer to mid-fall. The exact origins of Celosia are unknown, but it is thought to have been native to the dry slopes of Africa and India. Celosia has been used for herbal and medicinal purposes throughout China and other eastern countries. The seeds have been used in the treatments of eye ailments and blood diseases (Cornell 2006; Barash 2006; Foster and Chongxi 1992). Celosia is now distributed in warm temperate climates in Asia, Africa and the Americas (Figure 1). The distribution is concentrated in Asia and Africa where it is considered a weedy plant (Figure 1). Since it is native to tropical climates, *Celosia cristata* grow in full sun, but can tolerate partial shade (Cabi 2012). *Celosia cristata* prefers fertile, moist soil, but will grow in most soils including acidic, sand, loam and clay. The preferred soil temperature is 16°C (Gilman and Howe 1999).

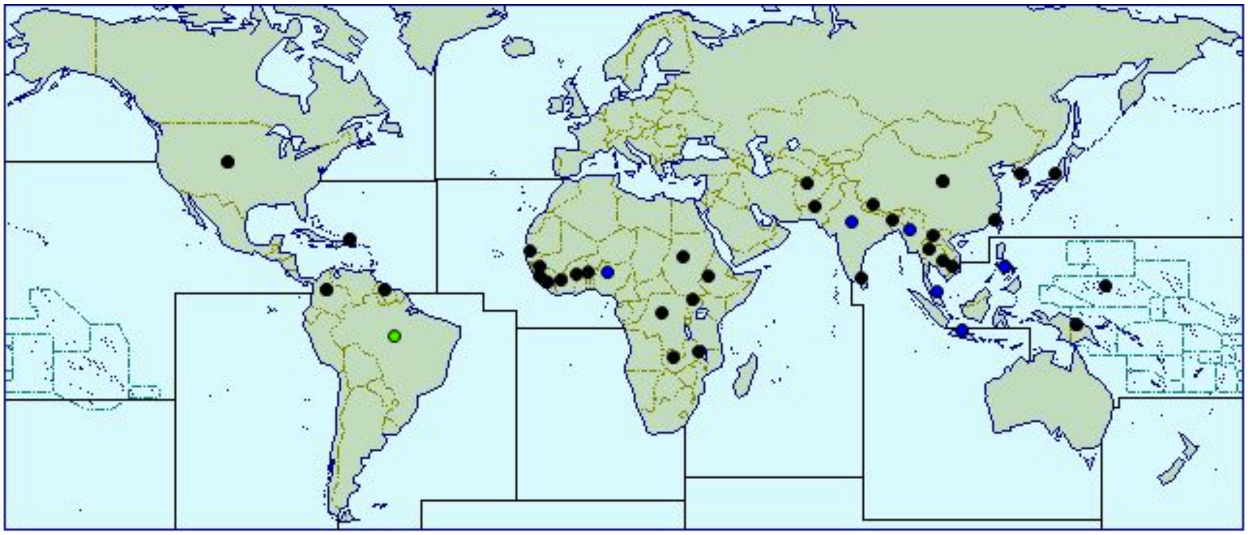

Figure 1. Worldwide distribution of *Celosia* species (Cabi 2012). The black circles indicate where *Celosia* species are present and blue circles indicate where *Celosia* species are widespread.

II. CROP HISTORY

A. Breeding & Domestication.

There is limited information on the early history of breeding and domestication of *Celosia cristata*, but it is thought to be first cultivated in East Asia from *C. argentea*. Some sources say that the *Celosia* was brought to Japan from China in the Nara period (A.D. 710-794) where it was established as an ornamental crop and various cultivars were developed (Foster and Chongxi 1992). One influential breeding company for Celosia is Sakata Seed Corporation. This company developed the 'Flame of Fire' cultivar that was awarded the All American Selections (AAS) bronze medal in 1935 (Sakata 2005). Although *Celosia cristata* is thought to have been in American gardens since 1737, this new cultivar marked the rise of popularity of Celosia in the US. Another important cultivar developed by the Sakata Seed Company is 'Chief' (Foster and Chongxi 1992; Sakata 2005). *Celosia cristata* 'Chief' is known for producing large uniform, globe-shaped flower heads and has a very uniform growth pattern that is advantageous in field production. It also performs well in hot climates and periods of high temperatures (McKinley and Wright 2010; Sakata 2005). Another important breeding company is Keift Seeds that bred the ‘Bombay Purple’ cultivar in 1996, as well as the notable ‘Bombay Yellow Gold’ known for its short cultivation time and high yield per m^2 (Gilman and Howe 1999). With many different varieties already on the market, breeders are continuing improvements on growth habit, yields, unique color, stress tolerance, as well as growth rate (Dole 2001).

Celosia cristata is historically has been grown from seed, starting out in field production. Since *C. cristata* is a tropical climate crop, field production seasons were limited in more temperate climate regions. This allowed for greenhouse production of the crop as well as informed the breeders on possible improvements for new cultivars. Another challenge that was faced and it continually a problem with many specialty cut flower production is the distribution chain (Scoggins 2009, Ortiz et al. 2012). Field production requires temperate conditions, which can limit the growing season and regions of the crop. One experiment looked at high tunnel production compared to field production of C. *cristata* in the Midwest region (Ortiz et al. 2012). High tunnels can potentially offer new possibilities in production of *Celosia* (Ortiz et al. 2012). In the distribution chain for *Celosia cristata* (Figure 2), the producer companies and commercial grower duties can overlap sometimes; many times distributors may not be part of the chain as well. While most times commercial growers sell to retailer, including florist shops and farmer’s markets, it is possible for consumers to buy directly from the growers in smaller scale productions.

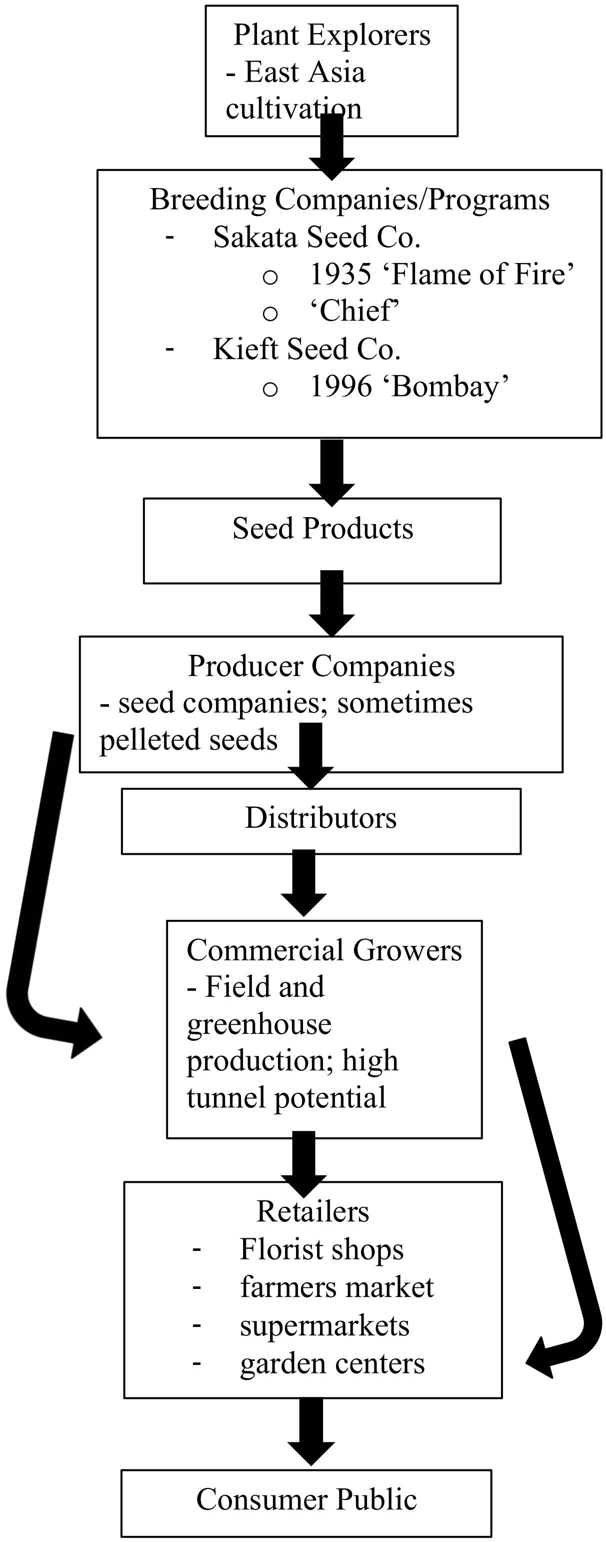

Figure 2: Distribution chain of *Celosia cristata* illustrating the important contributors in the production and distribution.

III. PRODUCTION INFORMATION

A. Current Production Practices.

Current production practices of *C. cristata* most commonly include field production in appropriate climates as well glass greenhouse production. In the US, field production is primarily in the southwest region due to the suitable climate. In greenhouse production, *C. cristata* can be produced year-round under the appropriate light levels and temperatures, but in gardens it is recommended to start sowing in May and no later than the end of June (Kieft-Pro Seeds 2010). Field production starts no later than June as well. Depending on the cultivar and whether it is propagated from seed or vegetatively the total crop time can vary, but it is generally 12-16 weeks (Kieft-Pro Seeds 2010; Sakata 2015). Most information found describes production practices from seed, although *C. cristata* can also be propagated from vegetative cuttings. Producer companies, such as Kieft Seed Co., offer normal seeds as well as pelleted and film-coated seeds (Kieft-Pro Seeds 2010). Seeds are sown one per cell in a 288 or larger plug tray with media that has a pH of 5.8-6.2 that is well drained (Kieft-Pro Seeds, 2010; Sakata 2015). The plug stage, from sow to transplant, is 2-3 weeks long. During this time *C. celosia* require a temperature of 20-22°C. The light requirement for plug production is light up to 26,900 Lux in the first three stages and 54,000 Lux in the final stage of growth (Kieft-Pro Seeds, 2010; Sakata 2015). It is important to maintain the soil moisture and not let the media dry out; if *Celosia* suffers from water stress it can result in premature flowering (Sakata 2015). Fertilizers in plug production can start after germination (3-4 days) at less than 100 ppm N and later in stage three this can be increased to 100-175 ppm N. During the plug stage no plant growth regulators (PGRs) are used to ensure that as a cut flower they reach sufficient length. *Celosia* is also sensitive to root damage, which can result in early bud formation or deformed flowers. Plantings should be done before plugs get root bound; this usually being at the 2-3 week point or when the first pair of true leaves unfolds (Kieft-Pro Seeds, 2010).

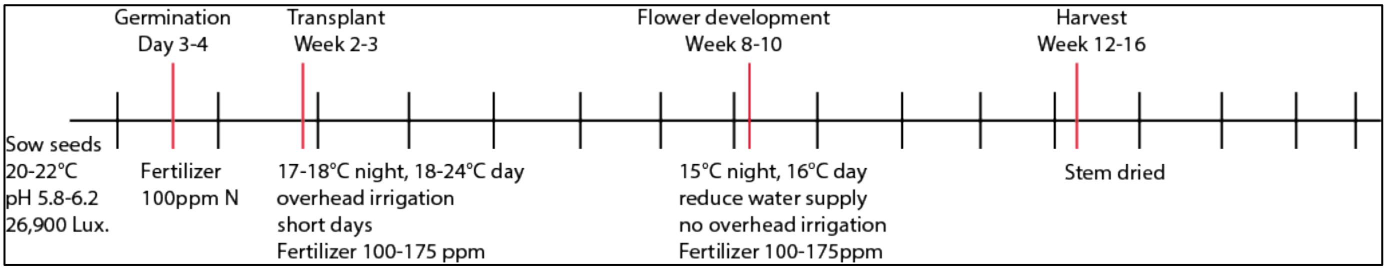

Figure 3: Crop production schedule for *Celosia cristata* illustrating major factors of plant growth. Time from seed sowing to harvest is 12-16 weeks.

When transplanted, *Celosia* should be planted at 64 plants/m^2 and netting can be used for support. *Celosia* is a quantitative short day plant, meaning that flowers will initiate under short days (Kieft-Pro Seeds, 2010; Sakata 2015). To reach appropriate stem length the day length should lie between 12 to 13 hours. Some growers suggest providing a dark period for a minimum of 12 hours for 5 to 6 weeks and to not start short days until 1 week after planting (Kieft-Pro Seeds, 2010). The temperature for planting through start of flower development should be 17-18°C during nights and 18-24°C during days. During this time overhead irrigation is often used, especially in the morning, to maintain moist media (Kieft-Pro Seeds, 2010; Sakata 2015). The total time from transplant to flowering is 10-14 weeks. Once flower development starts the temperature can be dropped to 15°C during nights and 16°C during days. Water supply should be reduced and no overhead irrigation after flower development or once plants are 40-50 cm tall; irrigating only when foliage wilts is suggested to help prevent disease (Kieft-Pro Seeds, 2010). Other common problems for *Celosia* include aphids, thrips, leaf miners, mildew and *Botrytis*. It is recommended to preventatively treat against *Botrytis* a week after transplanting. Fertilizer is continued during this growing phase at 100-175 ppm N. Since this is cut flower production of *C. cristata* PGRs are generally not used, although a spray of B-Nine/Alar can be used when the final desired stem length is achieved (Kieft-Pro Seeds, 2010).

While many cut flowers are harvested before the flower matures, in production of *Celosia* plants are harvested 3-4 weeks after the flower seems mature. This is to ensure that the stem hardens and is 'woodified' prior to harvest (Kieft-Pro Seeds, 2010). At harvesting, the stems are often dried to prevent *Botrytis*. *C. cristata* can be stored and transported cool with a minimum temperature of 5-6°C. Some difficulties that arise during transportation include temperature fluctuations and movement of the plants. A constant temperature during transportation can prevent condensation and, therefore, *Botrytis* infection. By packing the plants securely this can help prevent movement and breaking of the stems. *C. cristata* have a vase life that lasts 2 weeks at a minimum and can then be dried as well (Kieft-Pro Seeds, 2010; Sakata 2015).

B. Current Production Statistics.

The world's largest floriculture markets include the US, western Europe and Japan. In these markets floriculture expenditure is not expected to increase. The US imported about 65% of all cut flowers from Colombia in 2013, compared to 55% in 2003 (Van Rijswick 2015). These statistics illustrates an overall trend in global competition and market stagnation and the need for US growers to determine options to remain competitive in the market.

The wholesale value of all floriculture production in the US is $3.98 billion. Looking specifically at cut flower production, it accounts for 9% of this overall wholesale value respectively (Figure 4; USDA 2015). This value of cut flowers grown in the top 15 producing states in the US is $354 million in 2014, down 3% from 2013. California is the top producer of cut flowers in the US accounting for 28% of the total cut flower value (USDA 2015). Specialty cut flowers are classified as species other than *Rosa* L., *Dianthus caryophyllus* L., *Chrysanthemum xmorifolium* Ramat., and *Alstroemeria* L; therefore including *C. cristata* (Ortiz et al. 2012). From 2005 to 2011, specialty cut flower production increased from 81% to 91% of total US cut flower production (Ortiz et al. 2012). This increase illustrates a focus on specialty cut flowers in the US that are advantageous because of the proximity of production to the intended market (Ortiz et al. 2012). While there is limited data on the overall cut flower production of *Celosia* species, it has a total value of $6.28 million for all sales bedding and garden plant production, which is a small percentage of total bedding and garden production (USDA 2015). While this is not cut flower production, it can be seen as a reflective value of the species *Celosia*.

For cut flower production, 51.2% of the total number of operations is field production (Figure 5). There are a total of 1008 field operations. This can be compared to 820 operating greenhouses, 88 shade structures, and 51 natural shade operations (USDA 2015). The production of *C. cristata* aligns with this data being commonly produced in the field and greenhouses, while uses of shaded and natural shade structures and are limited and still emerging (Ortiz et al. 2012).

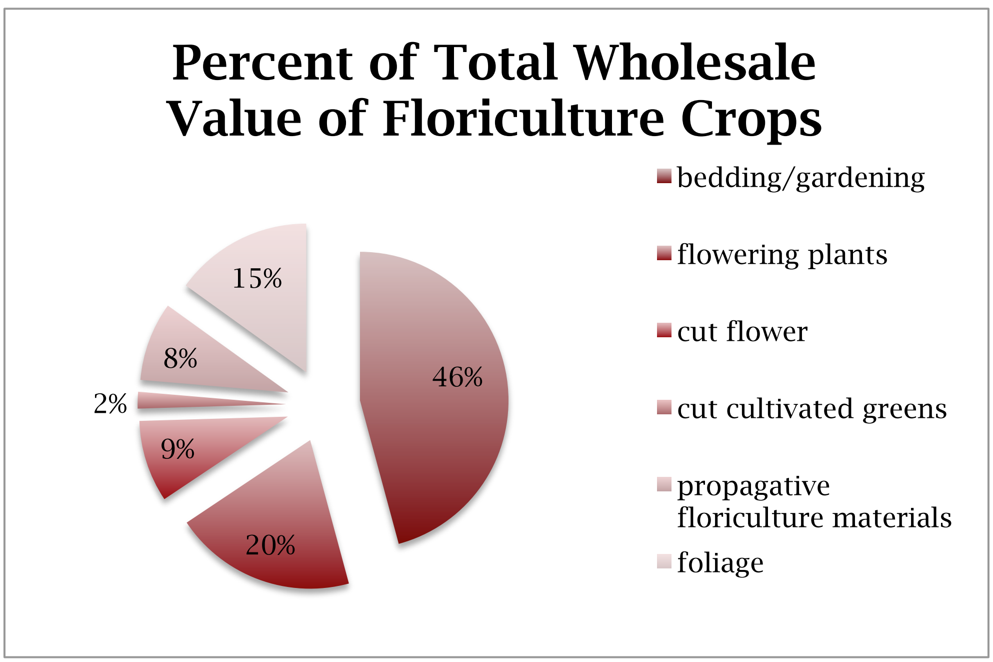

Figure 4: The percent of total wholesale values of floriculture crops. The total wholesale value of all floriculture crops is $3.98 billion. 46% of this is bedding and gardening plants; which include annuals and herbaceous perennials. Flowering plants are 20%, cut flower 9%, cut cultivated greens 2%, materials 8% and foliage 15% (USDA 2015).

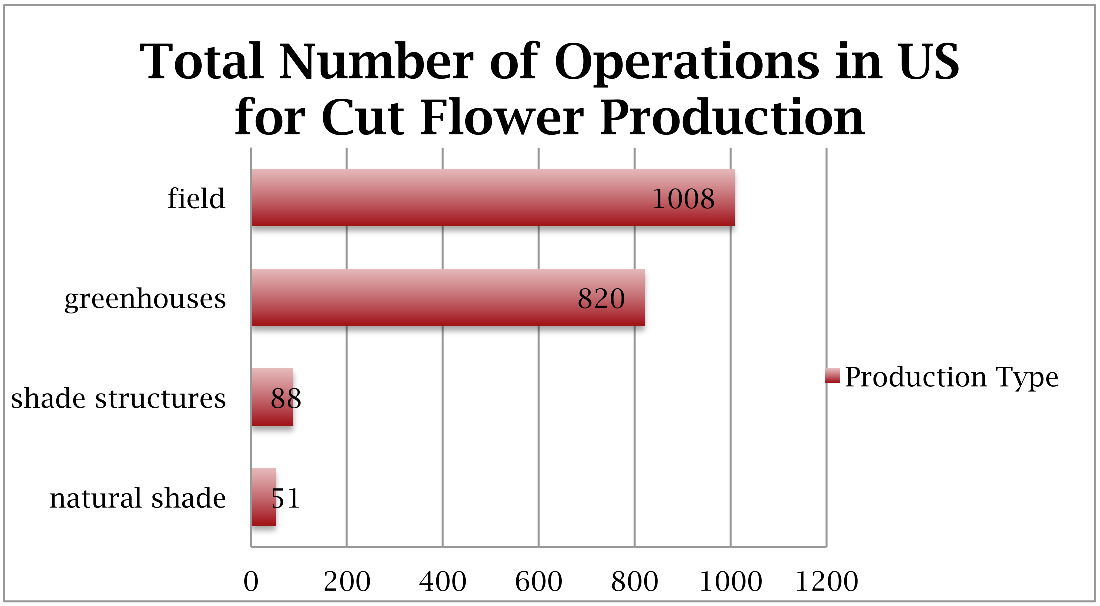

Figure 5: Comparison of number of operations for different production types in cut flower production. Most operations are either field or greenhouse production for cut flowers. Shade structures and natural shade are used little for cut flowers currently (USDA 2015).

There are three main series or cultivars of *C. cristata* on the market for cut flower production: the 'Chief' series, the 'Bombay' series and 'Spring Green'. Other notable cultivars are 'Kurume' and 'Supercrest' (Table 1; Kieft-Pro Seeds 2010; Sakata 2015). Since *C. cristata* is also produced as a potted flowering plant, other cultivars are available such as 'Amigo' and 'Jewel Box'. However, these are not specific to cut flower production as the latter cultivars are (Cornell 2006). The 'Chief' series was developed by the Sakata Seed Co. and is currently produced as seed (Sakata 2015). For three or four years, 'Chief' was taken out of circulation in the US only being available in Japan. After complaints from growers in the US, the cultivar was made available again in 2009 (McKinley and Wright 2010). The 'Chief' series has a height and width of 30cm x 20cm and is notable for produces large, uniform globe-shaped flower heads. They are also highly suitable or production during periods of high temperature. Sakata offers 'Carmine', 'Fire', 'Gold', 'Persimmon', 'Red', 'Rose', and 'Mix' seeds of the 'Chief Series'. These options range in color and growth habit but are all distinguished by the globe-shaped flower head (Sakata 2015). One advantage of the 'Chief' series is that is can be used in both field production and in greenhouses. This is not the case with the 'Bombay' series, which are bred specifically for greenhouse production (Kieft-Pro Seeds 2010).

TABLE 1. Major cut flower Celosia (*Celosia cristata*) cultivars currently on the market and their growth size (height x width), flower type, and the usual production type (Kieft-Pro Seeds 2010; Sakata 2015).

Cultivars on the Market	Plant Height x Width (cm)	Flower Type	Production Type
'Chief' (Sakata)	30cm x 20cm	Globe-shaped	Field/Greenhouse
'Bombay' (Kieft)	70cm-1m x 13cm	Comb-shaped	Greenhouse
'Spring Green' (Kieft)	1-1.2m x 13cm	Comb-shaped	Greenhouse
'Kurume' (Takii)	70cm-1.2m x 13cm	Globe-shaped	Field
'Super Crest' Mix	70cm-1m x 13cm	Mix of Globe and Comb-shaped	Field

Table 1. Characteristics of major cut flower *Celosia* cultivars. The cultivars vary on plant size, flower type and production type. While 'Bombay' and 'Spring Green' are bred for greenhouse production, other cultivars are more commonly used in field production (Kieft-Pro Seeds 2010; Sakata 2015).

The 'Bombay' series has a shorter production time as well as better stress resistance and transportability. The rounded stems and no offshoot flowers allow for high-density production common in greenhouses (PanAmerican Seeds 2015). This high-density production is economically beneficial because growers are able to produce more crops in the same amount of space. The 'Bombay' series have large comb-shaped heads that are offered in a wide range of colors. Ball Seed separates the series into two categories: classic colors and fire colors. The classic colors include a variety of shades of yellow, orange, red, purple and pink. The fire colors are narrower with smaller leaves in comparison to the classic colors and are distinguished by their bicolor inflorescences (Ball Seed 2015). These two-toned flowers are aesthetically pleasing to both retailers and consumers. Along with the producing the 'Bombay' series Kieft Seed Co.

also bred the cultivar ‘Spring Green’. This cultivar is very similar to ‘Bombay’, the only notable difference being the longer height of 1-1.2m (Ball Seed 2015). The cultivars ‘Kurume’ and ‘Super Crest’ are often used in field production and have shown varied success. They are often found to produce smaller flower heads and an overall low yield (NC State 2000). Overall, the cultivars available range in color, flower head shape, stress resistance and yield results.

Figure 6. The difference between the globe-shaped (left) and the comb-shaped (right) cultivars. The image on the left shows the bright inflorescences of the ‘Chief Series’. The image on the right shows the comb-shaped flower of the ‘Bombay Dark Red’ cultivar. (Kieft-Pro Seeds 2010; Sakata 2015).

IV. PROPOSED CROP TRANSFORMATION

A. Crop Production Change(s) for the Future.

To remain economically viable and sustainable in the cut flower market, a change in the production methods is increasingly important. Some of the main problems affecting specialty cut flowers, *C. cristata* included, are growth efficiency during production and post-harvesting protocols (Kieft-Pro Seeds 2010). Improvements in both of these areas could ultimately result in extended vase life of the plant, which would appeal to growers and consumers. Through improving the growth efficiency of *C. cristata* this could potentially reduce the amount of time needed in production. This reduced production time would allow for an overall more sustainable production process by decreasing the energy and water inputs necessary.

Looking at the production of *C. cristata*, one existing challenge faced by growers is when to harvest the plant for optimal vase life and efficiency. As mentioned previously while other specialty cut flowers harvests can occur before full anthesis (flowering), *C. cristata* must wait until the stems become 'woodified' or hardened before the plants can be harvested to ensure the plants are sturdy. This means that the production often extends 3-4 weeks after anthesis (Kieft-Pro Seeds 2010). Growers must decide whether to wait this extra time for full flower maturation and strong stems or harvest the plants early risking resulting in weaker stems but faster production. While cultivars are currently being bred for attributes influencing growth habit, there is a need for further development in regards to early stem and anthesis development that would sufficiently reduce production time. Genetic improvements that produce sturdier stems that mature earlier could potentially allow for plants to be harvested prior to anthesis. While mutations may not be found that are capable of this, breeding could select for these directional changes and create an improved cultivar. Through these changes in growth efficiency, the production time of *C. cristata* could be reduced, which would result in a more energy-efficient and sustainable practice.

B. A New Production Schedule for Your Crop.

Since the proposed transformation of growth efficiency is in genetic improvements and breeding selection, changes in the new production schedule are limited compared to changes in the growing environments. Looking specifically at *C. cristata* grown in the greenhouse, the new production schedule would deviate from the current practices in the total number of weeks to harvest. With the new changes that would create greater growth efficiency, the total production time would occur at approximately 9-13 weeks after sowing compared to the current harvest occurring at week 12-16. This shortened production time is 3-4 weeks earlier due to the fact that this is the amount of time it currently takes for the stems to harden after anthesis (Kieft-Pro

Seeds 2010). With the potential breeding improvements the total production time could be shortened, while still producing durable and quality plants.

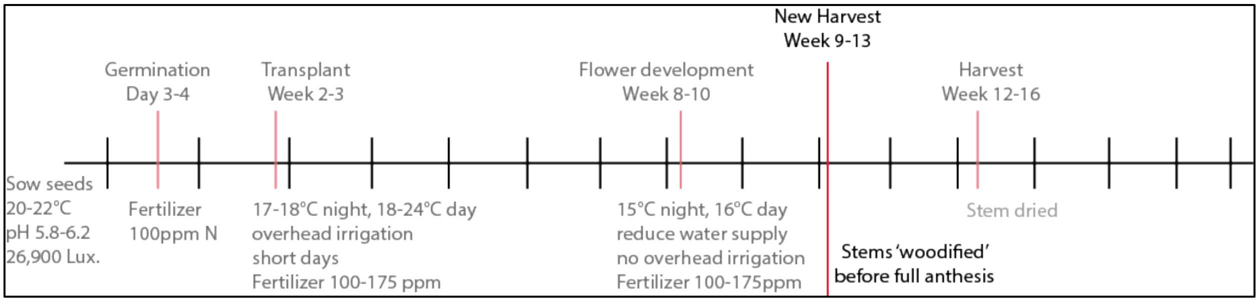

Figure 7. Potential new production schedule for *C. cristata.* The potential genetic improvements have the potential to shorten the time to harvest by 3 weeks. The new harvest date would be at week 9-13 when the stems are deemed durable for post harvest protocol.

Since the proposed changes focus primarily on the growing habits of the stem of *C. cristata*, there would be little to no change in the timing of flower bud initiation or development; the plants would be harvested closer to anthesis as opposed to after. Although it is unknown if this new *C. cristata* cultivar would require differing environmental conditions (i.e. lighting, irrigation, nutrients), based on previous cultivar developments it can be assumed that this new cultivar would not need different requirements (Kieft-Pro Seeds 2010; Sakata 2015). Possible changes in the production of the new *C. cristata* cultivar could result in modifications in post-harvesting protocol and shipping. Since the plants will be harvested earlier this would consequently result in longer vase life. One study showed this relationship between earlier harvest date and longer vase life; it found that stems of 'Fire Chief' *Celosia* harvested with flower heads <2 cm in diameter had a vase life 14 days longer than stems with flower heads >5 cm in diameter (Ahmad and Dole 2014). In current shipping there are challenges with the breaking of stems; the new changes have potential in limiting this problem by creating more durable plants that can handle the stress of transportation.

C. The New Crop Ideotype.

By examining and identifying the important traits and production characteristics of *C. cristata,* a new crop ideotype can be established based on the proposed change of growth efficiency. This new crop ideotype and the proposed traits are selected based on these characteristics that would allow *C. cristata* to thrive in controlled environment production. This desired ideotype of *C. cristata* has the potential to result in genetic improvement and overall desired phenotype that can be grown (Anderson et al. 2006). One important trait that breeders need to consider in the new ideotype is a faster growth rate. Selecting species that demonstrate a faster growth rate would be beneficial because it allows for an overall shorter production time; the faster the species is able to grow, the less time and resources are required. This would mean selecting species that exhibit early flower bud initiation and development (McKinley and Wright 2010). In cut flower production, this would mean that the consumers are able to obtain the product earlier in the season. Another possible advantage of faster growth rate is the possibility to grow a larger quantity of plants. With a faster turn around rate, more plants can be grown and more profit can be achieved. This shorter production time would also benefit the consumers due to a possible lower price value. Negative consequences of a faster growth rate, may include shorter overall height due to the shortened internode elongation periods (Anderson et al. 2006). With an important factor of cut flower production being stem length, further studies and research for this trait need to look more closely at how faster growth rate could affect the overall visual quality and stem elongation of *C. cristata*.

Since one of the main goals of cut flower production is this long stem length, one trait to be aware of is the durability and strength of stems. Many cultivars currently on the market, including the ‘Chief series’ and ‘Bombay’, are already described as having more durable stems, but more improvements can always be made. The round stems of these cultivars create a more durable stem compared to other cultivars (PanAmerican Seeds 2015). More durable stems are advantageous during production because they can withstand greater flower density and allow for greater stem elongation (PanAmerican Seeds 2015). Having these round stems is also beneficial because it allows for greater stress resistance and good transportability. The stronger stems are able to withstand more movement in shipping, therefore reducing overall breakage of flowers during shipping (Kieft-Pro Seeds 2010). While these current cultivars of *C. cristata* are able to produce more durable stems, they are still susceptible to growth disturbances caused by fluctuations in the environmental conditions. Low light intensity, short days and low temperatures are found to cause flat stems in many cultivars of *C. cristata* (Kieft-Pro Seeds 2010). In future breeding, looking for and selecting for cultivars that exhibit more resistance to these light and temperature fluctuations could result in more consistent and reliable stems.

Another important trait to consider for the new ideotype is uniform growth habit. One characteristic that breeders could continue to select changes for is the absence of off shoot flowers. Without these off shoots, the plant is able to have a more upright and uniform growth pattern (Kieft-Pro Seeds 2010). Cultivars of *C. cristata* exhibiting this trait would be beneficial because they would produce better quality yields and allow for high-density production (NC State 2000). Similar to the durability of the stems, some cultivars currently available are beginning to demonstrate this uniform growth pattern. There still is need for continued research into the ways production conditions could improve these manipulate this trait to create a more resilient pattern.

These traits of a faster growth rate, stronger stems, better stress resistance, and uniform growth can potentially contribute to the proposed change of increased growth efficiency. A faster growth rate, of flowering and more importantly the stem development, could help *C. cristata* shorten overall production by having the stems harden simultaneously as anthesis. This could be encouraged by the cultivars that have stronger stems resulting in better resistance to stress. Improvements in one or all of these traits could help create the new ideotype that allows for shorter production time. While implantation of these traits of the new ideotype will not fully perfect the production of *C. cristata*, they can possibly help change the production into a more sustainable practice. With further research investigating the pros and cons of each trait and the overall effects, a better understanding of the new ideotype can be achieved and as a result a more sustainable and energy-efficient production of *C. cristata* is viable.

V. ACKNOWLEDGEMENTS

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