# Interspecific Breeding for Warm-Winter Tolerance in *Tulipa gesneriana* L.

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## EXECUTIVE SUMMARY

Focus on breeding of *Tulipa gesneriana* has largely concentrated on appearance. Through interspecific breeding with more warm-tolerant species, tolerance of warm winters could be introduced into the species, decreasing dormancy requirements and expanding the range of tulips southward. Additionally, long-lasting foliage can be favored in breeding to allow plants to store more energy for daughter bulbs. Continued virus and fungal resistance breeding will decrease infection. Primary benefits are for gardeners and landscapers who, under the current planting schedule, are planting tulip bulbs annually, wasting money. Producers benefit from this by reducing cooling times, saving energy, greenhouse space, and tulip bulbs lost to diseases in coolers.

# I. INTRODUCTION

## A. Study species

Tulips (*Tulip gesneriana* L.) are one of the most historically significant and well-known horticultural crops in the world. Since entering Europe via Constantinople in the mid-sixteenth century, the Dutch tulip market became one of the first "economic bubbles" of modern civilization, creating and destroying fortunes in four brief years (Lesnaw and Ghabrial, 2000). Since this time, tulips have remained extremely popular as more improved cultivars are released. However, a problem remains: even though viral resistance and long-lasting cultivars are introduced, few are capable of surviving in a climate with truly mild winters and only select cultivars are able to store enough energy for another year of flowering, even in climates with colder winters. Current planting schemes suggest planting annually, wasting tulip bulbs (Dickey, 1954).

The problem is that little focus has been placed on tulip breeding as a landscape plant, both because of breeding for use as a cut flower crop and its unreliability in perennial gardens. Therefore, temperate tulips should be selected for longer and later flowering, as well as greater foliage retention and bulb regeneration to become more adaptable in perennial flower gardens, with a secondary goal of *Rhizoctonia* (both *R. solani* and *R. tuliparum)* resistance, which can decimate tulip populations (Schneider et al., 1997). Additionally, species from milder climates where winter soil temperatures remain above 5°C should be favored for this development of cultivars suitable for planting in more tropical environments. Finally, tulip virus-resistance breeding is necessary to continue to improve tulip virus resistance.[1]

### *i. Longer and later flowering*

Despite *T. gesneriana* being known for their early, cheery flowers, later flowering cultivars would be beneficial in three ways: the decreased likelihood of frost, more high-quality developed stems, and more consistent flowering. Frost likelihood after emergence of tulips is extremely likely, as they often surface before the final frost date. Hard frosts or even freezes during this period pre-flowering post-emergence sometimes causes flower stems to be permanently bent or deformed, often resulting in flower abortion. Later emergence prevents this by avoiding the frost date and allowing the stems to develop fully, ensuring the plant's ability to replicate for the next season (Gill et al., 2013).

### *ii. Foliage retention and bulb regeneration*

Frequently, old stands of tulips (depending on the cultivar, two to ten years old) lose their vigor and cease flower production, instead producing a "blind" stem (one that has only one emergent leaf). Often, this is due to insufficient sunlight, premature dieback or physical removal of tissues, or simply adverse conditions. The ephemerality of tulips makes planting them a gamble on their conditions; if the stem is even slightly damaged, the tulip plant will likely no longer flower. If tulips could retain their foliage for longer periods, more starches could be stored in bulbs,

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[1] Historical breeding has focused mostly on Tulip virus X (TVX) and breaking viruses such as Tulip breaking virus (TBV), top-breaking virus (TTBV) and Rembrandt breaking virus (TRBV) (Lesnaw and Ghabrial 2000).

increasing the vigor of flowers in subsequent years, making tulips more likely to return and flower perennially (FIG I).

### *iii.* Rhizoctonia *resistance*

In wet conditions, *Rhizoctonia* is particularly aggressive, especially to the tender tulip bulbs. Resistance could be found in tulip species native to wetter environments, particularly in western Turkey and far northern Africa and in small, wetland-edge ecosystems throughout Turkey and Iraq. Tulip bulbs produce a sclerenchyma shell or tunic around the bulbs annually to protect themselves from pathogens that they outgrow each year. Some of the species from wetter environments likely have a modified coating that would be able to ward out water as well as the bacteria and fungi that it conveys.

### *iv. Warm-winter tolerance*

Warm-winter tolerance likely is the most difficult goal to achieve in tulips. Although tulips are native to a large band geographically, many of the tulips in arid regions lie within high-altitude climates that maintain lower soil temperatures than the arid plain. The outliers that lie in lower elevation or, more importantly, warmer ecosystems, could be valuable for such breeding as would likely be better adapted for areas that rarely cool down in the winter.

### *v. Continued viral resistance*

As is important with any recurring viral or fungal disease, constant vigilance by the grower is key to prevention. New cultivars should aspire to not only equal but also improve on the resistance of past cultivars to maintain a lead on virus mutations and new viral and fungal threats.

## B. Taxonomic classification and geographic distribution in the wild

### i. *Genus*

*Tulipa* is a genus within the family *Liliaceae* that includes wild species of tulips native to northern Africa to China, surrounding the Mediterranean and extending north into Southern Russia, as well as the mountainous areas of the Middle East (Pavord, 1999). It is one of the few genera of true tunicate bulbs.

### ii. *Subgenus*

The genus *Tulipa* contains four subgenera: *Tulipa*, *Eriostemones*, *Clusianae*, and *Orithyia*. *Tulipa* and *Eriostemones* were the original two subgenera, with *Tulipa* divided into five subcatergories and *Eriostemones* into three sub-subgenera, and these groups divided further (Southern, 1967; Zonneveld, 2009). However, Zonneveld et al. (2009) proposed the last two subgenera, *Clusianae* and *Orithyia*, and recommended abolishing the second-tier divisions within the original subgenera since many tulip hybrids crossed these divisions.

### iii. *Species*

The study species, *T. gesneriana* L., is logically categorized in the subgenus *Tulipa* (Christenhusz et al., 2013; Zonneveld, 2009). This specific species seems to be originally endemic to the plains of Turkey, but through centuries of diaspora, has colonized areas throughout Europe and parts of North America (Govaerts, 2008; Kartesz, 2014). This species represents cultivated tulips, which are spilt into groups by classification by their specific crosses (*cf.* Table 1).

### iv. *Invasiveness*

Few cultivars—save specialized new and heirloom tulip cultivars—have the potential to colonize. However, the species *T. clusiana* and *T. sylvestris* are already naturalized into a few niches. *T. clusiana* is reported in Riverside County, California, U.S., and *T. sylvestris* is reported in a handful of counties in the States of Pennsylvania, Maryland, and Massachusetts, as well as areas of Michigan, Illinois in the U.S. and the Province of Ontario in Canada (Kartesz, 2014). Both of these species could be considered either invasive or naturalizing, depending on the context and site. No searchable invasive list specifically qualifies either species as invasive.

### *v. Ideal Conditions*

*Tulipa* spp. often requires uncommon conditions to thrive. Since they usually come from temperate arid grasslands of central and Mediterranean Afro-Eurasia, tulips thrive in chilly (sometimes-freezing) 5±10°C (40±20°F) winter temperatures with plentiful rain (Ahrens, 2003). In summer, the plains dry down; the tulips become completely dormant while the temperatures rise and the precipitation plummets. They can be extremely well adapted to locations with mild springs and autumns, and only require summers to be dry and warm (Sytsma and Rose, 2015).

These conditions vary significantly from species to species, although most require the basic conditions above: hydration in winter, growth in spring, dieback in summer, and root growth in fall. For example, the *T. clusiana*, which thrives in Riverside, California, USA (USDA Zone 9b), prefers much warmer conditions and does not require cold winters to regenerate inflorescences. It thrives in the Northern Mediterranean climate of California, possibly making it a candidate for breeding for warm-winter tolerance (Kartesz, 2014).

## II. CROP HISTORY

### A. Breeding & domestication

#### *i. Tulips in the East*

Tulips have had a long and laborious travel from their native land. Most scholars cite the mountainous ranges of the Tien Shan and Pamir Alai as the origin of the genus *Tulipa*, citing the extreme genetic variation in the area (Wilford, 2006). Through the millennia, tulips have moved across the Afro-Eurasian subcontinent, spreading into Gibraltar, India, into Western Mongolia, into Greece, Italy, and even Spain (Pavord, 1999).

#### *ii. Tulips in the Middle East*

Often referred to as the origin of the tulip, the Middle East played a huge role in the breeding and development of the Tulip. Turkey is known as the origin of the garden tulip, *Tulipa gesneriana*, as the numerous sultans of the area made it the quintessential flower of the Ottoman Empire. The sultans helped boost the tulip to become a futures market, nearly the first of its kind, even before the more common "Tulipomania" in the Netherlands in the $17^{th}$ century. Growers bred for long, pointy petals, making their tulips look completely foreign from the Dutch and Western European varieties. It was during this period that the western breeders were beginning to cause a stir in the European market (Pavord, 1999).

#### *iii. Tulips in Europe*

Aside from normal Western appropriation of culture and flowers, European breeders manipulated the tulip to fit around their "cultured" image. Rounded petals were the norm, and flowers became more subdued, but still showy. Dutch colonization, though waning, allowed importation of gold, silver, gems, silks, and other luxury items, expanding purchasing power in the region. Newfound popularity of tulips became the outlet for the excess gilders, and a discovery of a new type of tulip—the "broken" tulip—propelled the markets even further. Futures were traded for bulbs not even released yet (Day, 2004). A wealthy merchant apparently paid 2500 gilders for a single Viceroy tulip—equivalent to the annual output of a good-sized farm. A single broken 'Semper Augustus' tulip was sold for twice that.[2]

#### *iv. Tulips in the Modern Age*

Nowadays, tulips are seen as a triumph of Man over Nature. Sold in vast quantities for nearly all seasons, tulips show the sophistication of growers and popularity of the bulbs. They have become a mainstay in temperate gardens throughout Europe and the Americas, used for every holiday from December to June. Tulips have even crept into the forest landscape of both America and Europe, creating a new group of tulip species, *neo-tulipae*.

## III. PRODUCTION INFORMATION

### A. Current production practices

Current production of tulips for cut flower is straightforward: a 60-day cold period is best for early and vigorous flowering to stimulate bud formation followed by finishing in a cool greenhouse or similar structure (Cocozza Talia, 1973). Three main methods of planting cut flowers are used: field planting, greenhouse pot, and hydroponics.

The easiest of these is field planting, as the bulbs can simply be placed with fertilizer and antibiotics into the soil. However, the tulips must be timed perfectly to be ready for market by

[2] "Money & Power: The History of Business" (Means, 2001).

spring, which is difficult to predict, especially in atypical winters. It is the most feasible for farmers with large portions of open fields in climates with light winters.

Two kinds of pot production are primarily used for tulips and are sorted by their target finishing date, with a third schedule for finishing during the December holidays. The earliest tulip cycle, used for holiday decorations, are not common in the United States, i.e. poinsettias (*Euphorbia pulcherrima*), amaryllis (*Hippeastrum* spp.), and paperwhites (*Narcissus* 'Ziva') are far more common. For Valentine's Day and early Easter sales, a steep temperature drop and long cold treatment are used, while the later spring schedule slowly acclimates to the 4°C cooler before it is removed for production (Cocozza Talia, 1973; De Hertogh, 1996; Flamingo, 2011; Gill et al., 2013); see Fig. 3-5 for precise scheduling information.

The third and most suitable method for flexible cut flower production is hydroponic growth. Precooled bulbs (usually 9°C) are placed carefully on egg-carton shaped crates (Gill et al., 2013). These crates are placed on trays containing a nutrient solution that is stagnant, flowing, or misting (Flamingo, 2011). The water level is filled to the bottom of the bulb and the bulbs are allowed to form roots, then either moved to a cooler for a finishing treatment or a cool greenhouse at roughly 9°C (Flamingo, 2011; Gill et al., 2013). This allows plants to have very little spacing and maintain an acceptable height.

For all three methods, few plant growth regulators (PGRs) prove useful. Flamingo suggests drenching plants with 5-10 ppm Bonzi immediately after removal from cooler. Other applications are unnecessary, as the plant typically remains compact when given acceptable greenhouse conditions. Gibberellic Acid (GA) is often applied on bulbs in experiments to simulate cold treatments, but this is rarely as successful as a cold treatment.

## B. Current production statistics

Tulips have long been an important worldwide crop. At their peak, they were more valuable than gold, to the point where paintings by famous artists might fetch a comparable sum. Through modern developments of tissue culture, mechanization, and hybridization, tulips have been sped up to pass quickly through production. In 2013, the Netherlands had 10349 ha of tulips growing in fields, both for dry bulbs and for flowers, making up 72.8% of spring flower production (Hanks, 2015). Nearly 161 million stems of tulips were sold in 2014, with an average price of 36.5¢/stem, totaling $58.7 million. Major production (greater than $100,000 gross wholesale sales) is confined to 15 states, of which only California, Oregon, and Washington do not withhold data (USDA, 2015).

## IV. TABLES AND FIGURES

Table 1. *Tulipa* Classes, flower/time, size, and notes (Jauron, 1998; Van Engelen, 2015).

| Type | Flower/*Time* | Size (height) | Remarks |
|---|---|---|---|
| | *Early* | | |
| Single Early | Very early flowers | 25-45cm | Sweet scent |
| Double Early | 10cm diameter double | 30cm | Less range of colors |
| Greigii | Contrast with foliage | 20-30cm (up to 50) | Striped or mottled foliage |
| Kaufmanniana | Lotus-like | 10-20cm | Long lived perennials |
| Fosteriana/ Emperor | Huge flowers | 35-50cm | Long lived Perennials |
| Species | Varies. | 10-40cm | Long lived Perennials |
| | *Mid* | | |
| Darwin Hybrid | Vibrant flowers | 50-75cm | Unreliable Perennial |
| Triumph | Shapely | 20-60cm | Darwin x Single Early; great for forcing |
| Parrot (late) | Fringed and scalloped flower | 35-55cm | Unique flowers, great cut flower |
| | *Late* | | |
| Single Late | Uniform | 50-75cm | Consistent, reliable; great cut |
| Double Late | "peony" flowers | 30-50cm | Easily damaged |
| Vindiflora | Green remains on sepals/tepals | 30-50cm | Cut flowers, bedding |
| Lily-flowering | Petals flare out on top | 40-60cm | Long-lasting flowers |
| Fringed | Lacy edges | 40-65cm | Lacy addition to arrangements |
| Rembrandt | "Broken" flowers | 45-60cm | Virus-free breaks |
| Multiflowering | Produces at least four flowers per stem | 40-50cm | Great for unique cut flowers |

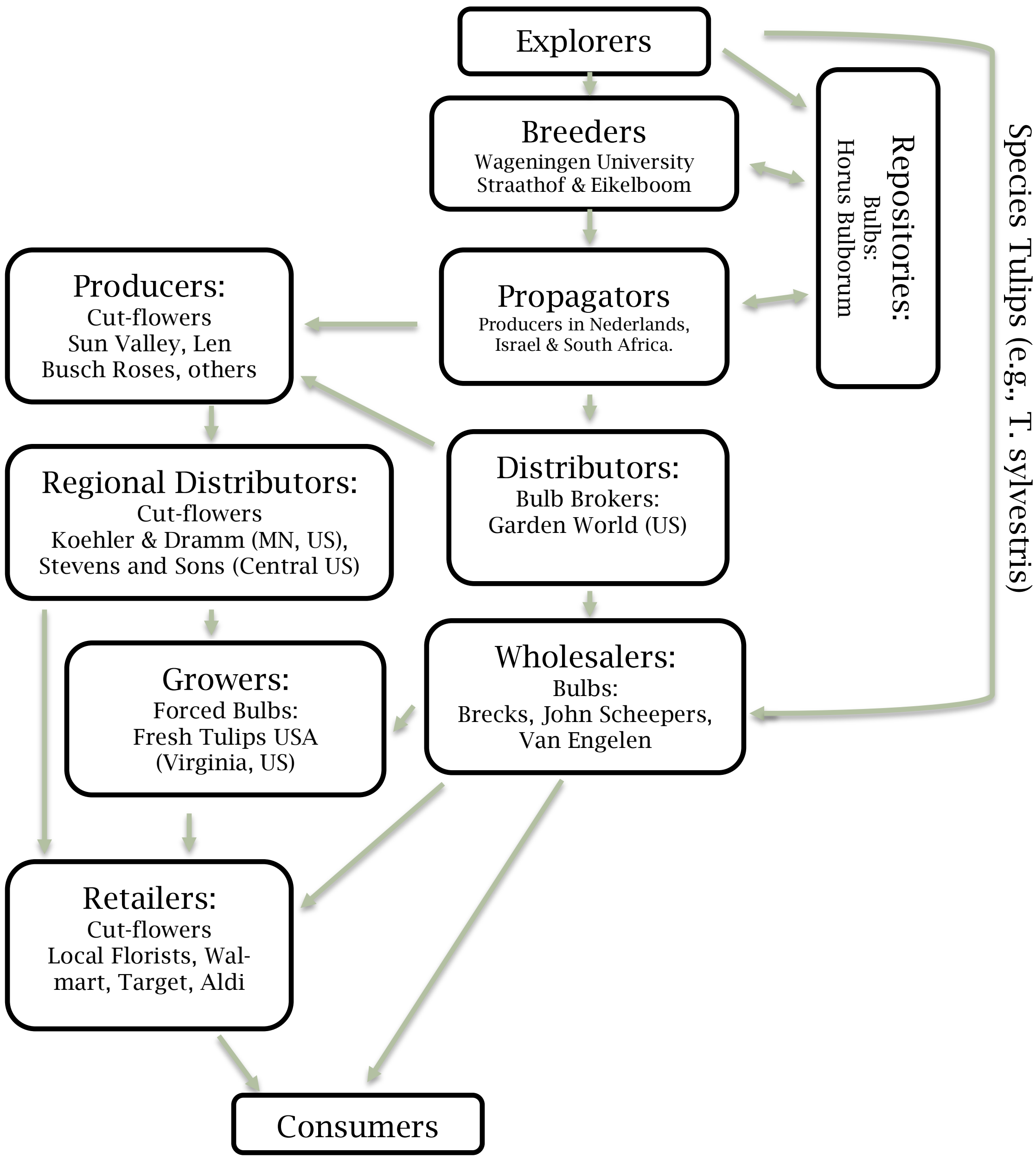


*Figure 2*

Tulip Horticultural Distribution Chain (modified from Drew et al., 2010).

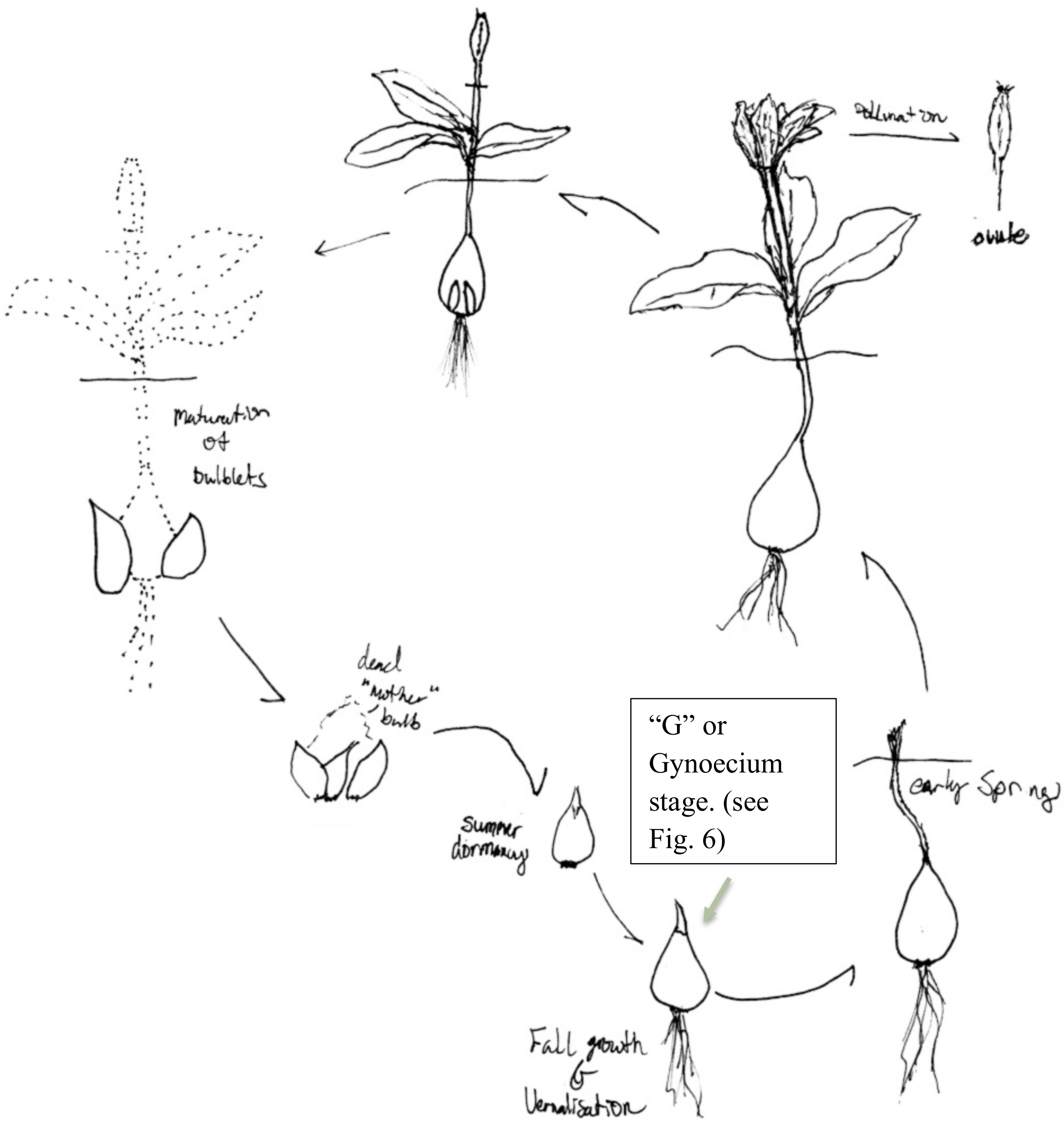


*Figure 3*

Diagram showing the annual growth of *Tulipa gesneriana* (Credit: Author)

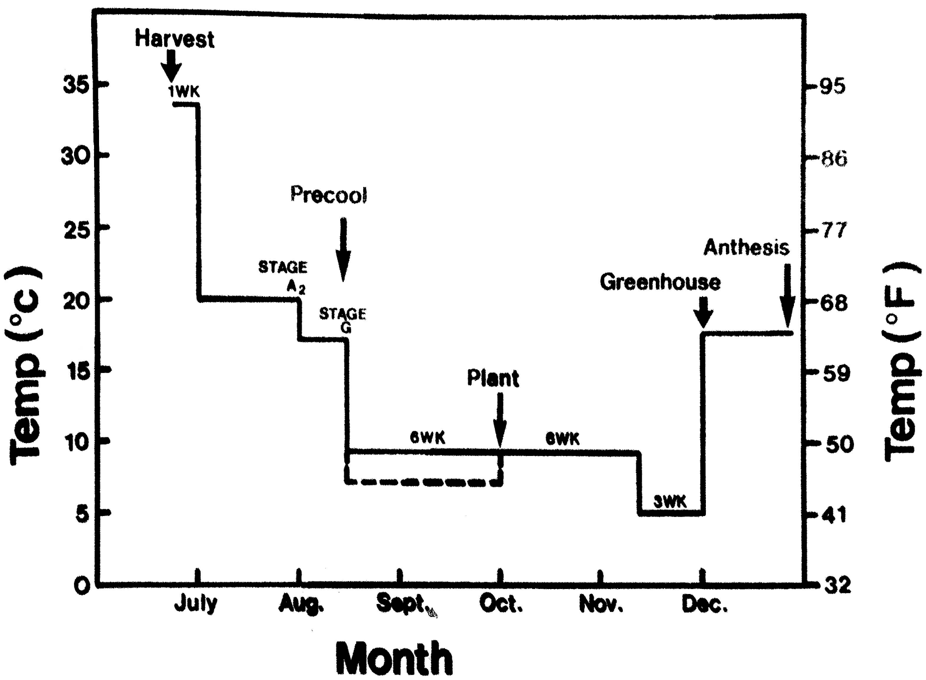


*Figure 4*

Standard forcing for December/January (winter holidays) flowering (De Hertogh, 1996).

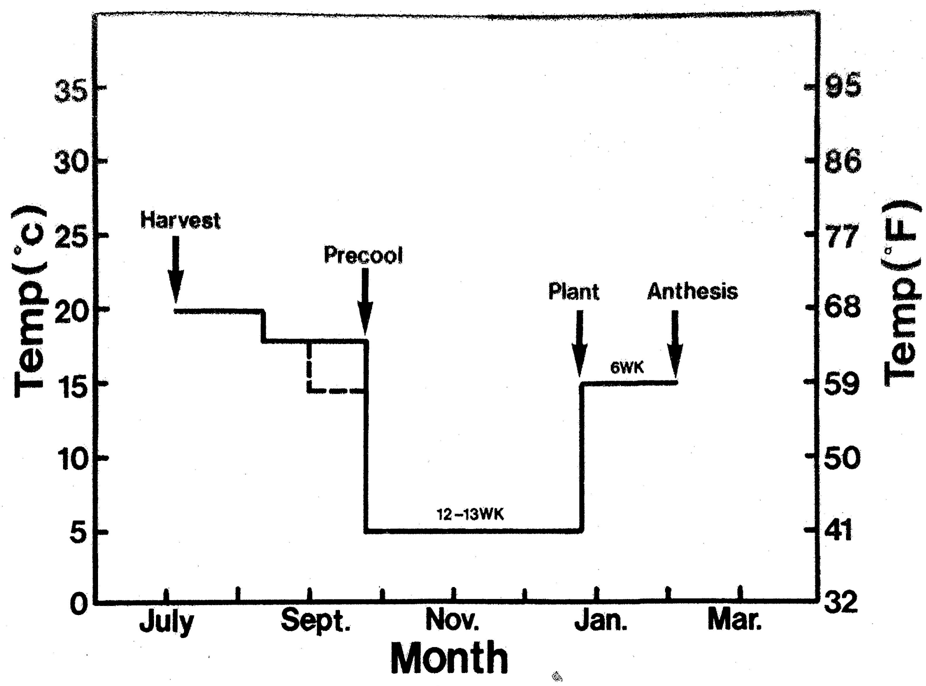


*Figure 5*

Standard forcing for mid-February (Valentine's Day or early Easter) flowering (De Hertogh, 1996).

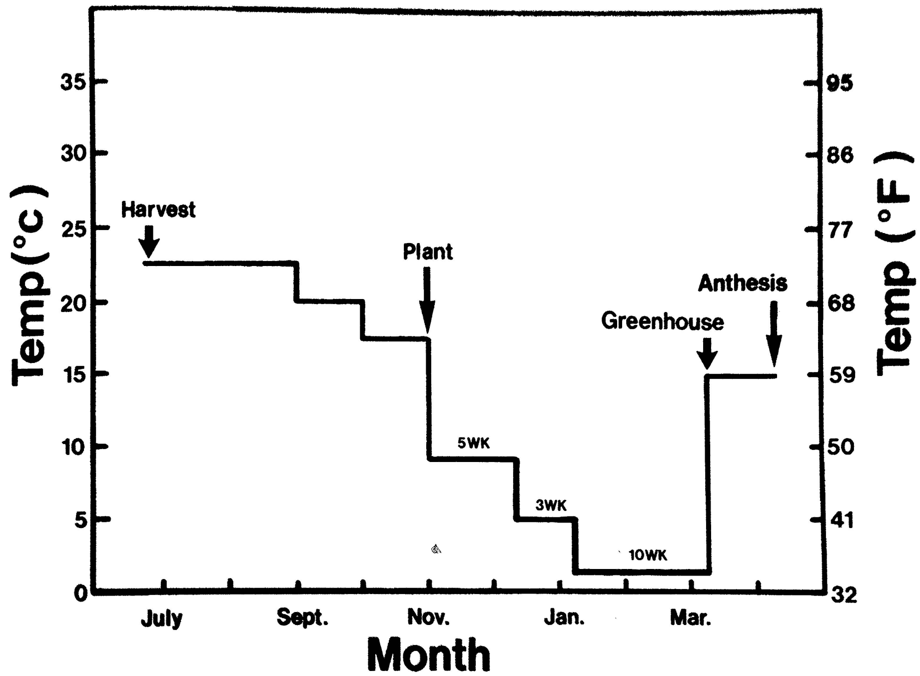


*Figure 6*

Standard forcing for Mar/April (late Easter, Mothers' Day) flowering (De Hertogh, 1996).

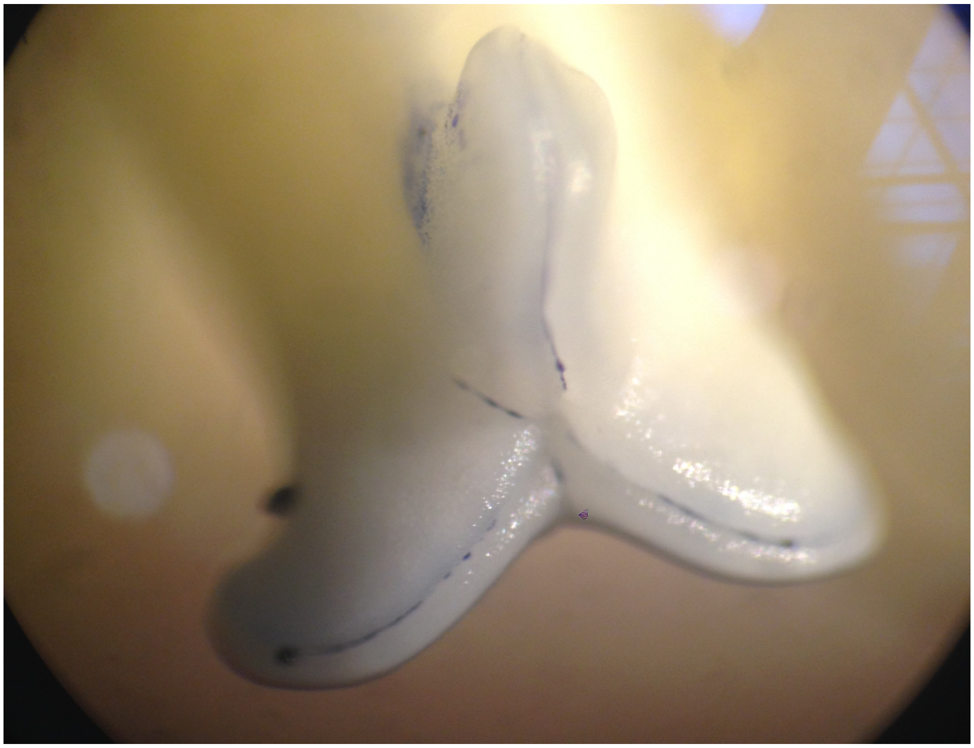

*Figure 7*

Photo of stigma at bulb “G” (gynoecium) stage (credit: Author).

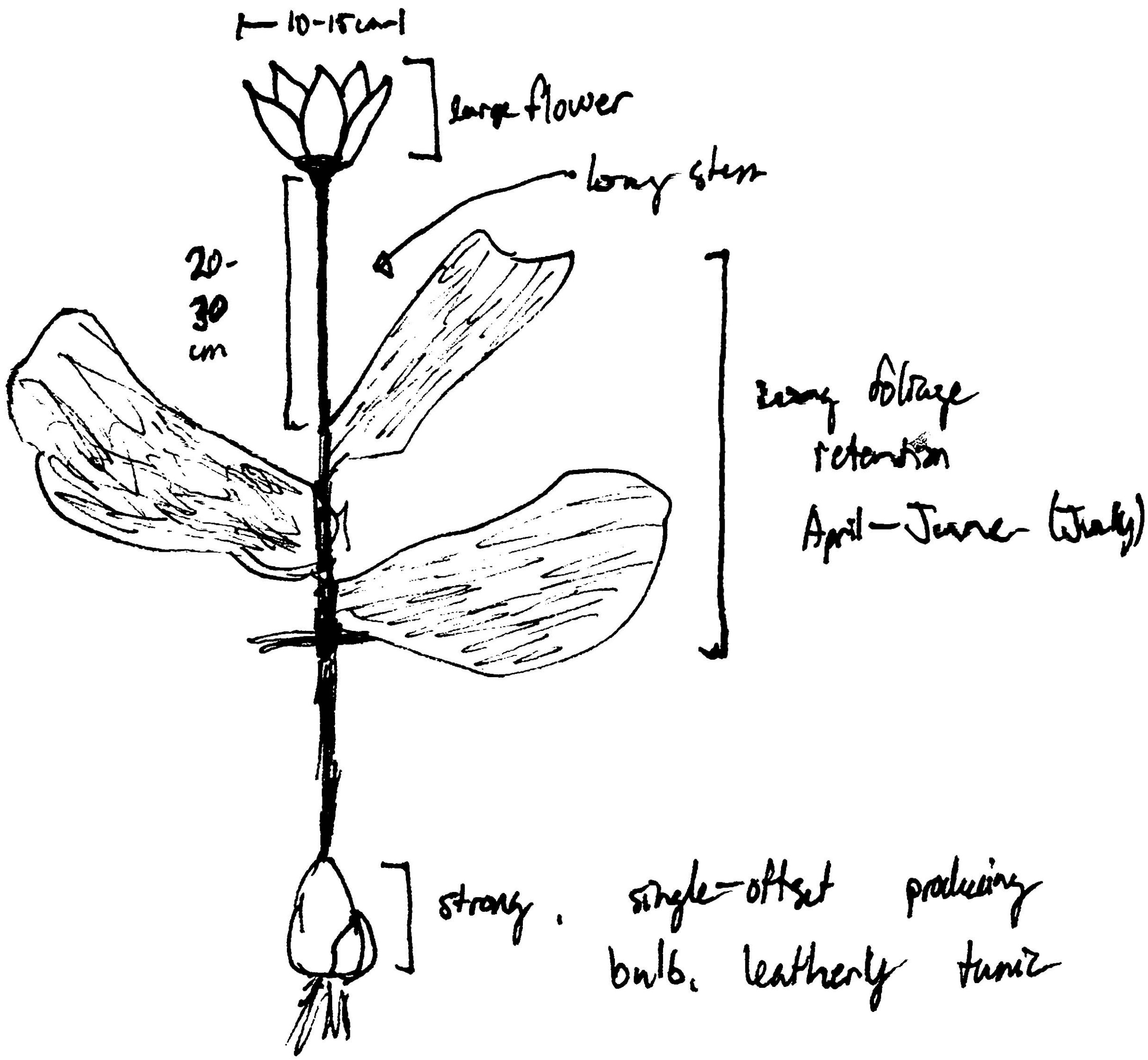


*Figure 8*

The new tulip ideotype (credit: Author).

## V. PROPOSED CROP TRANSFORMATION

### A. Crop production change(s) for the future

One of the largest problems with tulip breeding is the lack of interest in breeding for landscaping tulips. Most cultivars that survive perennially were originally grown by Dutch cut flower breeders and were discovered to be able to grow as herbaceous perennials. Additionally, tulip growers are able to replace bulbs cheaply, spending money on new bulbs to avoid pests, disease, and the general decline of second-year crops. However, if more growers were able to grow tulips that could survive perennially, less money would need to be spent on replanting and replacing field stock. There are three major problems with this proposition. Firstly, the method of harvesting would need to change completely. Flowers are harvested swiftly by plucking up the entire stem from the inside of the bulb. This is problematic as it eliminates the plant's only chance for regeneration. However, if late-flowering cultivars were field-grown, the longer stem would negate the need to pluck off the entire organ, leaving the base leaves behind to regenerate for next year.

The second problem is diseases. Tulips are extremely susceptible to many diseases, especially *Botrytis, Rhizoctonia*, and *Fusarium* (Flamingo, 2011; Schneider et al., 1997). These magnify in soil after years of cultivation. Ideally, tulips would produce a shell that would protect, at least partially, against these invaders. Breeding with leathery species, such as *T. clusiana* or *T. praestans*, can introduce resistance to viruses and fungi.

Thirdly, flowers in tulips tend to diminish rapidly after the first year, both in quality and quantity. As the bulbs multiply, they slowly lose the vast starch reserves that large bulbs have. To prevent this, tulips must be bred to produce fewer offsets or even grow from the same bulb every year. Perennialization of the bulb would make it much easier for plants to regenerate annually.

Lastly, tulips require extensive cold periods to flower, which are infrequent in the southern United States. Breeding with species with greater ability to overcome short winters would increase their profitable range in the United States and allow them to become a common part of the Southern Garden.

## B. A new production schedule for Tulips

Changing the winter schedule for cooling would be beneficial to many areas in the production community. Growers would be able to produce tulips with much less delay than is presently required, saving space in coolers and greenhouses. By breeding with species that have less quiescence, tulips could be made to lose a significant amount of their dormancy. For example, for mid-February flowering schedule, the 10-12 week cooling period could be reduced to 6-10 weeks or less.

Retention of foliage is also important for growing tulips that can maintain themselves, since tulips retain their foliage for just as long as they did in the wild, even though they have much more energy-intensive flowers. If tulips were bred to keep their foliage for two weeks to a month longer, bulbs would have a much greater chance of producing offsets and naturalizing into garden spaces. This would give the added benefit of allowing bulb producers to shorten their production cycles (usually up to five years) to just three or four years. In the future, tulips could even be annualized for flowers in the following spring, when planted in May.

### C. The new crop ideotype

The ideal growth habit and flowering schedule for these new "hot hybrid" tulips would be much like their Northern counterparts: Large, symmetrical flowers with at least four inches of stem from the top leaf to the base of the flower. However, unless the petals were specifically bred to remain round, the species tulips would likely influence the shape and make the petals slightly pointy (Fig. 7). Ideally, the cycle for garden and landscape growth would remain the same except for their smaller winter requirement: half the length of dormancy in cold, an extra 2-4 weeks of foliage retention in the spring, later flowering, and disease resistance.

The new crop is designed to give gardeners around the world the chance to grow one of the most beloved flowering crops with fewer problems and inconveniences. The goal is to achieve an extremely low-maintenance plant, and breeding with species varieties of tulips can help achieve this, making perennial tulips available to gardeners and producers everywhere.

## VI. ACKNOWLEDGEMENTS

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