

**T.C.
AKDENİZ ÜNİVERSİTESİ**



**BREEDING OF HYBRID MALE-STERILE ORNAMENTAL SUNFLOWERS
AND EVALUATION OF THEIR ORNAMENTAL POTENTIALS**

Oğuzhan GÜNAYDIN

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This thesis was accepted by the jury on 26/05/2025 with unanimity / ~~majority~~ vote.

Prof. Dr. Songül Sever MUTLU (Advisor)

Prof. Dr. Faik KANTAR

Assoc. Prof. Dr. Hasan PINAR

ABSTRACT

BREEDING OF HYBRID MALE-STERILE ORNAMENTAL SUNFLOWERS AND EVALUATION OF THEIR ORNAMENTAL POTENTIALS

Oğuzhan GÜNEYDİN

MSc Thesis in Department of Agricultural Biotechnology

Supervisor: Prof. Dr. Songül Sever MUTLU

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Sunflower (*Helianthus annuus* L.) was solely used as an ornamental plant until the 18th century. It is used in landscaping as a border plant and in combination with other ornamental plants, both indoors and outdoors. Sunflowers are also used as potted ornamental plants and as cut flowers. Vase life is considered as a significant selection criteria for cut flower breeders and sterile varieties have a longer vase life in comparison to fertile varieties due to the reduced ethylene synthesis. Ornamental sunflower has a wide range of colors such as purple, orange, yellow, light-yellow, red-brown, white, and lemon-yellow colors. The objective of this study was to investigate male-sterile ornamental sunflower hybrids for vase life, flower colors, and plant structures. In this context, A (CMS) and B (maintainer) lines developed using CMS method within the scope of TUBITAK project 122R004, resistant to Sulfonylurea group herbicides, were crossed and male-sterile hybrids were obtained. Morphological traits such as flowering time, germination time and rate, branching status and position, flower head attitude, plant height, stem length, flower head diameter, stem diameter, disc diameter, ray flower characteristics, pollen fertility, leaf size and color, the color of the ray flowers (petal) and disc flowers (sexual flowers) were investigated to determine the ornamental potential of the hybrids obtained. The results demonstrated that the vase life of 31 variety candidates varied between 9.2 and 14 days. The vase life of commercial varieties used for control/check ranged from 8 to 11 days. These results were achieved without any vase solution indicating that variety candidates exhibited high quality, robust plant structures, genetic superiority, and high market potential. Furthermore, according to the observations conducted to determine the ornamental potential of hybrid variety candidates, it was concluded that 15 candidates were suitable for outdoor ornamental plants in landscaping areas and public spaces, 12 candidates were found to be desirable for cut flower purposes, and, four dwarf-type candidates were determined to be suitable for use as potted plants. Within the investigation of ray flower color inheritance studies, the ray flower color of male-sterile hybrids were compared with parental lines. The results indicated the dominant colors and which parental combinations should be used in crosses to obtain the desired ray flower color. It was observed that yellow color was dominant over orange and lemon colors, and several color variations such as purple, red, lemon and apricot colors were achieved by crossing parental lines with different gaillardia tones. Red, orange, lemon, and reddish-brown, exhibited genotypic recessiveness and were phenotypically less prevalent in the majority of hybrids. This study highlighted important features on the inheritance of ray flower color traits in ornamental sunflowers, providing directions in achieving desirable color variations in ornamental crops. It also provided important and useful informations for hybrid breeding projects in the development of ornamental

sunflower variety candidates and achieving various colors and tones suitable for the market.

KEYWORDS: CMS, Cut flowers, Floral color inheritance, Hybrid development, Ornamental plant breeding, Ray flowers, Vase life

COMMITTEE: Prof. Dr. Songül Sever MUTLU

Prof. Dr. Faik KANTAR

Assoc. Prof. Dr. Hasan PINAR



ÖZET

HİBRİT ERKEK KISIR SÜS AYÇİÇEKLERİNİN ISLAHI VE SÜS BİTKİSİ POTANSİYELLERİNİN DEĞERLENDİRİLMESİ

Oğuzhan GÜNAYDIN

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Danışman: Prof. Dr. Songül Sever MUTLU

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Ayçiçeği (*Helianthus annuus* L.), kesme çiçek, saksılı süs bitkisi ve peyzaj düzenlemelerinde yaygın kullanılan önemli bir süs bitkisidir. Vazo ömrü, kesme çiçek ıslahçıları için önemli bir seleksiyon kriteri olarak kabul edilir. Son yıllarda geliştirilen kısır çeşitler, etilen sentezinin azalması sebebiyle fertil çeşitlere kıyasla daha uzun bir vazo ömrüne sahiptir. Ayçiçeğinde, oldukça yaygın sarı dilsî çiçek renginin yanında mor, turuncu, açık-sarı, kırmızımsı kahverengi, beyazımsı, ve limon sarısı renklerde geniş bir renk yelpazesi mevcuttur. Bu çalışmanın amacı, yerli erkek-kısır süs ayçiçeği hibritlerinin süs bitkisi olarak kullanım potansiyelleri ve vazo ömrünün belirlenmesi, ve dilsî çiçek renk kalıtımının incelenmesidir. Bu kapsamda, Akdeniz Üniversitesi'nde TÜBİTAK-122R004 nolu proje kapsamında sitoplazmik erkek kısırlığı (CMS) sistemiyle geliştirilen ve Sülfonilüre grubu herbisitlere dayanıklı A (CMS) ve B (maintainer) hatları melezlenmiştir. Elde edilen 31 adet erkek-kısır hibritin süs bitkisi potansiyellerini belirlemek amacıyla; çimlenme süresi ve oranı, dallanma durumu ve pozisyonu, bitki boyu, yaprak büyüklüğü ve rengi, çiçeklenme zamanı, dilsî çiçek özellikleri, polen verimliliği, çiçek tablasının çapı ve duruşu, çiçek sapı uzunluğu ve çapı, dilsî ve disk çiçeklerinin rengi gibi morfolojik özellikleri ve vazo ömrü değerlendirilmiştir. Geliştirilen çeşit adaylarının 9.2 gün ve 14 gün arasında değişen vazo ömrüne sahip olduğu belirlenmiştir. Kıyas amacıyla kullanılan ticari şahit çeşitlerin vazo ömrü ise 8 ve 11 gün arasında bulunmuştur. Bu sonuçlar, herhangi bir vazo çözeltisi kullanılmadan elde edilmiştir. Bu durum, elde edilen çeşit adaylarının kaliteli ve güçlü bir çiçek yapısına sahip olduğunu, genetik olarak üstün ve yüksek pazar potansiyeline sahip olduklarını göstermektedir. Geliştirilen çeşit adaylarından 15 tanesinin dış mekân süs bitkisi ve 12 tanesinin kesme çiçek olarak değerlendirilebileceği ve bodur tipteki dört çeşit adayının ise saksılı süs bitkisi olarak iç mekânlarda ve küçük bahçeler için kullanıma uygun olduğu belirlenmiştir. Geliştirilen hibritlerin dilsî çiçekleri renk açısından melezlemelerde kullanılan ana/baba hatların renkleri ile karşılaştırılmıştır. Elde edilen sonuçlar ulaşılmak istenen hibrit ayçiçeği dilsî çiçek rengine hangi renge sahip ebeveyn hatların kullanılarak ulaşılacağını ortaya koymuştur. Sarı rengin, turuncu ve limon rengine baskın olduğu, farklı gaillardia tonlarındaki ebeveyn hatların melezlenmesiyle mor, kırmızı, limon ve kayısı rengi gibi çeşitli renk varyasyonlarının elde edildiği tespit edilmiştir. Melezleme çalışmalarında dilsî çiçek renklerinin dağılımı, ebeveyn kombinasyonlarındaki baskın ve çekinik özelliklere göre belirli bir kalıba uymuştur. Sarı renk baskın olup hibritlerde sıklıkla gözlemlenmiştir. Kırmızı, turuncu, limon ve kırmızımsı kahverengi gibi diğer renk grupları ise genotipik olarak resesif olup, çoğu hibritte fenotipik olarak daha az sıklıkla gözlemlenmiştir. Bu çalışma, süs ayçiçeklerinde dilsî çiçek renginin kalıtımıyla ilgili önemli verileri ortaya koymuştur. Ayrıca, süs ayçiçeğinde yeni çeşitlerin

geliştirilmesi ve pazar talebine uygun renk varyetelerinin elde edilmesi için yürütülen ıslah programlarına katkılar sunacağı düşünülmektedir.

ANAHTAR KELİMELEER: Dilsı çiçek, Hibrit geliştirme, Kesme çiçek, Renk kalıtımı, Sitoplazmik erkek kısırlılığı, Süs bitkisi ıslahı, Vazo ömrü

JÜRİ: Prof. Dr. Songül Sever MUTLU

Prof. Dr. Faik KANTAR

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PREFACE

This master's thesis was prepared as part of TUBITAK project 122R004 titled "Biotechnology Aided Development of Ornamental Sunflower Lines". The main subject of this thesis was outlined in the project as a follow-up study to be conducted after the official project duration. This master's thesis is expected to contribute to the scientific knowledge in ornamental plant breeding and shed light on future research.

I would like to express my heartfelt appreciation to my advisor Prof. Dr. Songül Sever MUTLU, for her kind and valuable guidance and the opportunities she provided for my academic and professional growth. I would also like to express my deepest gratitude to Prof. Dr. Nedim MUTLU, for his helpful suggestions, support, and knowledge, which contributed greatly to my master's thesis. It is difficult to express just how grateful I am for their generous support and guidance throughout this journey.

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ACADEMIC DECLARATION

I declare that this study titled “BREEDING OF HYBRID MALE-STERILE ORNAMENTAL SUNFLOWERS AND EVALUATION OF THEIR ORNAMENTAL POTENTIALS” which I submitted as a Master’s Thesis, was written under academic rules and ethical values, and I have shown the source of all information that does not belong to me in this thesis.

26/05/2025

Oğuzhan GÜNAYDIN

Signature



SYMBOLS AND ABBREVIATIONS

Symbols

% : Percentage

° : Degree

bp : Base Pair

C : Celsius

cm : Centimeter

g : Gram

h : Hour

L : Liter

m : Meter

M : Molarity

mL : Milliliter

mm : Millimeter

V : Volt

μl : Microliter

Abbreviations

AFLP : Amplified Fragment Length Polymorphism

AHAS : Acetohydroxycarboxylate synthase

ALS : Acetolactate synthase

ANOVA : Analysis of Variance

ATP : Adenosine triphosphate

BC : Backcross

CMS : Cytoplasmic Male Sterility

CTAB : Cetyltrimethylammonium Bromide

DNA : Deoxyribonucleic acid

EDTA : Ethylenediamine Tetraacetic Acid

HCL : Hydrochloric Acid

IMI : Imidazolinone

K : Potassium

LSD : Least Significant Difference

Min : Minute

N : Nitrogen

NaCL : Sodium Chloride

P : Phosphorus

PCR : Polymerase Chain Reaction

pH : Potential of Hydrogen

RCBD : Randomized Complete Block Design

Rf : Fertility of restoration

RFLP : Restriction Fragment Length Polymorphism

SCAR : Sequence Characterized Amplified Regions

SSR : Simple Sequence Repeats

SU : Sulfonylurea

TBE : Tris-borate-EDTA

TRAP : Target region amplification polymorphism

TRIS : Tris (hydroxymethyl) aminomethane

UPOV : The International Union for the Protection of New Varieties of Plants

USDA : United States Department of Agriculture

UV : Ultraviolet Radiation

WG : Weighable Granules

A dot (.) is used as decimal separator in this thesis (e.g. “21.01”).

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1. INTRODUCTION

Sunflower (*Helianthus annuus L.*), a member of Asterales order, takes its name from its heliotropic mechanism. In addition to its importance as an oil crop, bird seed, and snack seed, it is also known for its use as an ornamental plant throughout the history, with its introduction to Europe by Spanish explorers (Putt, 1978). Sunflower, in German, *Sonnenblume* and in Spanish, *Girasol* refer to the same meaning in both languages. The yellow color, which is frequently seen in sunflowers, has become a symbol in weddings, celebrations, graduations, and various other occasions. The size of the plant and the impressive beauty of the inflorescence made this plant extremely valuable.

They are easy to grow and do not demand high labour in greenhouse conditions. Sunflower grows in almost all regions since it is not selective with regard to the type of terrain (Mladenović et al., 2016). The possibility of growing four times a year with varieties that reach the flowering stage in a short time makes year-round production possible. They are used in interior landscaping as potted plants and in gardens and various public green areas as border plants. Oil-type and ornamental sunflower breeding have reasonably different selection criterias (Mladenović et al., 2020). Ornamental sunflower breeders commonly consider criterias such as plant height, robust and compact plant structure, disease and herbicide resistance, ray flower (petal) color and flowering time rather than quality and quantity of the seeds (Atlagić et al., 2005).

Recently, ornamental sunflower varieties with different plant structures and flower colors have gained popularity in the ornamental plant market. In landscaping, parks, and gardens, varieties with a plant height of 50-170 cm and branching characteristics are commonly preferred. The branching trait is particularly critical for outdoor use, as it enhances the visual appeal of the plants over a large area. In addition, dwarf genotypes with small leaves, with an average plant height of 35-50 cm and short flowering period have been developed through breeding studies, making sunflowers highly desirable in the potted ornamental plant industry. In potted sunflowers, branching is present along the entire stem or basal (Jocić et al., 2015). These types of sunflowers are grown in greenhouses and transported to florists before blooming (Cvejić et al., 2025).

Sunflower floral structure consist of ray and disc flowers. Ray flowers are sterile without anthers. However, disc flowers are fertile, located in the center of the flower (Cvejić et al., 2010). Among the ornamental sunflower varieties used as cut flowers, sterile varieties have a longer vase life compared to fertile varieties. Pre-harvest treatments including fertilisation, irrigation, and growth regulators; harvesting factors including time and stage of harvest; and post-harvest treatments such as pre-cooling, pulsing solutions, preservatives and storage, define the post-harvest longevity of numerous cut flowers (De et al., 2015). To extend the longevity of cut sunflowers, it is expected for disc flowers to be sterile. Fertile varieties not only cause unwanted stains in floral arrangements but can also trigger allergic reactions in individuals with pollen allergies (Armitage, 1993). With the development of varieties with longer vase life, sunflower has become a very important ornamental plant with increasing economic importance in the cut flower industry. The discovery of cytoplasmic male sterility in sunflowers (Leclercq, 1969) provides a crucial tool for hybrid seed production. The CMS system enables the efficient production of hybrid varieties by eliminating the need for labor-intensive manual emasculation which is time consuming. Aside from the fact that

CMS is very cost-effective, it has also been adopted in a wide range of horticultural crops. This breakthrough has profound applications in commercial sunflower breeding, enhancing productivity and uniformity in hybrid seed crops. The CMS system also contributes to the development of sterile ornamental sunflower hybrids, which is a significant criterion sought in cut sunflowers, and to reach the desired place in the market.

The yellow color that first comes to mind when thinking of sunflowers is attributed to carotenoid pigments present in chromoplasts (Yue et al., 2008). However, due to its genetic diversity, ornamental sunflowers exhibit a remarkably wide color spectrum. In addition to various shades of yellow, some varieties exhibit orange, lemon yellow, red, red-brown, and purple coloration in their pseudo-ligulate (petal) flowers (Miller & Fick, 1997; Cvejić et al., 2016). Furthermore, the development of multi-colored varieties has expanded the use of sunflowers as ornamental plants. In addition, color variations in disc flowers, together with anthocyanin-containing varieties, have become common in outdoor and indoor use. The resulting color variation in ray flowers, is mostly determined by the interaction of genes regulating the synthesis of anthocyanin and carotenoid pigments. In recent years, progress in breeding studies has made it easier to determine the dominant color trait in ornamental sunflowers by combining parental lines with different pseudo-ligulate flower colors. This development has led to significant progress in increasing genetic diversity and achieving desired color traits in a more manageable way.

The aim of this study was to evaluate male-sterile ornamental sunflower hybrids developed through controlled crossing of different A and B lines in terms of vase life and plant characteristics that could potentially be used as cut flowers and for landscape arrangements and to determine the dominancy status of ray flower color trait.

2. LITERATURE REVIEW

Ornamental plants are known for their ability to thrive in a wide variety of environments and climates, as well as for their variety of colors, sizes and shapes. They are cultivated for their beauty, the positive energy they add to their surroundings and their visual appeal, which makes them a popular choice for creating aesthetic charm in gardens and landscapes. Ornamental plants are utilized in indoor spaces, outdoor settings, and landscaping areas for a wide range of purposes. Floriculture and landscaping focuses on the cultivation and management of plants for ornamental purposes in gardens, parks and public spaces (Kakkar & Lal, 2024). It also includes floral design and nursery production. Ornamental plants are primarily cultivated for aesthetic and commercial value.

Ornamental plant breeders focus on enhancing traits such as vivid flower colors, plant structures, and resistance to environmental stresses, diseases or pests. These improvements make ornamental plants suitable for landscaping, floriculture, and indoor decorations. Selection has historically been a primary method in ornamental breeding. Ornamental plant breeders carry out the identification of different traits that they find suitable for plant, the selection of parental lines, and the improvement of the desired traits using advanced technologies. Additionally, breeders aim to meet consumer demands, such as developing compact, long-flowering period, and post-harvest durability, ensuring their appeal in both domestic and commercial markets. One of the most widely used techniques is hybridization, which involves selection of different species or varieties to combine desirable traits (Datta, 2022). In recent years, breeding studies on ornamental sunflowers enabled the development of varieties with different floral color and flower structures for various uses, making ornamental sunflowers increasingly important in the ornamental plant market.

2.1. Origin and History of Sunflower

Sunflower (*Helianthus annuus* L.) belongs to the Asteraceae (Compositae) family, and it is native to North America. The genus *Helianthus* contains 51 species, involving 14 annuals and 37 perennials (Heiser et al., 1969; Schilling & Heiser, 1981). The word *Helianthus* is derived from the Greek word “helios” meaning sun, and “anthos” meaning flower. The base chromosome number of the genus *Helianthus* is $n = 17$.

Sunflower was cultivated by Native Americans in Arizona in the middle of the Bronze Age (National Sunflower Association, 2015). Sunflower seeds were roasted and consumed by Native Americans and used to extract the oil. They also used leaves for medicine, and tribe societies used pollen for ceremonial purposes (Heiser, 1951). Later on, it was spread to provide food to the humanity (Heiser et al., 1969). According to Wilson (1917), natives of North Dakota ate sunflower seeds as food. In Russia and Eastern European countries, it has been the primary resource for edible vegetable oil for generations (Putt, 1978).

In the 1700s, sunflower became a snack food that traveled from Western Europe to Egypt, Afghanistan, India, China, and Russia using trade paths (Putt, 1997). Cultivation for oil purposes happened at the end of the 1770s (Semelczi-Kovacs, 1975). Spain guided the first social interactions between Europe and North America. Therefore, it is logical to believe that the very first sunflowers were brought to Spain by early Spanish explorers,

along with Italy and France (Putt, 1997). After its introduction to Europe, the sunflower was cultivated exclusively as an ornamental plant for almost 250 years (Vrânceanu, 1977).

2.1.1. Sunflower as an Ornamental Plant

Sunflower derives its name from its “solar-tracking” behavior, a phenomenon known as heliotropism. Similarly, in French, the word *tournesol* comes from Old French, where *tourner* means “to turn” and *sol* means “sun,” reflecting the way sunflowers turn toward the sun. Schaffner (1900) stated that the flower head tilts 60 to 90 degree west in the evening and 50 to 170 degree east in the morning. During the night, leaf tips orient downward toward the soil surface. The structure of sunflower has unique characteristics. Head of the sunflower, or capitulum, is composed of small florets arranged in a dense, spiral pattern. This structure is supported by a thick stem and surrounded by bracts, which forms a composite inflorescence (Figure 2.1).

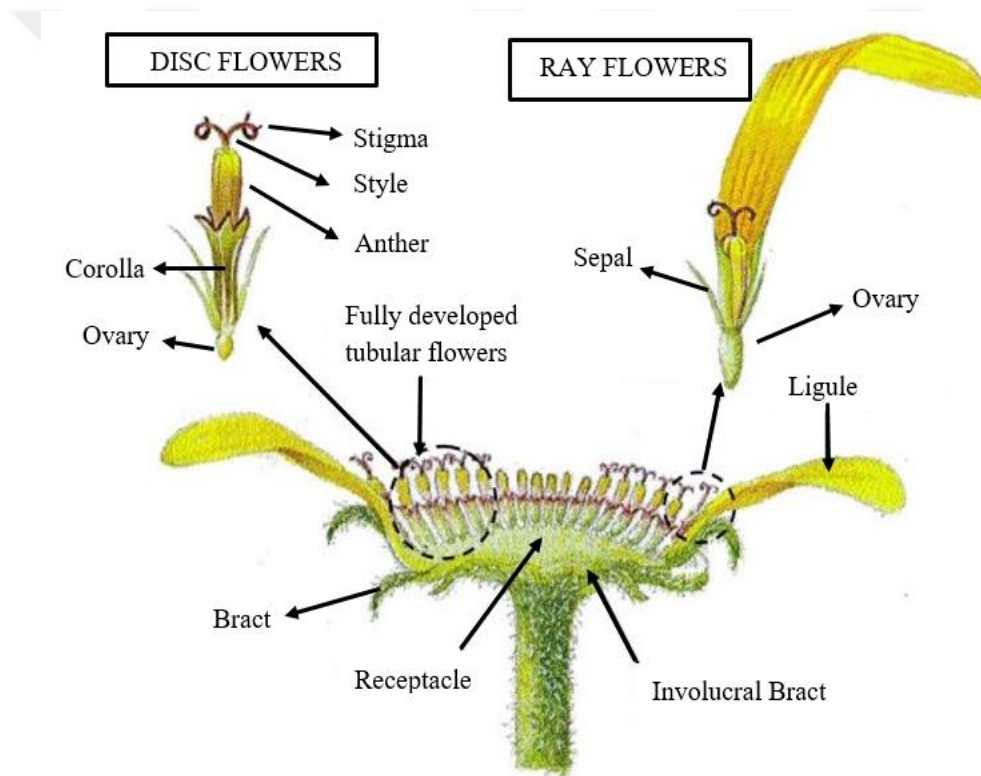


Figure 2.1. Anatomy of Sunflower Inflorescence

Sunflower is widely recognized as an appealing option in the ornamental plants sector due to its aesthetically pleasing characteristics and durability. Ornamental sunflowers are considered cut flowers, outdoor ornamental plants and potted decorative plants according to their purpose of use (Miklic et al., 2008). Because of its exquisite blossoms, ability to be arranged in pots, and ability to be cut and used in bouquets and arrangements, decorative sunflowers become progressively more important in the flower industry as opposed to numerous alternative ornamental plants (Melgares, 2001; de Moura et al., 2022). Numerous sunflower cultivars exhibit quick growth, with certain

types flowering in short time as 50 days. Additionally, many of these cultivars have the ability to produce multiple branches, enhancing their overall productivity and visual appeal (Cutler, 1997).

2.1.2. Usage as a Cut Flower

Cut flowers can be used for gift purposes and can be presented to the loved ones for various reasons to express passion, admiration, or apology (Yue & Hall, 2010). The main purpose of cut sunflower cultivation is to obtain as many functional and utilizable flowers as possible per unit area (Miklic et al., 2008; Kaya et al., 2012). Cut flower dealers and customers tend to avoid flowers with bent stems. There are different sunflower genotypes as cut flowers according to the intended purpose of use. When used as cut flowers, tall sunflower cultivars should have straight and strong stems and non-branching genotypes are frequently used in this context. Additionally, branching genotypes are also preferred in the case of “all along the entire stem” types. In non-branching genotypes, the flowers should be large in diameter and resistant to lodging, while in branching varieties, the central flower diameter is recommended to be smaller, with even smaller side flowers (Cvejić et al., 2010). Genotypes with 60-70 cm long lateral branches along the entire stem are recommended for cut flower purposes. Short et al. (2017) and Howard (2017) investigated the market potential of cut sunflowers, in the case of consumer demands. Specialty cut flowers were initially very common but have fallen out of popularity in the flower industry due to their inadequate vase life (Yue & Hall, 2010). Therefore, the studies are mainly focused on the longevity of the vase life of cut sunflowers in different preservative solutions (Devecchi, 2005; Kılıç et al., 2020; Ezz et al., 2021; AbdelRahman, 2022). Additionally, the determination of the optimal spacing between plants has been extremely effective in the studies carried out to determine its ornamental potential as cut flower in terms of plant structure, characteristics, and flowering (Süzer, 2010; Ferguson et al., 2012; Mladenović et al., 2020; Silva et al., 2018; Tomasi et al., 2024). In 2005, cut flower varieties have become more preferred in the market (Yue & Hall, 2010). In 2006, the wholesale value of cut flowers amounted to \$400 million, particularly in the United States (USDA, 2006b).

2.1.3. Usage as an Outdoor Ornamental Plant

Ornamental sunflowers are also used as outdoor decorative plants in parks and gardens. Landscape gardening involves the use of various garden designs and techniques to enhance landscapes, which are shaped by personal preferences and existing tools (Bailey, 1911). Outdoor plants are most sought after for their vigorous growth, extended flowering period, and optimal height, which combine to enhance both their beauty and overall performance (Cvejić et al., 2017). Sunflower cultivars developed for landscape designs display traits including resistance to low temperatures and diseases, mostly caused by humidity and wind. Kaya et al. (2012) reported that the height of these genotypes/cultivars usually ranges from 50 cm to 170 cm. The most important trait for this purpose of use is branching. Cvejić et al. (2017) analysed four ornamental sunflower inbred lines and reported that while branching was observed in all of the lines, there were considerable variations in the number and the length of branches. Putt (1964) reported dominant and recessive genetic controls of branching trait and suggested that branching is recessive and monogenically inherited. Hockett & Knowles (1970) reported a more complex inheritance of branching and introduced two new recessive genes, b_2 and b_3 ,

which caused branching along the entire stem when present as recessive homozygous genes, and determined that apical branching was induced when only one of these two genes was present. Nenov & Tsvetkova (1994) indicated that branching trait in wild sunflower species is regulated by dominant genes, whereas the branching of cultivated sunflower species is determined by recessive genes. Non-branching genotypes may fail to create a noticeable impact in large spaces such as parks and gardens. Therefore, branching genotypes are a better choice, as they can effectively cover vast areas and provide a more aesthetically pleasing appearance. In order to create harmony and contrast effects in landscape designs, varieties with yellow and orange colors and tones are frequently preferred. In recent years, ornamental sunflowers in a variety of colors and shades have been used in roadside strips, borders, and landscaping areas, creating visually stunning and harmonious combinations with other ornamental plants, significantly enhancing the aesthetic value and beauty of these spaces.

2.1.4. Usage as a Potted Ornamental Plant

Another major field of ornamental sunflower is potted plant cultivation. Plant height is one of the most important selection factors in potted ornamental sunflower varieties. In the late 20th century, the cultivation of sunflowers as potted plants emerged as a significant advancement in ornamental horticulture. Accordingly, in these varieties, it is desired for plants to be dwarf (50-100 cm plant height), to form smaller leaves, to have a short flowering time, and to have a compact structure by branching along the whole stem. Potted ornamental sunflowers require cultural practices such as planting time, pot size, as well as the application of plant growth regulators at the correct doses and methods to achieve optimum growth, plant architecture and aesthetic quality. Studies demonstrated that early planting accelerates flowering while reducing plant height; larger containers promote a more compact plant form, and growing more than one plant in the same container decreases plant size but enhances overall visual appeal (Vernieri et al., 2003; Wanderley et al., 2011). Additionally, paclobutrazol has been found to be more effective in controlling plant height and improving plant uniformity in both studies. The balanced application of these factors, along with controlled irrigation, and fertilizer applications has been shown to be very effective in the studies carried out for optimizing both aesthetics and productivity, therefore providing the best results in the commercial production of potted ornamental sunflowers (Li et al., 2020b). Despite the fact that the heights of varieties suitable for potted sunflower cultivation are proportional, the genetic background of the sunflower should be considered as well. Potted ornamental sunflower varieties should be kept at a visually aesthetic height, and the plant height should be approximately 2 times higher in comparison to pot size in length (Pallez et al., 2002).

2.2. Ornamental Sunflower Cultivation and Practices

Sunflower, in Europe, is only cultivated during spring. However, it can be cultivated and marketed all year round under ideal climatic conditions. Its wide range of colors, ability to be grown at least four times a year, short harvesting time, and ability to adapt quickly (Nascimento et al., 2016) contributed to the increase in demand for sunflowers. Ornamental sunflower cultivation possesses significant economic potential for year-round production in greenhouses, including during the winter season, while open field cultivation is only limited to spring and summer seasons in many regions (Garfinkel & Panter, 2014; Altman & Streitz, 1996). Additionally, sunflower growth stages are

systematically categorized (Table 2.1) by Schneiter & Miller (1981) and North Dakota State University (2023) to provide an understanding of the plant development, which is important for effective cultivation and management.

Table 2.1. Growth Stages of Sunflower

Sunflower	Days after planting	Stage	Definition
	10 days	Vegetative Emergence, VE	Seedling has emerged and the first leaf beyond the cotyledons is less than 4 cm long.
	15-35 days	Vegetative Stages (V-1, V-2, V-3, etc.)	These stages are determined by counting the number of developed leaves at least 4 cm in length beginning V-1, V-2, V-3, V-4, etc. If senescence of the lower leaves has occurred, count leaf scars (excluding those where the cotyledons were attached) to determine the proper stage.
			
	40 days	Reproductive Stages, R-1	The terminal bud forms a miniature floral head rather than a cluster of leaves. When viewed directly above, the immature bracts form a star-like appearance.

(continues on the next page)

Continuation of Table 2.1.

	55 days	R-2	The immature bud elongates 0.5 to 2.0 cm above the nearest leaf attached to the stem. Disregard leaves attached directly to the back of the bud.
	65 days	R-3	The immature bud elongates more than 2.0 cm above the nearest leaf.
	70 days	R-4	The inflorescence begins to open. When viewed from directly above, immature ray flowers are visible.
  	75 days	R-5 (R-5.1, R-5.2., R-5.3, etc.)	This stage is the beginning of flowering. The stage can be divided into substages depending upon the percentage of the head area (disc flowers) that has completed or is in flowering, e.g., R-5.3 (30%) or R-5.8 (80%).

(continues on the next page)

Continuation of Table 2.1.

	85 days	R-6	Flowering is complete and the ray flowers started wilting.
	95 days	R-7	The back of the head has started to turn pale yellow.
	105 days	R-8	The back of the head is yellow, but the bracts are still green.
	125-140 days	R-9	The bracts become yellow and brown. This stage is considered as physiological maturity.

The proper temperature for growth is 21-24°C, and the minimum temperature is required to be 5°C (Melgares, 2001). Otherwise, germination does not occur below 4°C (Alba & Llanos, 1990). On the other hand, high temperatures also have a negative impact on the germination rate and photochemical content (Puttha et al., 2023), while leading sunflower stems to elongate. Sunflowers generally adapt to a wide range of temperatures, from 13-17°C to 25-30°C. However, at lower temperatures, flowering is delayed (Melgares, 2001). Even though the plants can withstand temperatures as low as 6-8°C, lower temperatures can damage the apex of the plant, potentially causing branching of the stems (Alba & Llanos, 1990). Although sunflowers have deep root systems, approximately 60% of their roots are concentrated within the top 0-40 cm of the soil. Ploughing the soil to a depth of 30-35 cm with the help of a tractor, forming raised beds for better drainage in wet conditions, and controlling weeds are advisable. In addition, the growth and overall performance of sunflowers are significantly affected by cultural practices such as the depth at which seeds are sown, the spacing between plants, and the timing of the growing season (Pinkovskyi & Tanchyk, 2021). Most importantly, inorganic fertilizers containing major nutrients such as N, P, and K, as well as balanced application

rates, are critical for optimizing sunflower growth and productivity (Puttha et al., 2023). While ornamental sunflower breeders are more focused on visual appearance, it should be noted that seed size is also important for seed germination (Krstić et al., 2022), which plays a vital role in the plant life cycle, particularly in arid and semi-arid regions where limited water availability can significantly hinder the seed germination process (Toscano et al., 2017). The seed initially develops a root to reach beneath the soil in order to obtain water during emergence. Afterwards, the shoots begin to form (Puttha et al., 2023). Several researches have demonstrated that temperature and water potential have the most effects on the rate and percentage of seed germination, while genetic features such as seed coat thickness and dormancy are also a factor (Sy et al., 2001; Alvarado & Bradford, 2002; Norsworthy & Oliveira, 2006). In dry and semi-arid regions, water stress significantly reduces sunflower oil seed yield by negatively impacting seed germination and subsequent seedling development (Ahmad et al., 2009). Temperature positively influences seed germination up to an optimal degree, after which it negatively affects germination (Steinmaus, 2000), showing the importance of maintaining the most suitable temperature conditions for successful seed germination. Sghaier et al. (2023) identified an optimal temperature range of 15°C to 35°C for sunflower seed germination. Additionally, the germination rate of sunflower seeds decreases under non-suitable post harvest conditions, highlighting the critical importance of proper seed storage. Sunflower seed germination is maintained above 80% during storage in dry cold conditions and refrigerator (El-Saidy et al., 2016; Coradi et al., 2015). Toscano et al., (2017) stated that elevated temperatures coupled with reduced soil water potentials may restrict effective germination processes.

Planting density is highly beneficial in terms of increasing the flower quality. Recent studies demonstrated that morphological traits such as stem length, flower head diameter, and stem diameter varied at different planting densities. Süzer (2010) has stated that high-density planting was associated with increased sunflower height and reduced stem diameter. According to Rajcan et al. (2001), plants use this condition as a way of adapting their habitat in terms of competing for sunshine, a critical resource for photosynthesis. Mladenović et al. (2020) have observed that 25x25 cm planting density resulted in the tallest sunflowers with smallest stems along with flower head diameter. In addition, smaller flower diameters are preferred in the cut flower market, as they enhance their versatility and ease of use in a wide range of flower arrangements and bouquets (Mladenović et al., 2020). In contrast, Wien (2016a) discovered that planting densities of 22x22 cm to 30x30 cm encourages the development of larger sunflower heads, likely due to reduced competition for nutrients and sunlight. Furthermore, Mladenović et al. (2020). emphasized that smaller stem diameters, resulting from lower plant spacing, are particularly beneficial for the commercial production used in arrangements. However, planting density has been found to have no influence on the flowering time (Mladenović et al., 2020). In a study in which the potentials of cut sunflowers at five different planting densities (6x6, 7x7, 8x8, 9x9, 10x10) were analysed, the best results were observed at 8x8 planting density (İçöz, 2019). Ultimately, sunflower is cold-resistant and generally not damaged by the first frosts. Due to their deep root and taproot system, when compared to other decorative plants, sunflowers display better results under drought and salinity stress when appropriate irrigation methods are employed (Puttha et al., 2023). This is a major advantage for sunflower cultivation, especially in regions with limited water resources.

2.3. Morphological Traits Influencing the Potential of Ornamental Sunflowers

According to florists, the standard sunflower stem size ranges from 60-90 cm in length, 0.5-1.5 cm in diameter, and 8-15 cm in flower head diameter for cut flower purposes (Sloan & Harkness, 2006). It is advisable to harvest stems at the longest possible length to optimize their longevity, as their quality is influenced by their length (Curti et al., 2012). Sloan & Harkness (2006) evaluated the morphological traits such as number of stems, time from seeding to harvest, stem length and diameter, and flower head diameter of numerous ornamental sunflower cultivars and demonstrated the variability of these traits at different planting dates. Mladenović et al. (2017) evaluated 81 ornamental sunflower genotypes and observed morphological characteristics such as days to flowering, color of ray and disc flowers, plant height, branching, position of branching, flower head diameter, position of ray flowers, and sterility. Burnett (2017) and Cheema (2018) studied several morphological traits in their studies such as stem diameter which is a crucial trait for cut sunflowers and observed that stem diameter can be reduced by increasing planting density and pinching applications.

Carrillo-Ávila et al. (2015) investigated morphological performances of four ornamental sunflower hybrids such as plant height, leaf length, number of stems, flower head diameter, disc flower diameter, stem diameter, leaf width, and distance between nodes under variable water applications and different fertilization treatments to determine the most proper cultural practices for different market demands. Similarly, Patil (2018), examined several growth parameters to determine the overall performances of ornamental sunflower genotypes for different purposes of use. Commercial appeal of cut sunflowers is significantly shaped by major traits such as flower head diameter and stem length (Cvejić et al., 2017). Ray flower traits including color, shape, and density are also significantly important for market demands of cut flowers. Several researchers have observed the density and the genetic control of number of ray flowers in ornamental sunflowers (Šecero-Fišer et al. 1995; Soroka et al., 2020). Kaya et al. (2012) and Cvejić et al. (2025) recommended that ray flowers should be round, short, and straight, without exceeding the radius of the head, while fully surrounding the head without any gaps in between.

Leaf traits do not necessarily influence the market price of ornamental sunflower hybrids. However, they are very important for garden and pot production (Behe et al., 1999), and the deterioration of quality in cut sunflower leaves, stems, and flowers presents a financial challenge to producers and marketers globally, perhaps leading to market rejection (Tata, 2013). Among the leaf traits, one of the most important parameters that stands out is the small size of the leaves, which is among the demands of the market for usage as pots and bouquets (Cvejić et al., 2025). The intensity of green color in the leaves varies depending on the varieties, showcasing a broad spectrum of colors ranging from very light to very dark shades. Environmental factors can influence leaf size in particular, which varies considerably, from 8 to 50 cm in length (Gundaevev, 1971) with an elliptic, triangular or rounded shape, displaying remarkable diversity of morphological traits. Some genotypes with dark red and purple colors, which contain a high level of anthocyanin in their ray and disc flowers, display dark-colored leaves. In some cases, anthocyanin accumulation can even be observed at the tip of the leaves.

Plant height, which is a critical selection criteria, plays a key role in ornamental sunflower breeding, creating balance between aesthetic appeal and market demand. It is affected by environmental, climatic, and soil conditions. Studies have reported consistent and statistically important variations in plant height between hybrids and parental lines, with heterosis present in each of the hybrid combinations (Cvejić et al., 2017). The dwarfness gene was discovered in wild types and integrated into cultivated types by plant breeders, significantly contributing to the development of shorter and more resilient dwarf sunflower varieties (Kaya et al., 2012).

Additionally, standard height for hybrids varies from 150 to 180 cm. Dwarf varieties, typically between 50 and 100 cm, and semi-dwarf varieties with plant heights of 100 and 150 cm are recommended for patios, balconies, and small gardens due to their manageable sizes and resistance to lodging (Kaya et al., 2012; Hladni et al., 2014), which is known to be a quantitatively inherited trait regulated by both multiple genes with additive and dominant genetic responses (Marinkovic, 1982; Vranceanu & Stoescu, 1971b; Divita et al., 2012; Putt, 1966). In recent years, studies have revealed that plant height inheritance is primarily governed by additive gene action (Ghaffari et al., 2011; Nooryazdan et al., 2011; Machikowa et al., 2011; Tabrizi et al., 2012). However, it is also influenced by both additive and non-additive gene actions, with overdominance being a key factor (Farrokhi, 2008). Regarding the morphological traits such as plant height, stem size, and root system of the plant, lodging is a very complex trait in terms of genetic regulation (Miller & Fick, 1997).

The shape of the sunflower head can vary from concave to convex; in some cases, the head shape can also exhibit a deformation (Miller & Fick, 1997). Head attitude is another significant morphological characteristic that varies depending on the variety, particularly from an ornamental perspective. This characteristic encompasses a spectrum, ranging from horizontally aligned attitude to those that are overturned, where the sunflower head appears to face directly towards the soil (0° - 270°) (Kaya et al., 2012; Miller & Fick 1997). However, the desired head attitude for the aesthetic appearance of cut sunflowers should be between 90° and 135° , representing a position between vertical and inclined head attitude. This angle not only provides the flowers with a more attractive and balanced appearance but also optimizes the proper light. Head attitudes exhibiting a turned down position are generally unsuitable for cut flower production. Meanwhile, in oilseed types, this characteristic is particularly advantageous as it minimizes seed damage caused by birds, making it a preferred trait in such selections (Kaya et al., 2012).

The head diameter of sunflowers exhibits considerable variability, ranging from as small as 5 cm to as large as 50 cm, and it usually ranges from 18-25 cm for standard head diameter (Kaya et al., 2012). However, this size generally is considered desirable in balancing visual appeal, structural stability, and potential yield, especially in oil-type cultivars. Additionally, flower head diameter of 8-15 cm is recommended for cut flower use (Sloan & Harkness, 2006). Alam (1987) reported variations for flower head diameter for ornamental sunflower cultivars. Studies suggested that the flower head diameter of ornamental sunflowers is related to the genotype and environmental influences, similar to the height of the plant (Bonciu et al., 2010; Divita et al., 2012). Although some studies suggest that additive gene action plays a role in the inheritance of the head diameter (Machikowa et al., 2011; Tabrizi et al., 2012), other researchers have identified non-additive gene action as a contributing factor (Hladni et al., 2007; Karasu et al., 2010).

Sunflower breeders must consider planting density, as it plays a critical role in influencing and manipulating head diameter (Kaya et al., 2012). Recent studies provided evidence supporting the influence of planting density on this trait (Süzer, 2010; Wien, 2016b; Mladenović et al., 2020).

Sunflowers require approximately 60-70 days for flowering and 80-100 days to reach physiological maturity (Kaya et al., 2012). According to Miller & Fick (1997), the flowering period appears to be heritable. Flowering time is variable and influences the commercial and aesthetic value of ornamental sunflowers. Studies also suggested that early flowering was dominant over late flowering and mainly controlled by a single recessive gene (Fick, 1978; Jan, 1986). In the study of Divita et al. (2012), morphological traits including flower head diameter, plant height, leaf size, leaf width, length of the petiole, flower head diameter, disc diameter, number of stems per plant, number of ray flowers (ray flower density), and number of days to flowering were observed among sunflower hybrids and their parental lines. Among all the parameters tested, only the days to flowering exhibited no heterosis. Therefore, it was determined that the hybrids required less duration for flowering in comparison to parental lines (Divita et al., 2012).

Sunflower hybrids should reach physiological maturity in a shorter period than 107 days, and also, earliness is important to obtain greater yield. This is due to late-flowering hybrids being more vulnerable to the negative impacts of dry conditions brought on by high temperatures, whereas early-flowering hybrids are better equipped to withstand drought stress (Kaya et al., 2009a). However, Cvejić et al. (2017) and Cvejić & Jocić (2010) reported that in the case of ornamental perspective, sunflowers are ideal for garden use due to their varying flowering times, resulting in a prolonged flowering period in landscape designs while ensuring a constant supply to the cut flower market as a result of combining lines with late and early flowering periods.

2.4. Vase Life of Cut Sunflowers

Vase life is one of the most significant selection factors, defining the commercial performance of cut sunflowers because most cut flowers are imported from the Netherlands, Columbia, Kenya, and Israel, with most locally grown flowers being less efficient in shipping and having shorter vase life (Bogash et al., 2012; Nukui et al., 2004). Sterile varieties, due to their lack of pollen production, contribute to fresher and more appealing floral arrangements. Additionally, they have a longer vase life compared to fertile varieties (Armitage, 1993) and minimize the risk of pollen allergies for customers (Cvejić & Jocić, 2010), making them a preferable choice for commercial and decorative use. Gast (1995) has observed that the vase life of commercial ornamental sunflower cultivars varied between 4-13 days and suggested that a minimum of 10 days is desirable for post-harvest durability.

In order to extend the vase life of ornamental sunflowers, which is a commercially significant trait as a cut flower, post-harvest factors including stem number and recutting, storage temperature rates, and water uptake require detailed investigation (Kalinowski et al., 2023). Ethylene is the only natural plant hormone that can occur in gaseous form and is a well-known aging factor, including flower and leaf senescence (Pal, 2019; Abeles et al., 1992). Since leaves wilt and discolor in 3 to 5 days after harvest, vase life in cut sunflowers is primarily determined by leaf and then flower senescence (Jones et al.,

1993). It is well-established that ethylene performs a highly critical role in ethylene-sensitive flowers (Tripathi & Tuteja, 2007). The production of ethylene can influence cut flowers during transport and storage, resulting in reduced longevity and physiological issues such as petal wilting, senescence, abscission, chlorosis, and epinasty, all of which are influenced by ethylene production (De Martinis et al., 2015). These physiological issues resulting from ethylene biosynthesis are also associated with post-harvest performances of ornamental plants (Ebrahimzadeh et al., 2008). However, the vase life of cut flowers can be extended by vase solutions and pulsing treatments that inhibit ethylene action and decrease the production of hormones. Ethylene synthesis is reduced in sterile sunflower varieties that do not produce anthers, thus prolonging the vase life and the flowering period of cut sunflowers (Cvejić et al., 2010). However, petal senescence also takes place in pollen-free cultivars and is related to an increased ethylene release (Nichols, 1966; Borochoy & Woodson, 1989). Senescence marks the very last stage in the lifecycle of an entire plant. Flower senescence includes a chain of events that are regulated at the tissue and cell units by endogenous signals such as plant hormones, temperature, light, and nutrients (Iqbal et al., 2017). In ethylene-sensitive flowers, senescence is accompanied by ovary development and pollination, leading to the enhanced production of ethylene, which results in petal wilting, abscission, and increased respiration, accompanying the beginning of wilting and the inability of ray florets to reopen (Ebrahimzadeh et al., 2008; Nichols et al., 1983; Halevy & Mayak, 1981; Lawton et al., 1989).

Bacterial and fungal xylem infections are also known to have a negative effect on the longevity and vase life of cut flowers by clogging the xylem vessels, causing severe metabolic changes in the parenchyma cells of the xylem, thus preventing water transportation and preservative solutions (Yadeta & Thomma, 2013; Gomez-Merino et al., 2020). Cut flowers must be able to withstand many weeks in the distribution chain before customers receive the flowers. Therefore, studies have suggested that the resistance to senescence-inducing factors such as ethylene and bacterial infection is essential (Chandler & Cory Sanchez, 2012). Along with most cut flowers, it is xylem that supplies the flowers with water. As a proof, early flower wilting occurs when the xylem is restricted by an interruption at the end of the stem of cut flowers (Van Doorn, 2012). When cut flowers are harvested, they create a disparity between water uptake through the stem and transpiration, when xylem vessels are clogged (Finger et al., 2016). This phenomenon arises from microbial proliferation and tylose production, leading to a balloon-like expansion of the protoplasts in parenchyma cells which are located adjacent to the infected vessels and the formation of substances within the lumen of xylem vessels during vase life (Jedrzejuk et al., 2012; Bonsen & Kučera, 1990).

In sunflowers, stem length, which is an important selection criterion for cut flower breeding, varies from variety to variety. Stems are cut many times throughout the distribution chain to prevent clogging in the xylem and to optimize the length of the stem for appropriate use in bouquets as cut flowers within the post-harvest phase (Mensuali-Sodi & Ferrante, 2005; Dole & Wilkins, 2005). Clogging of the stem vessel system and xylem further increases the water stress and therefore results in a decrease in the vase life of cut sunflowers (Carlson & Dole, 2013). Long vase life refers to the possible adaptation to a long post-harvest transportation. However, it varies depending on the variety. As an example, the vase life of the “Firecracker” varies between 16-18 days on average (Short

et al., 2017). Vase life is directly correlated with stem length. Harvesting ornamental sunflowers at an early stage (R5), which generally takes place when the flowering starts (Naik et al., 2018), increases post-harvest durability and extends the vase life of ornamental sunflower stems. Also, stems harvested at the stage where ray flowers opened with a length of 50-60 cm are recommended to be marketed if they are sold directly from the field at a local market (de Moura et al., 2022; Armitage & Laushman, 2003; Dole & Wilkins, 2005; Curti et al., 2012; Schneider & Miller, 1981). The proper stage to harvest ornamental sunflower cultivars is when the ligules are fully developed and, if possible, remain perpendicular to the capitulum, which reduces damage during transportation (Melgares, 2001). However, it is advisable to conduct necessary trials to establish the proper stage, considering some cultivars or conditions can prevent the ligules from fully developing and limit their aesthetic value.

Armitage & Laushman (2003) and Curti et al. (2012) recommended harvesting ornamental sunflower stems to the longest possible length without compromising their visual appearance for use as cut flowers as a way of improving their shelf life. Longer stems harvested has been shown to absorb more water (Mensuali-Sodi & Ferrante, 2005). Since flowering includes tremendous amounts of cell division and expansion, it necessitates exceptionally excessive water levels (de Moura et al., 2022; Sanches et al., 2019). As bacteria cannot digest the membrane, and the xylem vessels are very small, bacteria cannot pass through the small pores in the membrane.

The physical presence of bacteria clogs the small pores in the membrane through which all the water must pass, along with decomposition products, which are mostly polysaccharides (Van Doorn, 1997). Water uptake usually falls below transpiration rate, leading to symptoms of net water loss such as wilting (Van Doorn, 2012). Early flower wilting can be avoided by either preventing the decrease in water uptake or by reducing the transpiration rate (Van Doorn, 2012). Inadequate water uptake is primarily due to the occurrence of bacteria that cause blockage of the xylem vessels. This problem occurs during the first 2-3 days of vase life (Van Doorn, 1997). The expected lifespan of various flowering plants is associated with the regulation of senescence, a process that differs among species and necessitates the optimization of water relations, limitation of abscission or wilting, management of microorganisms, along with respiration and ethylene production (Da Costa et al., 2021). Water inadequacy resulting from steady reductions in water uptake is strongly associated with petal wilting and flower senescence in most of the species of cut flowers (Da Costa et al., 2021).

Temperature is one of the most crucial post-harvest aspects impacting the overall condition and longevity of cut flowers (Da Costa et al., 2021). Maintaining or exporting plants at low temperatures has been shown to enhance their post-production durability (Halevy & Mayak, 1981). The storage of sunflowers at warmer temperatures had a negative effect on the opening of the flowers, which hindered the reflexing (or backward bending) of the ligules-petal like structures at the base of the ray florets, which led to a smaller flower diameter, as the ray florets did not fully extend as they typically would (Çelikel & Reid, 2002). Shchori & Steinitz (1980) observed that the vase life of cut sunflowers ranges from 9 to 15 days when maintained at 20°C and found that storing at 2-3°C for 5-10 days before placing in the vase had no effect on vase life. Also, Çelikel & Reid (2002) experimented the behavior of cut sunflowers when kept at temperatures between 0-20°C and observed that the respiration of cut sunflowers increased

concurrently with temperature. Therefore, respiration can be used as an effective tool to predict the longevity of vase life under different temperature conditions. Storing cut flowers at low temperatures was found to be the most suitable method for both transporting over long distances and for short-term storage by retail establishments (Da Costa et al., 2021). Çelikel & Reid (2002) found that the vase life of cut sunflowers decreased with an increase in storage temperature. Long-term interaction with undesirable temperatures has a detrimental impact on the overall life expectancy of cut flowers (Çelikel & Reid, 2002). In order to enhance the post-harvest life of cut flowers, the temperature during transport has to be lowered, as respiration has a crucial function in the induction of the senescence process (Finger et al., 2016). It is suggested by Finger et al. (2016) that procedures such as maintenance of water, preventing excessive temperatures, reducing any harm of wounds and infections, and releases from ethylene-generating gas sources help to minimize the deterioration of cut flowers in terms of vase life.

Within ten days at room temperature, Van Doorn et al. (1995) identified the presence of *Pseudomonas* spp., *Acinetobacter calcoaceticus*, and *Alcaligenes* sp., in the cut carnation flowers and stated that the longevity of cut carnation flowers was decreased due to restriction of water uptake by the stem. Vase life of various cut flowers including sunflower appears to be prolonged by pulsing solutions.

Nascimento et al. (2019) evaluated the postharvest durability of “Sunbright Supreme” sunflower. He suggested treating stems with a 4% sucrose pulsing solution in order to improve the longevity and promote proper bud opening. In this context, Ichimura & Hisamatsu (1999) stated that sucrose promotes bud opening and decreases ethylene production by increasing sugars content in cut snapdragon flowers.

The application of both hydrating and preservatives was found to shorten the vase life of cut sunflower cultivars and various other cut flower species (Clark et al., 2010). The treatment with salicylic acid, ascorbic acid, and thiamine in sunflower resulted in increased protein content, as well as enhanced catalase and peroxidase activities, while simultaneously lowering polyphenol oxidase activity and lipid peroxidation in both petals and leaves. Furthermore, vase life showed a positive relationship with the activities of peroxidase, catalase, and protein, but a negative relationship with polyphenol oxidase and lipid peroxidation (Shatoori & Saffari, 2020).

2.5. Breeding of Ornamental Sunflowers and Hybrid Development

Ornamental sunflowers and oil sunflowers have reasonably separate breeding requirements (Mladenović et al., 2020). The breeding program of the ornamental sunflower is focused on the selection of varieties on the basis of flower structure, height, types of branching, number and size of the flower heads, plant morphology, flowering time, and color, according to the intended use (cut flower, outdoor, pot plants) (Atlagić et al., 2005; Cvejic & Jocić, 2010). Each purpose of use has different requirements, such as aesthetic appeal, sterility, disease resistance, plant height, post-harvest durability, inflorescence, stem size, branching, and adaptability to different environments etc. and all of which contribute to increasing the ornamental value as well as the commercial value of sunflowers.

Recently, ornamental plant breeders have considerably improved the ornamental values and adaptability of sunflowers for various uses, not only in terms of a wider diversification of flower forms but also responding to the demands of a specific market. The outcome is that these breeding programs help ornamental sunflowers obtain a better position in the market. Common desirable characteristics of the ornamental sunflowers are resistance to low temperatures and resistance to leaf diseases. The selection of the parental lines significantly impacts the breeding process (Hladni et al., 2010). Qualitative traits display variability, which can be achieved with a genetically wide population in a successful breeding program (Mladenović et al., 2016; Cvejić et al., 2011). Therefore, the success of every breeding program in hybrid development is directly linked to the genetic diversity of its parental sources, making the accurate selection of parental lines essential for developing new varieties with desirable traits (Purwati & Herwati, 2016). In ornamental sunflower breeding, the main goal of hybrid development is to take advantage of heterosis (dominance and superdominance), which occurs when two genetically different parents are crossed, producing F1 generation with advanced traits in comparison to parental lines from both qualitative and quantitative perspectives (Kaya et al., 2012). These improved traits include plant height, flower structure, stem size, quality, etc., to develop more productive ornamental sunflower varieties.

The practical and effective use of heterosis in sunflower breeding became possible with the discovery of CMS (Leclercq, 1969) and the corresponding fertility restorer gene (Kinman, 1970). These advances made it possible to produce almost 100% hybrid seed (Vranceanu, 1974), overcoming previous limitations such as low seed purity and labor-intensive processes. The development of sunflower hybrids using CMS, involving the creation of inbred lines and examining their combining ability, has significantly improved yield potential and established sunflower hybridization as a commercially viable method (Putt, 1962).

Recent studies highlighted the importance of developing ornamental hybrids with different flower colors and plant structures to cover a wide range of customer preferences, which showed that such hybrids are not only visually appealing but also offer other practical advantages, such as improved durability and longer vase life for cut flowers (Cvejic & Jocić, 2010). Studies have also shown that F1 hybrids exhibited increased number of branches, and extended stem lengths in comparison to parental lines due to heterotic effects (Cvejic & Jocić, 2010; Cvejić et al., 2017).

These traits increase the suitability of hybrids for ornamental sunflower production while highlighting the importance of hybrid breeding as a critical tool for improving genetic variation. In the past few years, sterile sunflower hybrids developed by cut flower breeders have become popular on the international market. In the 1950s, Canada introduced the commercial use of hybrids by using highly self-incompatible inbred lines as the maternal line in hybrid production (Putt, 1962).

The production of F1 hybrids relies on parental inbred lines and specific techniques like male sterility and self-incompatibility. These hybrids offer commercial advantages but require annual propagation due to sterility (Datta, 2022). Analyzing the genetic variability within the germplasm collection played a crucial role in identifying diverse genotypes (Siddiqi et al. 2012). In addition, phenotypic characterization of the existing germplasm collection is crucial for breeders, as it allows them to distinguish and

identify different genotypes based on observable traits. This process is fundamental for selecting the most suitable genetic material for further breeding efforts (Purwati & Herwati, 2016).

2.6. Cytoplasmic Male Sterility (CMS) and Fertility of Restoration in Sunflower

Sunflower stands out as the sole member of the Asteraceae family known to possess a cytoplasmic male sterility (CMS) system. In sunflower, CMS is present only when the cytoplasm is sterile and the plant is homozygous for a recessive allele of the *Rf* gene in the nucleus. Sunflowers exhibiting CMS system typically develop anthers that are only half the usual length, rendering them non-protrusive from the corolla and further distinguishing their reproductive structure (Leclercq, 1969). The application of CMS in F1 hybrid seed production is essential in ornamental sunflower industry to develop male-sterile hybrids. The breeding of commercially produced hybrid sunflower is utterly on the basis of PET1 cytoplasm which is obtained from the cross between *H. annuus* and *H. petiolaris* (Nichterlein & Horn, 2005; Leclercq 1969). CMS can allow the use of heterosis in crops that are normally difficult to cross (Edwardson, 1956). It has been stated that fertility restoration genes occur in wild sunflower species and is under the regulation of either a single dominant gene or two dominant genes in the nucleus (Leclercq, 1971; Dominguez Gimenez & Fick, 1975).

Exceptionally, the complementary roles of more than two genes appear to be responsible for restoring pollen fertility. (Vrânceanu & Stoenescu, 1978). In addition, four fertility-restoration genes in wild types of *H. annuus* and *H. petiolaris* have been identified, suggesting that the presence of at least two dominant alleles at any of the four loci is necessary for the complete expression of fertility restoration (Dominguez Gimenez & Fick, 1975). In plants with CMS system, the *ATPase* gene is duplicated in the mitochondria. As a result, ATP cannot be transferred to the pollen, thus the plant is developed as male-sterile. After the discovery of PET1-CMS, studies to find functional male fertility restoration genes have started. While most CMS sources require at least two genes to restore fertility, some sources exhibit single gene restoration (Jan & Vick, 2007).

Kinman (1970) discovered that a single dominant *Rf₁* gene influenced male fertility restoration after identifying a male fertility restorer gene in the “T66006-2-1” sunflower line, which was achieved by the crosses between wild and cultivated sunflower (Serieys, 2005). *Rf₁* is the only gene that can restore male fertility in sunflower hybrids (Leclercq & Philippon, 1984). Various DNA markers such as RFLP, AFLP, SCAR and SSR markers were employed in the investigation of the *Rf₁* gene. The very first molecular marker linked to the *Rf₁* allele, which restores pollen fertility in the PET1-based CMS system, has been developed by Horn et al., (2002). Additionally, RAPD markers in association with RFLP markers were highly efficient in mapping the *Rf* gene (Horn et al., 2003). Markin et al. (2017) stated that SCAR markers HRG01 is more effective for detecting *Rf₁* in perennial species in comparison to HRG02, which performed better in annual species. The *Rf₁* gene was mapped to LG13, which is located in the 13th linkage group, with SSR marker ORS1030 (Kusterer et al., 2005).

Cytoplasmic male sterility (CMS) has been established in over 140 plant species, with more than 70 distinct types identified in sunflower (Laser & Lernsten, 1972; Liu et al., 2012). Remarkably, only the CMS-PET1 variant has been utilized exclusively for

hybrid development (Reddy et al., 2008). According to Leclercq (1969), male sterility was maintained when crossed with sterile cytoplasm carriers, which suggested that the fertility restoration mechanism must be inherent in the *H. petiolaris* species. The *Rf* gene in the nucleus or the *ATPase* gene in the cytoplasm can restore fertility all by itself. The *Rf₁* gene and the *Rf₂* gene both have an impact on pollen yield. To date, co-dominant markers that perform *Rf₁* gene-specific allelic discrimination and allele specific dominant markers have been developed using Next-generation sequencing (NGS) and bioinformatics analyses.

The utilization of cytoplasmic male sterility in F1 hybrid production has led to high yield and disease resistance in oilseed sunflowers, while enabling the development of ornamental sterile hybrids with longer vase life. Hybrid breeding relies on the use of cytoplasmic male-sterile lines, maintainer, and fertility restorer lines (Chen & Liu, 2014). In the development of male-sterile sunflower hybrids, A-lines (sterile cytoplasm, with *rfrf* genes in the nucleus) and B-lines (fertile cytoplasm, with *rfrf* genes in the nucleus) are obtained for each genotype. In this case, the A-line is the seed producing parent. The A-line is developed by crossing the B-line as the male parent with a female having sterile cytoplasm and fertility restoration genes, followed by several backcrosses. In addition, the A-line is maintained by crossing the sterile A-line with the B-line to obtain male-sterile hybrids. The B-lines are maintained by selfing in most cases. R-line, which is the inbred parent that restores fertility is also required in CMS breeding program. R-line has the genotype *RfRf* and is used as the pollen parent and maintained like the B-line. It is crossed to the restorer gene donor parent through backcrossing with the R-line as the recurrent parent.

2.7. Resistance to Imidazolinone and Sulfonylurea Group Herbicides

Weeds compete with sunflowers for light, water and nutrients in the early stages of development and can inhibit plant growth and development through allelopathic effects, causing loss of quality, yield, and increased production costs (Bükün & Uygur, 2001). The estimated losses to diseases, weeds, and insects in global sunflower production in the mid-1990s were \$1.36 billion annually (Hesley, 1999).

Transgenic herbicide resistant genes have been widely employed in various crops worldwide to enhance weed control, offering farmers a more efficient and effective means of managing unwanted vegetation. However, when it comes to sunflowers, the use of herbicide resistance has been more limited compared to other crops. Specifically, sunflower varieties that are resistant to herbicides such as IMI (Imidazolinone) and SU (Sulfonylurea) have been developed through traditional breeding methods, primarily utilizing backcrossing techniques with wild sunflower species (Kaya et al., 2012). Resistance for imidazolinone and sulfonylurea herbicides which has been discovered in a wild *H. annuus* population in Kansas, is one of the most significant traits in sunflowers (Al-Khatib et al., 1998). Thereafter, studies are mainly focused on resistance to IMI and SU group herbicides in common sunflowers (Kaya, 2015; Kaya et al., 2018).

IMI and SU group herbicide resistance have been transferred from wild species to cultivated types of sunflowers by backcrossing. These herbicides have shown high efficacy in controlling a wide range of weeds, offering flexible application timing, requiring minimal amounts, and posing low toxicity risks to mammals (Brown, 1990; Tan

et al., 2005). In 1996, Al-Khatib and Miller developed cultivated sunflowers by transferring IMI resistance from the wild type using conventional breeding techniques and named it “CLEARFIELD Technology”. These IMI-resistant sunflower lines have a single modified ALS (acetolactate synthase) gene with semi-dominant inheritance. The lines developed showed resistance to imazamox, imazethapyr and imazapyr at 2x doses and in Clearfield sunflower lines showed resistance to 3x doses in field trials (Miller & Al-Khatib, 2000). The resistance to IMI herbicides in Clearfield sunflowers results from a mutation in the acetolactate synthase (ALS), also known as acetohydroxyacid synthase (AHAS), which was first identified in a wild *Helianthus annuus* population (Pfenning et al., 2008).

Sulfonylurea group herbicides inhibit the activity of the enzyme AHAS and prevent the production of aromatic amino acids valine, leucine and isoleucine (Singh, 1998). IMI and SU herbicides are effective and have low toxicity, which is optional for agricultural uses. However, their use in hybrid development is based on herbicide resistant hybrids. This resistance is accomplished by modified *AHAS* genes and enzymes, which were first identified in sunflowers. This progress resulted in the commercialisation of herbicide resistant traits. The resistance is due to a form of the AHAS large subunit enzyme (AHASL), which resists herbicide inhibition and is controlled by a single, partially dominant gene (Sala et al., 2012).

Kolkman et al. (2004) identified two mutations in the sunflower *AHAS1* gene that were likely responsible for conferring resistance to AHAS-inhibiting herbicides. Specifically, “Ala205Val” was discovered in sunflower lines, which had been developed by the introgression of resistance traits into elite inbred lines (Al-Khatib et al., 1998; Al-Khatib & Miller, 2000; Miller & Al-Khatib, 2002). Miller & Al-Khatib (2002) also announced a new oilseed sunflower maintainer “HA425”, along with two fertility restorer lines “RHA 426” and “RHA 427” have been developed to exhibit resistance to imidazolinone herbicides. These varieties are designed to offer enhanced weed control by allowing the use of imidazolinone herbicides without damaging the sunflower plants. It was concluded that the function of the *AHAS1* gene is integral to both herbicide resistance and critical metabolic processes in sunflowers (Kolkman et al., 2004). This finding advanced the understanding of genetic mechanisms under herbicide resistance in sunflower and contributed to the development of more resilient varieties.

Sunflower lines developed to withstand some AHAS-inhibiting herbicides have been shown to be susceptible to foliar applications, and in many situations, they are also affected by residues from different AHAS-inhibiting herbicides in the soil (Howatt & Endress, 2006). The use of herbicide resistant varieties in sunflower production marks a significant advancement, and ongoing research in this area is contributing to the development of more resilient and high-yielding sunflower varieties in the future.

2.8. Inheritance of the Ray Flower Color in Sunflowers

The inflorescence of sunflower is mainly characterised by ray flowers and disc flowers. The noticeable flowers, distinguished by their long petals, are commonly known as ray or ligulate flowers, highlighting their distinctive form and function (Seiler, 1997). Ray flowers form the outer ring of petal-like structures and disc flowers are located in the center of the capitulum (Cvejić et al., 2010). Ray flowers are mostly sterile with a pistil,

style and stigma except anther (Seiler, 1997). On the other hand, disc flowers are fertile and the pollen is present, which is an undesirable criterion for cut sunflowers.

The color of the disc flowers can exhibit vibrant tones of yellow, orange, or red due to anthocyanin, while some varieties exhibit a purple coloration in disc flowers. The color of the ray flowers can differ from several tones of red to a lemon-yellow color (Cvejić et al., 2016). The opposite colors of disc flowers and ray flowers attracts the eye in a more contrasting way and creates a striking visual contrast that naturally captures the attention of people and pollinators i.e. bees. In sunflower, in terms of ornamental perspective, it is possible to encounter many ray flower colors such as red, light-yellow, orange, purple, red-brown, lemon and white color other than the common yellow color (Miller & Fick, 1997; Rudorf, 1961; Zhang et al., 2008). Studies included multiple modifications in ray flower colors (Cockerell, 1912; Fick, 1976).

Carotenoids are primarily produced by photosynthetic organisms, specifically within chloroplast and chromoplasts in plants (Britton et al., 2004). Due to the presence of carotenoids in chromoplasts, the yellow ray flower color is present in sunflowers (Yue et al., 2008). Carotenoids in chromoplasts are most likely synthesized for the attraction of pollinators (Bartley & Scolnik, 1995). On the one hand, Miller & Fick (1997) stated that the formation of red or purple coloration in ray flowers is attributed to anthocyanins. Several studies reported that yellow ray flower coloration was dominant in F1 populations resulting from crosses between ornamental sunflower lines having yellow ray flowers and lines having lemon, lemon-yellow, orange, apricot colored ray flowers (Fick, 1976; Skaloud & Kovacik, 1978; Šećerov-Fišer & Škorić, 1988; Miller & Fick, 1997; Yue et al., 2008). When the lines with red ray flowers were crossed with yellow, orange or lemon-yellow ray flowers, the resulting F1 plants exhibited a “gaillardia” pattern, with red stripes near the center of the ray flowers (Fick, 1976). Genes that are in homozygous recessive state determine the other types of ray flower colors such as the *o* gene controls orange, the *l* gene controls lemon, the *ly* gene controls lemon-yellow and the *ap* gene, which is controlled by a single gene, controls apricot ray flower color through independent and complementary genetic mechanisms (Leclercq, 1968; Tolmachev, 1998; Sharypina et al., 2008; Vedmedeva, 2019). Complementary interaction of dominant alleles of other genes controlled the yellow coloration in ray flowers (Tolmachev, 2006). Fick (1976) and Šećerov-Fišer & Škorić (1991) found that two genes were involved in the expression of the red ray flower color, but only one gene was present in the orange and lemon ray flower colors.

It was also concluded that lemon color displayed recessive epistasis to orange and yellow color (Fick, 1976), while red coloration of ray flowers was partially dominant over yellow and lemon-yellow colorations. Fick (1976) stated that the yellow coloration of ray flowers in ornamental sunflowers were dominant over orange and lemon colors. A single dominant gene is responsible for the presence of anthocyanin pigment in the disc florets (Mosdijis, 1982). Luczkiewicz (1975) investigated the inheritance of several morphological traits and stated that three complimentary dominant genes, *Sa*₁, *Sa*₂, and *Sa*₃, controlled the color of the stigma and style and indicated that the presence of anthocyanin pigments in the stigma was dominant.

The inheritance of ray flower color trait in ornamental sunflowers has been reported in the literature by several researchers. These studies have demonstrated the

genes controlling ray flower color trait and that which ray flower color is dominant in the F1 phenotype, along with segregation ratios in the F2 generations as a result of crossing different ray flower colors, and therefore revealed the variations that can be obtained in ornamental sunflower combinations by crossing different colored parents (Fick, 1976; Miller & Fick, 1997; Tolmachev, 2006; Yue et al., 2008; Sharypina et al., 2008; Divita et al., 2012; Cvejić et al., 2016; Peretyagina et al., 2018), which contributed to a more detailed understanding of color inheritance. Yue et al. (2008) observed that lemon ray flower color did not have any harmful effect on the development of the plant. Mladenović et al. (2020) determined that red and purple tones in ornamental sunflowers are associated with anthocyanin accumulation, while yellow and orange tones are linked to carotenoid accumulation. Furthermore, it was emphasized that the variation in pigment accumulation levels among different varieties significantly influences the diversity in color tones (Mladenović et al., 2020). In a comprehensive study by Dowell et al. (2019), flower morphology, color pigmentation and color characteristics of ray and disc flowers were observed under greenhouse and field conditions and these traits were mapped through 5788 SNP markers. Yue et al. (2008) investigated the ray flower color of 120 F2 plants and observed that lemon color was controlled by two recessive genes, after which TRAP and SSR markers were used to map the *Yf1* gene, which was mapped to linkage group 11.

The naming of sunflower ray flower colors is quite complex and challenging due to the large number of variations and color shades. Expanding the color naming scale can provide more accurate classification and selection opportunities for both vendors and customers, while also offering significant advantages for ornamental sunflower breeders in the development of new varieties. Zorić et al. (2020) proposed new approaches to ensure a more accurate and objective categorisation of ray flower colors of ornamental sunflowers using Flower Color Image Analysis (FloCIA) software, creating a more effective color categorisation from both scientific and commercial perspectives.

3. MATERIAL AND METHOD

This study was conducted at Akdeniz University, Faculty of Agriculture, Ornamental Plants Research and Application Greenhouses and fields located between 36°53'56.65"N and 30°38'51.39"E in Antalya, Türkiye during 2024-2025. The laboratory studies were carried out in the Agricultural Biotechnology Laboratories of Akdeniz University, Faculty of Agriculture.

3.1. Plant Material

The breeding materials used in this study consist of A (CMS) lines and B (maintainer) lines that had been developed within the framework of the TUBITAK project under the code 122R004. In the beginning process of the development of parental A and B-lines, Sulfonylurea (SU) group herbicide resistant homozygous restorer line was crossed with commercial sterile Sunrich Orange F1, in the fall season of 2019. Following season, resulting F1 hybrids were selfed and F2 populations were obtained with a segregation ratio of 1:1 for male sterility/fertility and SU herbicide resistance. In the fall of 2024, SU herbicide resistant fertile F2 plants were backcrossed to Sunrich Orange F1, resulting in the development of BC1F1-A groups. SU herbicide resistant fertile BC1F1 plants were backcrossed to emasculated Peredovik maintainer lines and F1-B groups were obtained. BC1F1-A and F1-B groups were backcrossed several times to 15 commercial ornamental sunflower hybrids; and A (CMS) and B (maintainer) lines at advanced stages (BC4F1, BC3F1, BC2F1, BC1F2) were obtained for each of the 15 hybrids.

Commercially available 11 fertile F1 hybrid including “Earthwalker, All Sort Mix, Autumn Beauty, Dwarf Big Smile, Dwarf Teddy Bear, Dwarf Incredible, Abendsonne Red, Lemon Queen, Dwarf Sunspot, Velvet Queen, Evening Colors” (Table 3.1) and five sterile F1 hybrid “Deep Orange, Sunrich Orange, Strawberry Blonde, Suntastic Pink Bicolor, Junior” (Table 3.2) was used for comparison of vase life and morphological characteristics of the hybrids developed in this study.

Table 3.1. Commercially available fertile ornamental sunflower varieties used for comparison

Plant Materials				
Image	Commercial Name	Height	Branching	Tolerance to Sulfonylurea (SU) group herbicides
	Abendsonne Red	150-200 cm	Present	Susceptible

(continues the next page)

Continuation of Table 3.1

	All Sort Mix	90-170 cm	Present	Susceptible
	Autumn Beauty	150-180 cm	Present	Susceptible
	Dwarf Big Smile	15-50 cm	Present	Susceptible
	Dwarf Incredible	15-50 cm	Absent	Susceptible
	Dwarf Sunspot	45-60 cm	Absent	Susceptible
	Dwarf Teddy Bear	15-40 cm	Absent	Susceptible
	Earthwalker	100-150 cm	Present	Susceptible

(continues on the next page)

Continuation of Table 3.1

	Evening Colors	120-200 cm	Present	Susceptible
	Lemon Queen	180-210 cm	Absent	Susceptible
	Velvet Queen	120-150 cm	Present	Susceptible

Table 3.2. Commercially available sterile ornamental sunflower varieties used for comparison

Plant Materials				
Image	Commercial Name	Height	Branching	Tolerance to Sulfonyleurea (SU) group herbicides
	Deep Orange	100-180 cm	Absent	Susceptible
	Junior	60 cm	Present	Susceptible

(continues on the next page)

Continuation of Table 3.2

	Strawberry Blonde	150-180 cm	Present	Susceptible
	Sunrich Orange	90-150 cm	Absent	Susceptible
	Suntastic Pink Bicolor	30-50 cm	Present	Susceptible

3.2. Method

3.2.1. Cultivation and Practices

3.2.1.1. Seedling Production

A and B-lines developed within the scope of the project were sown on February 17, 2024 for seedling production. Ornamental sunflower seedlings were then transplanted into the greenhouse on March 2, 2024. The seeds were sown at a depth of 1.5-2 cm in styrofoam trays specifically designed for seedling production, containing a well-prepared 3:1 mixture of peat and perlite to ensure optimal germination and growth conditions. After sowing the seeds, the trays were covered with a layer of vermiculite (Figure 3.1).



Figure 3.1. Preparation of the trays for the germination of ornamental sunflower seeds

They were then sealed with plastic wrap to prevent water loss and maintain consistent humidity, and subsequently placed in a dark room to facilitate germination. When the hypocotyl was visible (A1 stage), the plastic wrap was removed and the trays were left under greenhouse conditions to monitor the seedling development (Figure 3.2).



Figure 3.2. Development of the seedlings under greenhouse conditions after germination

3.2.1.2. Field preparation and transplantation of seedlings to the field

The area in the greenhouse was irrigated thoroughly using drip irrigation until the soil was sufficiently moistened, after which the drip pipes and foreign objects were removed. Weeds were killed using glyphosate, and 18N-46P-0K fertilizer was incorporated in the field. After this process, a pre-emergent herbicide (Stomp ® Aqua) was applied. The planting area was ploughed twice to a depth of 20-25 cm with a hoeing machine and leveled with a rake.

The seedlings were transplanted into the prepared field when they reached 2-3 true leaf stage at a distance of 20 cm, 70 cm between rows and 120 cm between wide rows. During the growth and development stage, the plants were irrigated to prevent water stress using drip irrigation system laid on top of the ground to maximize water efficiency. After transplanting the seedlings, fungicide was applied (Maxim ® Quattro) to the root zone of each seedling in order to prevent fungal diseases and soil-derived pathogens (Figure 3.3) and weed control was implemented through mechanical methods.



Figure 3.3. Applications conducted during the field preparation

3.2.1.3. Fertilisation

Plants were fertilized through drip irrigation weekly with balanced fertilizers in a soluble form at V4 stage, such as 15N-15P₂O₅-15K₂O or 18N-18P₂O₅-18K₂O at the rate of 2 gNm² (Puttha et al., 2023). After crossing was completed and the back of the head has started to turn pale yellow (R7 stage), Potassium Nitrate (13N-0P-46K) and Magnesium Sulphate (MgSO₄ 7H₂O) were applied to promote seed set.

3.2.2. The Selection of the CMS (♀) and Maintainer (♂) Lines

3.2.2.1. Sulfonylurea Herbicide Tolerance

When the plants reached the 4-6 and 7-8 leaf stage, Gromstar ® Agrobrest (75% Tribenuron-methyl WG-50) herbicide was applied at the rate of 1.5 g/100 l of water using battery-powered backpack sprayer for the selection of plants resistant to Sulfonylurea (SU) group herbicides (Figure 3.4).



Figure 3.4. Herbicide application to identify plants resistant to SU group herbicides

3.2.2.2. Identification of plants carrying maintainer and restorer (*rf*) nucleus using Marker-Assisted Selection

One of the most important selection criteria of ornamental cut sunflowers is that flower arrangements should be appealing and fresh, and should not expose pollen allergy to consumers (Armitage, 1993; Cvejić & Jocić, 2010). It is also known that in cut sunflowers, sterile varieties have a reasonably longer vase life compared to fertile varieties. During the development of B-lines, the pollen was collected from the A-group lines carrying heterozygous *Rfrf* nucleus and were backcrossed with the B-group plants that has fertile cytoplasm-sterile nucleus. All the plants resulting from this cross were fertile (pollen present) due to their fertile cytoplasm, regardless of their nucleus status. Consequently, in order to determine *Rf1/rf1* genotypic discrimination of these fertile individuals their DNA's were isolated and screened by SCAR marker (Horn et al., 2002) and B-lines carrying *rfrf* genotype in the nucleus were identified, and were used in the crossing combinations.

a. DNA Isolation

For molecular marker analyses, the DNA was isolated from the young leaf tissue of B-lines (Figure 3.5) according to the protocol described by Gentzbittel et al., (1992) with slight modifications.



Figure 3.5. Leaf sample collection from young leaves of B-lines

Extraction buffer was prepared with 2% CTAB, 20 mM EDTA, 100 mM Tris HCl (pH 8), 1.4 M NaCl and 0.2 % β -mercaptoethanol. Samples of young leaf tissues were transferred into eppendorf tubes and were ground by adding 200 μ L of CTAB solution. After this process, an additional 250 μ L of CTAB solution was added to each tube and the samples were incubated at 65°C for 1 h. Following this, 450 μ L Chloroform: Isoamyl alcohol mixture (24:1 v/v) was added to the tubes and the mixture was centrifuged to form a two-phase solution. The upper phase was carefully transferred to a new 300 μ L tube with a pipette assuming that DNA was present in the upper phase (supernatant). 300 μ L of 100% isopropanol solution was added to the upper phase and the tubes were kept overnight at 20°C. Following the next day, the samples were centrifuged and DNA pellets were formed at the bottom of the tubes. The supernatant on the pellets was carefully removed and centrifuged by adding 300 μ L of 70% ethanol to each tube. This process was repeated twice. Lastly, the remaining solution in the tubes was carefully removed. After the pellets were dried for an hour, DNA stock solutions were prepared by adding 100 μ L distilled water.

b. SCAR Analysis

Two different dominant markers, originating from a gene associated with the *Rf1* gene and identified as potential candidate for *Rf1*, were used. The PPR621.5_F1/PPR621.5_Rev primer combination produced a 164 bp band exclusive to rf, whereas the PPR621.5_F2/PPR621.5_Rev primer combination generated a 164 bp band exclusive to the Rf (restores fertility in the nucleus) allele.

The PCR components used for testing SCAR primers are shown in Table 3.3. DNA amplification was performed using a thermal cycler. The PCR profile consisted of one cycle of 94°C for 2 min, 30 cycle of 94°C for 30 sec, 62°C for 30 sec, 72°C for 1 min, followed by 4 min of extension at 72°C and one cycle of 4°C.

Table 3.3. PCR components used in SCAR analysis

Components	Amount
DNA	2 µL
10X Taq amonium buffer ((NH ₄) ₂ SO ₄)	1.5 µL
25 mM MgCl ₂	1.5 µL
5 mM dNTPs	1.5 µL
2.4 U/ µL Taq DNA polymerase	0.2 µL
10 mM 67NO4 Primer (Forward)	1.8 µL
10 mM 67NO4 Primer (Reverse)	1.8 µL
ddH ₂ O	4.7 µL
TOTAL	15 µL

c. Gel Electrophoresis

In order to visualize the PCR products of SCAR primers under UV light, 3% (400 ml TBE buffer solution, 12 g agarose, 6 µL Ethidium Bromide), 2% (400 ml TBE, 8 g agarose, 6 µL Ethidium Bromide) and 1.5% agarose gels were prepared. The preparation of 1X TBE buffer is described below. To prepare the 10X stock buffer solution, 108 g of Tris, 55 g of boric acid, and 7.5 g of EDTA were dissolved in 1 L of distilled water. 10X solution was then diluted with 9 L of distilled water to obtain 1X buffer solution and used for gel electrophoresis. 5 µL of loading buffer, containing 15 ml of glycerol, 35 ml of distilled water, and 0.05 g bromophenol blue, was added to the PCR products and were loaded onto agarose gel. Electrophoresis was carried out in 1X TBE buffer solution with an electric current of 110 volts for 2 hours. 3 µL of 100 bp DNA Ladder (Thermo, GeneRuler) was added into the first gel wells. Gel imaging was performed using a Minilumi DNR Bio-Imaging Systems device for the results.

3.2.2.3. The selection of the parental lines (CMS-A and B-lines) in terms of ornamental use

The B-lines carrying the *rfrf* gene in the nucleus were subjected to selection to determine the ones to be used for crossing combinations. Genotypes with 60-70 cm long lateral branches, colors, including yellow, lemon, brown-yellow (almost orange), red-

brown (brownish gaillardia pattern with yellow tips), lemon-yellow, tile-red, dark reddish maroon (red gaillardia pattern with yellow tips), purple (purple gaillardia with lemon tips) were selected. The plants, which featured a variety of flower colors with a 8-15 cm in flower head diameter and the ones having 60-70 cm long lateral branches along the stem, were particularly selected for their suitability as cut flowers, outdoor plants, and indoor (potted) use. In addition to the flower color, during the selection process, attention was also given to the those with disc flowers proportional to the head diameter.

3.2.3. Crossing of the Parental Lines

Plants with different ray/disc flower colors, flower and stem/branch structures were selected from both parental lines and were labeled accordingly. To ensure the development of hybrids displaying variations in ray flower colors and to investigate the dominance/recessiveness of ray flower color traits in ornamental sunflowers, it was ensured that the selected lines had distinctly different ray flower colors. Crossing combinations (A line x B line) were established under this criterion. None of the A-lines crossed with its own B-line (maintainer). Conventional hybridisation method was used. The CMS lines were used as the female parents (♀), while the maintainer lines served as the male parents (♂), ultimately leading to the creation of new hybrid male-sterile ornamental sunflower variety candidates. During this process, the plants selected for combinations were isolated using cloth bags immediately before inflorescence begins to open (Figure 3.6), specifically prior to the R5 stage (Schneiter & Miller, 1981), to prevent contamination.



Figure 3.6. Isolation of flower heads

Due to the different flowering times of the A and B-lines, pollen from selected (labeled) plants of the B-lines was manually collected at regular intervals by gently tapping the back of the flower heads, allowing the pollen to fall onto paper (Figure 3.7). During this process 70% alcohol was used to prevent contamination. For each

combinations, once the labeled A-lines entered the flowering stage, pollen collected from the B-lines was carefully deposited to the flower heads of corresponding A-line several times, thus creating AxB combinations (Figure 3.8). After the AxB crosses were completed, the plants were labeled for harvesting.



Figure 3.7. Pollen collection process from B-lines



Figure 3.8. Performing the crossing process

3.2.4. Harvest

Harvest is best timed after the R9 stage, which marks physiological maturity, where bracts become yellow and brown (Schneiter & Miller, 1981), seeds reach maximum dry weight and the seed moisture content is between 20-25% to ensure optimal quality and minimize losses in terms of seed drop (Puttha et al., 2023). Therefore, after reaching physiological maturity, isolated sunflower heads were harvested using scissors in order to evaluate the morphological performances and vase life of the hybrids in the following season. When the harvested sunflower heads were completely dry, the seeds of the hybrids obtained were carefully removed by hand. The seeds were then carefully cleaned to remove any remaining plant parts and other materials using a sieving system (Figure 3.9). After this process, the seeds of each hybrids were stored at 4°C in locked nylon packets with labels containing the date of crossing and the codes of the parental lines used during crossing.



Figure 3.9. Seed harvesting procedure from the hybrids obtained

3.2.5. Vase Life Evaluation of the Hybrids

The seeds of the hybrids obtained were sown into trays on August 23, 2024. After monitoring seedling development, healthy seedlings were transplanted into the field (Figure 3.10), and the seeds of the commercially available five sterile and 11 fertile varieties, which were used as control/check, were sown into trays on August 30, 2024. Cultivation and practices were applied as stated in 3.2.1. The field experiment was conducted using a Randomized Complete Block Design (RCBD) with three replications, where five plants were grown in each replication. Due to the variability of flowering times, each sunflower was harvested at commercial harvest maturity every other day with a sterilized scissors with a length of 55 cm when most of the ray flowers positioned at 90 degrees (before the most outer row of the disc flowers are visible) (Figure 3.11) and was immediately put in buckets to prevent water loss. Before harvesting the sunflowers, morphological traits such as plant height, flowering time, branching status, position of

branching, stem length and diameter, were recorded in the field. Harvested flowers were then placed in glass jars with three replications where five flowers are placed in each replication. Further morphological traits such as flower head attitude, density of ray flowers, pollen presence, width in relation to length of ray flowers, ray flower profile and attitude, flower head and disc flower diameter, disc flower color, ray flower (petal) color, and vase life of each genotype were recorded in laboratory conditions. All leaves were removed from the lower portion of the stem, leaving only the upper three leaves intact. The vase life of each flower was evaluated in each 1000 mL glass jars with 750 mL of distilled water (Kılıç et al., 2020) in Akdeniz University, Landscape Architecture Laboratory (with an average temperature of 24°C and 12 h light/12 h dark conditions). The vase life was defined as the number of days from the date the flowers are placed in the glass jars to the date the quality of the flowers begins to deteriorate (petal wilting, petal curling and whole flower wilting) (Çelikel & Reid, 2002). The vase life trial was conducted according to Randomized Complete Block Design (RCBD) with three replicates, where five flowers were used for each replication.



Figure 3.10. Experimental setup for vase life evaluation



Figure 3.11. Field preparation for the vase life evaluation

3.2.5.1. Morphological analysis of the hybrids obtained and evaluation of the overall performances for ornamental use

Hybrids resulting from the crosses between A and B lines were evaluated for morphological characterization and ornamental performances according to UPOV (2000) and Sloan & Harkness (2006). The data collected are listed below. Observations were carried out using 15 individual plants for each line.

a. Germination rate and time; Observations were recorded immediately after sowing to monitor germination progress. Seeds were considered as successfully germinated when the plants emerged above the soil surface, and the cotyledons became fully visible and developed which represents A2 stage. This ensured proper germination recording.

b. Time of beginning of the flowering (number of days from sowing); It represents the day in which the seeds were sown in trays to the date on which 50% of the ray flowers appeared, with the majority of the ray flowers positioned at a 90-degree angle (Figure 3.11) (Dole & Wilkins, 1999; VBN, 2019), was considered “flowering time.”



Figure 3.12. Maturity picture of the ornamental sunflower demonstrating the angle of the ray flowers at 90-degrees

c. Leaf: size and intensity of green color; Observations were made at E4 stage (Figure 3.12). A scale of 1-very small, 3-small, 5-medium, 7-large, 9-very large was used to determine leaf size. A scale of 1-very light, 2-light, 3-medium, 4-dark, 5-very dark was used to characterize leaf color.



Figure 3.13. E4 stage in sunflower representing the time when the star bud peels away from the leaves and becomes visible

d. Ray flower: density; The density of ray flowers was determined at F3.2 stage (when the disc flowers started to bloom). A scale of 1-very sparse, 2-sparse, 3-medium, 4-dense, 5-very dense was used.

e. Ray flower: attitude of base in relation to head; Observations were made when the ray flowers were fully opened and the five-six most outer rows of disc flowers had their anthers visible. A scale of 1-erect, 2-semi-erect, 3-horizontal was used for this observation.

f. Ray flower: width in relation to length; Observations were made at F3.2 stage. A scale of 1-very narrow, 2-narrow, 3-broad, 4-very broad was used.

g. Ray flower: profile; Observations were made when the ray flowers were fully opened and the five-six most outer rows of disc flowers had their anthers visible. A scale of 1-flat, 2-rolled, 3-twisted, 4-strongly recurved was used.

h. Ray and disc flower: color; Ray flower color was evaluated on the basis of the color with the largest surface area. The darkest area was observed in multicolored flowers with a gaillardia pattern. Disc flowers are located right in the center of the flower inflorescence. Therefore, observations were recorded at F3.2 stage, targeting the center of the head where sexual flowers are arranged, using a color measurement device (Konica Minolta CR-400 Chromameter).

i. Disc flower: production of pollen; Observations were recorded at F3.2 stage. A scale of 1-absent, 9-present was used.

j. Disc flower: diameter; Disc flowers are located only in the center of the head. Using a digital caliper, measurements were recorded across the center of the head, from one end to the other, excluding ray flowers.

k. Head: diameter; Measurements were recorded at F3.2 stage across the central head from one end to the other with a digital caliper.

l. Head: attitude; Observations were made when the ray and disc flowers were fully opened. A scale of 1-horizontal, 2-inclined, 3-vertical, 4-half-turned down, 5-turned down, 6-over turned was used to record observations.

m. Stem size: length and diameter; In the case of non-branching types, stem length was measured as the distance from the base of the plant to the point where the stem meets the head (top of the flower). In the case of branching types, stem length was measured from the base of the branch to the head (top of the flower). Stem diameter was measured 40 cm below the floral receptacle both in non-branching and branching types with a digital caliper.

n. Plant: height; Measurements were recorded at F1 stage in which the flower bud bends; the ray flowers are outwards of the disc. This trait was measured from the soil surface of the plant to the highest part of the plant.

o. Plant: branching; A scale of 1-absent, 9-present was used to record the observations.

p. Plant: position of branching; A scale of 1-only basal, 2-predominantly basal, 3-throughout, 4-predominantly apical, 5-only apical, 6-none was used to record the position of branching.

3.2.6. Statistical Data Analysis

All data obtained from the field observations were analyzed in accordance with the experimental design used. The analysis of variance (ANOVA) method was performed using the PROC procedure (SAS Institute, 1999). Averages were compared using Fisher's Least Significant Difference (LSD) test and the LSD (0.05) values were calculated.

4. RESULTS AND DISCUSSION

In the spring season of 2024, a total of 947 seeds belonging A and B lines were sown and 648 seeds (68.4%) germinated successfully. Herbicide application was performed on March 23, 2024, when the plants reached 6-8 leaf stage. A total of 384 plants (%59), 188 plants from A-lines and 196 plants from the B-lines, were observed to be resistant to SU group herbicides (Table 4.1). SU herbicides attacks the growing point of weeds, stops the development, and consequently kills the susceptible plants (Figure 4.1) by inhibiting AHAS, also known ALS enzyme. Segregation of resistant and susceptible plants fit the expected ratio of 1:1, respectively. Conventional sunflowers are known for their susceptibility to SU herbicides. The first introduction of SU herbicide resistant M7 homozygous hybrid, in which the tolerance trait was revealed through induced mutagenesis, was launched in 2008 (Gabard & Huby, 2004). SU herbicide DuPont™ Express™, with an active ingredient of Tribenuron-methyl, controls a large number of weed crops in more than 30 countries in Europe and the USA (Streit, 2012). Although there are no studies concerning the development of ornamental sunflower hybrids resistant to SU herbicides, several studies on the development of conventional sunflower hybrids resistant to IMI-group herbicides have been carried out in many countries, including Türkiye (Kaya et al., 2013; Kaya et al., 2018; Harmancı et al., 2024).



Figure 4.1. General view of the plants one week after herbicide application

During the development of the B-lines in accordance with the project, A-group plants carrying sterile cytoplasm with heterozygous Rfrf genotype in the nucleus were backcrossed to the related B-lines carrying fertile cytoplasm with homozygous Rfrf nucleus and as a result, 50% rfrf and 50% Rfrf backcross populations (fertile) were obtained. Leaf samples were collected for DNA isolation to determine nucleus fertility status of the Sulfonylurea resistant B group plants on April 8, 2024. Results showed that 50% of the population had rfrf and remaining 50% had Rfrf genotypes. Then the B-lines

with a homozygous genotype (rfrf) in their nucleus were used as the male parent (♂) in crossing combinations (Figure 4.2).

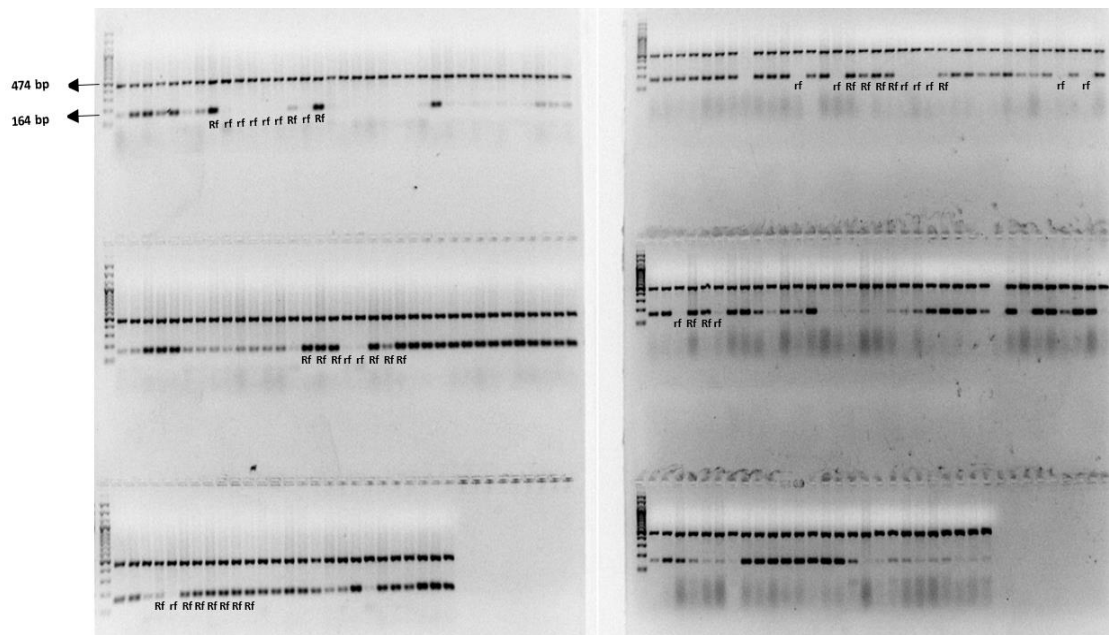


Figure 4.2. Image from gel electrophoresis results from SCAR marker (PPR621.5_F2/Rev) analysis of B-lines

During the same season, plants with high ornamental potential, selected from A and B lines having different colors and tones than each others, were crossed to create AxB combinations. A total of new 31 hybrid lines were developed as a result of this crossing combination (Table 4.2).



Figure 4.3. Ornamental sunflower cultivation under greenhouse conditions in the spring season of 2024

Table 4.1. Backcross generations of parental lines selected

Code	Generation of the plants used as the A-lines (♀)			Seeds Sown	Seeds germinated	Herbicide Tolerance	
	♀	x	♂			Susceptible	Resistant
F1E- AxB	BC3F1-F1E	x	BC1F2-B(F1E) _{rr}	40	23	11	12
F1G- AxB	BC2F1-F1G	x	F2-B(F1G) _{rr}	30	23	4	19
BC3F1- F1G	BC2F1- F1G	x	F1G	70	38	14	24
F1R- AxB	BC1F1-F1R	x	BC1F2-B(F1R) _{rr}	40	22	7	15
F1S- AxB	BC2F1-F1S	x	BC1F2-B(F1S) _{rr}	100	77	27	50
F1T- AxB	BC2F1-F1T	x	BC1F2-B(F1T) _{rr}	50	41	15	26
BC3F1- F1T	BC2F1-F1T	x	F1T	39	31	11	20
BC3F1- F1V	BC2F1-F1V	x	F1V	60	27	13	14
BC1F1- F1X	F1-F1X	x	F1X	60	18	10	8
Total				489	300	112	188
Code	Generation of the plants used as the B-lines (♂)			Seed Sown	Seeds germinated	Herbicide Tolerance	
	♀	x	♂			Susceptible	Resistant
BC2F1-B(F1S)	BC1F1-B(F1S) _{rr}	x	F1S	4	4	2	2
BC1F2-B(F1S)	BC1F1-B(F1S)	x	BC1F1-B(F1S)	44	32	17	15
BC1F2-B(F1P)	BC1F1-B(F1P)	x	BC1F1-B(F1P)	40	35	17	18
BC1F2-B(F1K)	BC1F1-B(F1K)	x	BC1F1-B(F1K)	19	13	6	7
BC2F1-B(F1O)	BC1F1-B(F1O) _{rr}	x	F1O	2	2	0	2
BC1F2-B(F1F)	BC1F1-B(F1F)	x	BC1F1-B(F1F)	24	20	9	11
BC1F2-B(F1T)	BC1F1-B(F1T)	x	BC1F1-B(F1T)	45	35	15	20
BC1F2-B(F1E)	BC1F1-B(F1E)	x	BC1F1-B(F1E)	36	24	10	14
BC2F1-B(F1H)	BC1F1-B(F1H) _{rr}	x	F1H	57	44	20	24

(continues on the next page)

Continuation of Table 4.1.

BC1F2-B(F1D)	BC1F1-B(F1D)	x	BC1F1-B(F1D)	36	24	12	12
BC2F1-B(F1V)	BC1F1-B(F1V)	x	BC1F1-B(F1V)	12	4	0	4
BC1F2-B(F1J)	BC1F1-B(F1J)	x	BC1F1-B(F1J)	44	36	10	26
BC2F1-B(F1T)	BC1F1-B(F1T) rr	x	F1T	30	25	13	12
F2-B(F1G)	F1-B(F1G) rr	x	F1-B(F1G) rr	29	21	7	14
F1-B(F1X)	F1-B(F1) rr	x	F1X	36	29	14	15
Total				458	348	152	196

Table 4.2. AxB crossing combinations conducted

AxB combinations carried out in the spring season of 2024			
Code	A (CMS) Lines (♀)	X	B (maintainer) Lines (♂)
185	F1E- AxB	X	BC2F1-B(F1S) rf
186	F1E- AxB	X	BC1F2-B(F1P) rf
187	F1E- AxB	X	BC1F2-B(F1K) rf
192	F1G- AxB	X	BC1F2-B(F1S) rf
191	F1G- AxB	X	BC2F1-B(F1O) rf
190	BC3F1- F1G	X	BC2F1-B(F1O) rf
193	F1R- AxB	X	BC1F2-B(F1S) rf
194	F1R- AxB	X	BC1F2-B(F1K) Rf
129	F1R- AxB	X	BC1F2-B(F1F) Rf
195	F1R- AxB	X	BC1F2-B(F1S) Rf
196	F1S- AxB	X	BC1F2-B(F1T) Rf
209	F1T- AxB	X	BC1F2-B(F1E) rf
210	F1T- AxB	X	BC2F1-B(F1H) rf
205	F1T- AxB	X	F2-B(F1G) rf
198	BC3F1- F1T	X	BC1F2-B(F1D) rf
199	F1T- AxB	X	BC1F2-B(F1F) rf
200	F1T- AxB	X	BC2F1-B(F1V) rf
201	F1T- AxB	X	BC1F2-B(F1J) rf
203	F1T- AxB	X	BC1F2-B(F1P) rf
197	F1T- AxB	X	F1-B(F1X) rf
206	F1T- AxB	X	BC1F2-B(F1S) rf
207	F1T- AxB	X	BC1F2-B(F1F) rf
208	F1T- AxB	X	BC1F2-B(F1E) rf

(continues on the next page)

Continuation of Table 4.2.

211	BC3F1- F1V	X	BC1F2-B(F1K) rf
212	BC3F1- F1V	X	F2-B(F1G) rf
213	BC1F1- F1X	X	BC1F2-B(F1F) rf
214	BC1F1- F1X	X	BC1F2-B(F1S) rf
215	BC1F1- F1X	X	F2-B(F1G) rf
216	BC1F1- F1X	X	BC2F1-B(F1T) rf
189	BC3F1- F1G	X	BC2F1-B(F1O) rf
188	F1G- AxB	X	BC1F2-B(F1F) rf

When the plants in each crossing combinations reached physiological maturity (R9 stage), the seeds of the each group were harvested on June 22, 2024 (Figure 4.4). Then seeds were sown on August 23, 2024, in accordance with the observations necessary for the vase life trial, ray flower color inheritance studies, and morphological analysis (Figure 4.5). Commercial varieties which were used as control/check were sown on August 30, 2024.



Figure 4.4. Physiological maturity stage in sunflower in which the bracts become yellow and brown



Figure 4.5. Sowing the seeds of the hybrids obtained in trays for evaluation purposes

Seedlings of hybrids and commercial cultivars were transplanted into the field on August 30 and September 7, respectively. A total of 1058 seeds were sown, from which 779 (73.6%) successfully germinated (Table 4.3). The rate of the germinated seeds in hybrids was observed to be 66.5%, while the commercial varieties showed a higher overall germination rate of 90.5%.

Table 4.3. Seeds sown for the evaluation in the fall season of 2024

Codes of the hybrids obtained	Seeds Sown	Seeds germinated
129	24	17
185	24	18
186	24	15
187	24	8
188	24	15
189	24	17

(continues on the next page)

Continuation of Table 4.3.

190	24	18
191	24	15
192	24	15
193	24	16
194	24	15
195	24	15
196	24	16
197	24	19
198	24	16
199	24	17
200	24	16
201	24	18
203	24	15
205	24	16
206	24	17
207	24	15
208	24	16
209	24	15
210	24	17
211	24	20
212	24	16
213	24	20
214	24	18
215	24	20
216	24	17
Total	744	495
Commercial varieties	Seeds Sown	Seeds germinated
Abendsonne Red F1	18	17
All Sort Mix F1	20	18
Autumn Beauty F1	20	19

(continues on the next page)

Continuation of Table 4.3.

Deep Orange F1	20	18
Dwarf Big Smile F1	20	19
Dwarf Incredible F1	20	19
Dwarf Sunspot F1	20	19
Dwarf Teddy Bear F1	18	17
Earthwalker F1	20	19
Evening Colors F1	20	19
Lemon Queen F1	20	19
Velvet Queen F1	20	18
Sunrich Orange F1	20	19
Strawberry Blonde F1	20	18
Suntastic Pink Bicolor F1	20	19
Junior F1	18	16
Total	314	284



Figure 4.6. Development of the seedlings of the hybrids under greenhouse conditions before transplantation



Figure 4.7. Development of the plants three weeks after planting



Figure 4.8. Development of the plants four weeks after planting

Morphological traits such as germination time and rate, leaf size and the intensity of green color of the leaves were recorded during the period until flowering. The very first flowering occurred on October 2, 2024. The ornamental potential and morphological characteristics of 31 new variety candidates and commercial varieties were evaluated. The results of the morphological analysis of the qualitative and quantitative traits and overall performances of the hybrids are given between Table 4.4 and 4.11.



Figure 4.9. Image showing the intensity of anthocyanin in the leaf tips, leaf veins, and the whole stem

In sunflower, seeds are accepted as germinated when the plants emerged above the soil surface, and the cotyledons became fully visible and developed. According to the results of the analysis, the germination time of the hybrids obtained varied between 2-2.33 days. In addition, the germination time of the commercial F1 hybrids investigated in the study was observed as 2 days. The germination rate was calculated as the ratio of successfully germinated seeds to the total seeds sown. Based on the results, the germination rate of the hybrids obtained varied between 20.3% (187) and 83.7% (211). The germination rate of commercial checks ranged from 90.7% for the “All Sort Mix” variety to 93% for the rest of other commercial varieties investigated (Table 4.4). The germination rate of the hybrids obtained was determined to be lower than commercial varieties. It was concluded that this might be due to low seed quality. Low seed quality of hybrids might be due to the inadequate development of the embryos and/or accompanying tissues of the sown seeds due to high temperature stress which they exposed during seed set /filling process after crossing in the field. Indeed, the average air temperature during fertilization and the following period (grain filling/embryo development stage) was around 35-40°C, which may have negatively affected the development and quality of the seeds. As a matter of fact, it is known that seed quality

and yield increase especially in oil sunflower varieties when the fertilization and grain filling period is cooler (Kaya 2023).

Krstić et al. (2022) related the germination success of the seeds to the seed quality and the seed size. Gay et al. (1991) determined that seeds germinated successfully at a temperature between 5°C and 40°C, with an optimum temperature of 25°C. Silva et al. (2018) observed that the seeds of the six ornamental sunflowers varieties were germinated on the third day and noticed that germination was completely done on the 9-10th day. Silva et al. (2018) also observed that the germination rate of varieties studied ranged between 75% and 99% at temperatures between 22° and 35°. Successful germination rates may vary depending on the seed quality, environmental factors, and temperature. Toscano et al. (2017) observed that ornamental sunflower seeds exhibited strong germination potential within the 15°C to 30°C range. Kaya et al. (2024) stated that seed priming method displayed a positive effect on germination success in sunflower seeds, while minimizing problems such as seed deterioration.

Flowering time in ornamental sunflowers is considered as the time when the surface of the most ray flowers appears. According to the results, there were significant variations in flowering time (days to flowering) among the hybrids and commercial checks. The mean flowering time of hybrids was 48.7 and ranged from 41.5 days (196) to 56 days (187). The time from sowing until flowering varied between 55-56 days in sterile cultivars and between 48.4-60.7 days in fertile cultivars with a mean flowering time of 55.3 days, suggesting that pollen production might be a subject determining the flowering time of the hybrids (Table 4.4). The results are in agreement with the results reported in the study of Divita et al. (2012), indicating that days required for flowering had no heterosis effect in hybrids obtained. Results also showed that the male sterile hybrids developed in this study blooms in a shorter period of time (avg. 48.7 days) compared to commercial cultivars (avg. 55 days) used in the study.

Cvejic et al. (2016) investigated morphological traits of four sunflower genotypes and that of the hybrids resulted from the crosses between these genotypes. They reported that hybrids showed significant variations compared to parental lines, in which the days to flowering was observed to be 69-79 days. Divita et al. (2012) reported that hybrids required less time for flowering. Sloan & Harkness (2006) have reported that the time from seeding to harvest of cut sunflower cultivars varied between 51.6 and 69.2 days. Mladenović et al. (2016) observed the four ornamental sunflower genotypes in terms of days to flowering which ranged between 48.7 days and 65.4 days. Patil (2018) evaluated 20 ornamental sunflower genotypes for morphological traits. They reported high variation in flowering time which ranged between 33.4 days and 81.7 days among the sunflower genotypes. Vuppalapati (2005) reported significant differences in terms of number of days from sowing to flowering, which varied from 42 days to 75 days. Similar results were observed in the study of Mladenović et al. (2017).

Table 4.4. The analysis of variance results of germination rate, germination time, and flowering time of the hybrids (* represents the fertile commercial varieties; ** represents the sterile commercial varieties)

Hybrid code	Germination Time (days)	Germination Rate (%)	Flowering Time (days)
129	2,00 ± 0,00 ^c	71,28 ± 0,28 ^h	53,01 ± 0,24 ^{c-i}
185	2,00 ± 0,00 ^c	74,33 ± 0,33 ^f	47,28 ± 0,29 ^{j-p}
186	2,00 ± 0,00 ^c	58,67 ± 0,33 ^m	44,47 ± 0,53 ^{opr}
187	2,33 ± 0,00 ^a	20,33 ± 0,33 ⁿ	56,44 ± 0,73 ^{bc}
188	2,00 ± 0,00 ^c	60,67 ± 0,33 ^l	45,13 ± 0,57 ^{opr}
189	2,13 ± 0,13 ^{bc}	70,33 ± 0,33 ^h	46,11 ± 1,75 ^{mnop}
190	2,04 ± 0,04 ^c	72,67 ± 0,33 ^g	45,80 ± 1,33 ^{nopr}
191	2,22 ± 0,11 ^{ab}	62,67 ± 0,33 ^k	47,00 ± 1,26 ^{lmnop}
192	2,00 ± 0,00 ^c	65,67 ± 0,33 ⁱ	47,71 ± 0,45 ^{j-p}
193	2,13 ± 0,13 ^{bc}	66,33 ± 0,33 ⁱⁱ	50,53 ± 1,94 ^{g-m}
194	2,00 ± 0,00 ^c	60,33 ± 0,33 ^l	53,47 ± 1,50 ^{c-i}
195	2,00 ± 0,00 ^c	63,67 ± 0,33 ^j	54,61 ± 2,77 ^{b-h}
196	2,00 ± 0,00 ^c	67,33 ± 0,33 ⁱ	41,53 ± 0,96 ^r
197	2,15 ± 0,08 ^{bc}	80,67 ± 0,33 ^d	50,05 ± 1,98 ⁱ⁻ⁿ
198	2,00 ± 0,00 ^c	66,50 ± 0,29 ⁱⁱ	47,86 ± 1,62 ^{j-p}
199	2,00 ± 0,00 ^c	70,67 ± 0,33 ^h	48,88 ± 1,80 ^{i-o}
200	2,12 ± 0,06 ^{bc}	66,33 ± 0,33 ⁱⁱ	44,51 ± 1,44 ^{opr}
201	2,00 ± 0,00 ^c	75,67 ± 0,33 ^e	48,84 ± 1,45 ^{i-o}
203	2,00 ± 0,00 ^c	62,33 ± 0,33 ^k	51,59 ± 0,73 ^{e-k}
205	2,00 ± 0,00 ^c	66,67 ± 0,33 ⁱⁱ	47,32 ± 1,23 ^{j-p}
206	2,35 ± 0,05 ^a	70,67 ± 0,33 ^h	53,53 ± 1,92 ^{b-i}
207	2,07 ± 0,07 ^{bc}	63,67 ± 0,33 ^j	50,98 ± 2,12 ^{f-l}
208	2,00 ± 0,00 ^c	66,33 ± 0,33 ⁱⁱ	44,00 ± 0,40 ^{pr}
209	2,13 ± 0,13 ^{bc}	66,00 ± 0,58 ⁱ	54,03 ± 3,04 ^{b-i}
210	2,06 ± 0,06 ^{bc}	70,67 ± 0,33 ^h	45,75 ± 0,72 ^{nopr}
211	2,00 ± 0,00 ^c	83,67 ± 0,33 ^c	48,51 ± 0,36 ^{j-p}
212	2,00 ± 0,00 ^c	75,67 ± 0,33 ^e	47,76 ± 0,69 ^{j-p}
213	2,00 ± 0,00 ^c	83,33 ± 0,33 ^c	50,21 ± 0,82 ^{h-n}
214	2,11 ± 0,11 ^{bc}	75,67 ± 0,33 ^e	47,11 ± 2,42 ^{k-p}
215	2,05 ± 0,05 ^c	83,33 ± 0,33 ^c	51,18 ± 1,71 ^{f-l}
216	2,11 ± 0,11 ^{bc}	70,67 ± 0,33 ^h	44,74 ± 2,08 ^{opr}

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Continuation of Table 4.4

Mean	2,06	68,15	48,70
Min	2,00	20,33	41,53
Max	2,35	83,67	56,44
Commercial cultivars	Germination Time (days)	Germination Rate (%)	Flowering Time (days)
Earthwalker F1*	2,00 ± 0,00 ^c	93,33 ± 0,33 ^a	56,12 ± 0,06 ^{bcd}
All Sort Mix F1*	2,00 ± 0,00 ^c	90,67 ± 0,33 ^b	54,58 ± 1,37 ^{b-h}
Autumn Beauty F1*	2,00 ± 0,00 ^c	93,67 ± 0,33 ^a	58,02 ± 2,11 ^{ab}
Dwarf Big Smile F1*	2,00 ± 0,00 ^c	93,33 ± 0,33 ^a	48,47 ± 0,07 ^{j-p}
Dwarf Teddy Bear F1*	2,00 ± 0,00 ^c	93,33 ± 0,33 ^a	51,80 ± 0,57 ^{d-j}
Dwarf Incredible F1*	2,00 ± 0,00 ^c	93,67 ± 0,33 ^a	60,73 ± 0,90 ^a
Abendsonne Red F1*	2,00 ± 0,00 ^c	93,33 ± 0,33 ^a	51,50 ± 0,25 ^{e-l}
Lemon Queen F1*	2,00 ± 0,00 ^c	93,67 ± 0,33 ^a	56,00 ± 1,32 ^{bcde}
Dwarf Sunspot F1*	2,00 ± 0,00 ^c	93,67 ± 0,33 ^a	58,07 ± 0,79 ^{ab}
Velvet Queen F1*	2,00 ± 0,00 ^c	93,33 ± 0,33 ^a	56,72 ± 0,64 ^{abc}
Evening Colors F1*	2,00 ± 0,00 ^c	93,67 ± 0,33 ^a	56,48 ± 1,00 ^{bc}
Deep Orange F1**	2,00 ± 0,00 ^c	93,33 ± 0,33 ^a	55,00 ± 0,44 ^{b-g}
Sunrich Orange F1**	2,00 ± 0,00 ^c	93,67 ± 0,33 ^a	55,33 ± 0,00 ^{bcdef}
Strawberry Blonde F1**	2,00 ± 0,00 ^c	93,33 ± 0,33 ^a	56,00 ± 0,00 ^{bcde}
Suntastic Pink Bicolor F1**	2,00 ± 0,00 ^c	93,33 ± 0,33 ^a	56,00 ± 0,00 ^{bcde}
Junior F1**	2,00 ± 0,00 ^c	93,67 ± 0,33 ^a	56,00 ± 0,00 ^{bcde}
Mean	2,00	93,31	55,43
Min	2,00	90,67	48,47
Max	2,00	93,67	60,73

The size of the leaves was evaluated at E4 stage on a scale of 1 to 9, with 1 being very small, 3-small, 5-medium, 7-large, and 9-very large. Results showed significant variations in leaf size among hybrids and commercial checks. The leaf size of the hybrids obtained varied between a value of 1.63 (206) and 4.47 (193), exhibiting a variation between small and medium leaf size. Five hybrids including 187, 190, 191, 206, and 213 displayed a leaf size of very small to small size, while others exhibited small to medium sizes. Results indicates that hybrids exhibited an ideal performance for ornamental purposes in terms of leaf characteristics. Because none of the hybrids obtained exhibited a large or very large sizes of leaves which is not desirable leaf trait for ornamental sunflowers. It was noticed that commercial varieties also displayed a leaf size between a value of 1.17 (Abendsonne Red) and 5.00 (Sunrich Orange, Strawberry Blonde, Suntastic Pink Bicolor, Junior), displaying a variation between very small and medium size. Divita et al. (2012) investigated the size of the leaves in various ornamental sunflower genotypes with heterosis being present.

The intensity of green color of the leaves was investigated on a scale of 1-very light, 2-light, 3-medium, 4-dark, 5-very dark and showed significant variations among hybrids and commercial cultivars. The hybrids obtained displayed an intensity between light to medium (2.68) tones (187) and dark (4.00) tones (208) of green color, with an average intensity of medium to dark green colors (Table 4.5). The color of the leaves in commercial varieties varied between a value of 2.00 and 4.00, representing an intensity between light (Dwarf Big Smile, Dwarf Teddy Bear) and darker green colors (Deep Orange). None of the hybrids developed or commercial cultivars used in the study displayed a very dark green color in the leaves. It was observed that the hybrids with purple, red, and reddish brown colored ray flowers with dark tones of sexual flowers exhibited darker green tones in the leaves, and anthocyanin accumulation was significantly dense in their leaf tips, leaf veins and entire stem (Figure 4.11).

Luczkiewicz (1975) observed anthocyanin coloration of stems, petioles, and leaf veins in 137 plants of F2 generations and determined a ratio of 3 anthocyanin:1 green coloration, suggesting monogenic inheritance of this trait, which appeared to be regulated by other genes. Anthocyanin accumulation was also detected in several parts of the plants in F1 generations (Luczkiewicz, 1975). Vedmedeva & Soroka (2016) examined various characteristics, including leaf size and color in 11 inbred lines of sunflower and reported significant variations in leaf size and number of stems per plant, while estimating the impact of mutant genes governing ray flower color and profile, dwarfness, and the number of leaves and ray flowers. It was concluded that the genes for leaf color *lb* (light brown), *lg* (light green), and *y* (yellow) were reported to have no detrimental impact on the important agronomic traits evaluated (Vedmedeva & Soroka, 2016).

Table 4.5. The leaf characteristics of the ornamental hybrids developed and commercial sunflower cultivars

Genotype	Leaf: size	Leaf: intensity of green color
129	3,78 ± 0,22 ^{abcde}	3,55 ± 0,15 ^{abcde}
185	3,89 ± 0,40 ^{abcd}	3,28 ± 0,20 ^{b-g}
186	4,00 ± 0,58 ^{abcd}	3,42 ± 0,30 ^{a-f}
187	1,68 ± 0,00 ^{de}	2,68 ± 0,00 ^{gh}
188	3,40 ± 0,40 ^{abcde}	3,40 ± 0,31 ^{a-f}
189	2,90 ± 0,25 ^{abcde}	3,51 ± 0,39 ^{abcde}
190	1,83 ± 0,38 ^{cde}	3,20 ± 0,20 ^{cdefg}
191	1,67 ± 0,38 ^{de}	3,22 ± 0,11 ^{cdefg}
192	2,87 ± 0,35 ^{abcde}	3,00 ± 0,00 ^{efgh}
193	4,47 ± 1,67 ^{abc}	3,07 ± 0,07 ^{defg}

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Continuation of Table 4.5

194	4,03 ± 1,17 ^{abcd}	2,71 ± 0,20 ^{fgh}
195	2,83 ± 0,23 ^{abcde}	3,63 ± 0,20 ^{abcde}
196	2,60 ± 0,40 ^{abcde}	3,67 ± 0,24 ^{abcde}
197	2,10 ± 0,63 ^{bcde}	3,85 ± 0,09 ^{abc}
198	3,72 ± 0,86 ^{abcde}	3,86 ± 0,07 ^{abc}
199	3,13 ± 1,27 ^{abcde}	3,93 ± 0,07 ^{ab}
200	3,13 ± 1,27 ^{abcde}	3,69 ± 0,06 ^{abcde}
201	3,78 ± 1,09 ^{abcde}	3,61 ± 0,31 ^{abcde}
203	3,60 ± 0,95 ^{abcde}	3,00 ± 0,00 ^{efgh}
205	2,56 ± 1,24 ^{abcde}	3,48 ± 0,25 ^{abcde}
206	1,63 ± 0,45 ^{de}	3,42 ± 0,30 ^{a-f}
207	2,68 ± 0,37 ^{abcde}	3,52 ± 0,29 ^{abcde}
208	2,47 ± 0,74 ^{abcde}	4,00 ± 0,00 ^a
209	3,24 ± 1,27 ^{abcde}	3,48 ± 0,44 ^{abcde}
210	3,99 ± 1,92 ^{abcd}	3,65 ± 0,24 ^{abcde}
211	3,51 ± 0,66 ^{abcde}	3,22 ± 0,40 ^{cdefg}
212	3,09 ± 0,99 ^{abcde}	3,12 ± 0,17 ^{defg}
213	1,89 ± 0,73 ^{cde}	3,67 ± 0,35 ^{abcde}
214	3,00 ± 0,39 ^{abcde}	3,72 ± 0,28 ^{abcd}
215	2,49 ± 0,38 ^{abcde}	3,75 ± 0,38 ^{abcd}
216	2,67 ± 0,19 ^{abcde}	3,39 ± 0,31 ^{a-f}
Mean	2,99	3,44
Min	1,63	2,68
Max	4,47	4,00
Commercial cultivars	Leaf: size	Leaf: intensity of green color
Earthwalker F1	3,89 ± 0,49 ^{abcd}	3,00 ± 0,00 ^{efgh}
All Sort Mix F1	3,48 ± 0,55 ^{abcde}	3,00 ± 0,00 ^{efgh}
Autumn Beauty F1	4,53 ± 1,07 ^{ab}	3,00 ± 0,00 ^{efgh}
Dwarf Big Smile F1	3,00 ± 0,23 ^{abcde}	2,00 ± 0,00 ¹

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Continuation of Table 4.5

Dwarf Teddy Bear F1	2,07 ± 0,39 ^{bcde}	2,00 ± 0,00 ¹
Dwarf Incredible F1	3,76 ± 0,04 ^{abcde}	3,00 ± 0,00 ^{efgh}
Abendsonne Red F1	1,17 ± 0,17 ^e	2,33 ± 0,33 ^{hi}
Lemon Queen F1	4,00 ± 0,33 ^{abcd}	3,00 ± 0,00 ^{efgh}
Dwarf Sunspot F1	3,47 ± 1,01 ^{abcde}	3,00 ± 0,00 ^{efgh}
Velvet Queen F1	3,56 ± 0,11 ^{abcde}	3,00 ± 0,00 ^{efgh}
Evening Colors F1	4,15 ± 0,18 ^{abcd}	3,00 ± 0,00 ^{efgh}
Deep Orange F1	4,89 ± 0,99 ^a	4,00 ± 0,00 ^a
Sunrich Orange F1	4,33 ± 0,00 ^{abc}	3,00 ± 0,00 ^{efgh}
Strawberry Blonde F1	5,00 ± 0,00 ^a	3,00 ± 0,00 ^{efgh}
Suntastic Pink Bicolor F1	5,00 ± 0,00 ^a	3,00 ± 0,00 ^{efgh}
Junior F1	5,00 ± 0,00 ^a	3,00 ± 0,00 ^{efgh}
Mean	3,83	2,90
Min	1,17	2,00
Max	5,00	4,00

Plant height is a crucial parameter, determining the use of sunflower as an indoor potted or outdoor ornamental plant. Results showed that there were significant variations among the hybrids for plant height, which ranged from 154.6 cm (187) to 65.9 cm (190). A significant variation also existed among the 16 commercial varieties evaluated in the study (Table 4.6). The heights of the tallest variety was 172.7 cm (Autumn Beauty), while the height of the dwarf type was determined to be 38.8 cm (Dwarf Big Smile), respectively. These findings are in line with those of Vuppalapati (2005). Vuppalapati (2005) studied variability in plant height using 18 varieties of ornamental sunflowers including “Velvet Queen” and “Dwarf Teddy Bear” which were also used in this thesis. He reported that plant height of varieties ranged from 46 cm to 198 cm. Cvejic et al. (2016) reported that plant height of ornamental sunflowers varied between 122 cm and 161 cm. Similar to our results big variations in plant height were reported by Mladenović et al. (2016). Mladenović et al. (2017) found that plant height ranged between 36.9 cm and 195 cm, indicating that these genotypes can be used for different purposes in terms of ornamental perspective. In the study of Silva et al. (2018), morphological characteristics of ornamental sunflowers such as plant height, stem diameter, disc diameter, and flower head diameter, when harvested at R5.5 stage were investigated. Silva et al. (2018) reported that plant height varied between 100-138.5 cm. Sloan & Harkness (2010) tested the stem lengths of three ornamental sunflower varieties and observed that it varied from 159 cm to 198 cm. Divita et al. (2012) determined that ornamental sunflower hybrids exhibited heterosis in plant height. The big variation found in the plant height of sunflower hybrids developed in this thesis demonstrates the

suitability of them in different areas of use such as balconies, gardens, borders, and interior designs.

The branching status of the hybrids was evaluated on a scale of 1-absent, 9-present. As branching was present in both parental lines within each of crossing combinations, hybrids obtained exhibited branching at different levels. Results indicated that the majority of hybrids (67%) had dense branching with a scale value of 9.00, while other genotypes exhibited a variation between a value of 3.50, representing a sparse branching, and a value of 8.70, representing a very dense branching (Table 4.6). The hybrids with dense branching might be well suited for outdoor plant use. In commercial F1 cultivars, branching varied between a value of 1.00 and 9.00. Among those cultivars with no branching (single-headed) including “Dwarf Incredible”, “Deep Orange”, and “Sunrich Orange” are exclusively used for cut flower. Partial branching was observed in “All Sort Mix”, Dwarf Teddy Bear”, “Abendsonne Red”, “Dwarf Sunspot” and “Junior” varieties.

Branching position was evaluated on a scale of 1-only basal, 2-predominantly basal, 3-overall, 4-predominantly apical, 5-only apical, 6-none (branching is absent). Results showed that differences in branching position among hybrids and cultivars were significant. In the hybrids, the branching position varied between a value of 3.15 and 5.58. The 25% of the hybrids exhibited complete branching, while 65% of them had branching at predominantly apical positions, and the remaining 10% developed branching only in the upper parts of the stem (Table 4.6). Similar variations was also observed in commercial F1 varieties. Moreover, no basal branching was observed in the hybrids evaluated. However, in the experiment of vase life evaluation, when stems harvested at 55 cm, it was noticed that single-headed varieties formed basal branching. This condition was interpreted as a reaction of the plant in response to the pinching stress (removal of apical meristematic regions) caused by harvesting.

When using ornamental sunflowers in landscape settings, branching is a desirable trait since it allows for a more compact plant architecture, which will let the plant to cover a larger area. In addition, in genotypes displaying branching, the length of the side branches and the number of branches per plant are also significant factors, determining the potential of ornamental sunflowers for use in landscape designs. The number of branches per plant is directly correlated to the position of the branching. Armitage & Laushman (2003) suggested that in the use of ornamental sunflowers as cut flowers, single-headed (non-branching) varieties displayed more favourable flower head diameter and quality of overall inflorescence. In a study of heterosis estimation, Cvejic et al. (2017) investigated traits such as flowering time, number of branches per plant, the length of the branches, and lateral inflorescence diameter of the hybrid sunflowers derived from the combination of four sunflower genotypes and reported heterosis for the number of branches and flowering period of side branches. Additionally, Wien (2016a) suggested that number of side branches per plant could be increased by pinching applications, which provides positive advantages to ornamental sunflowers for use in different areas. Mladenović et al. (2017) studied branching positions in sunflower genotypes and reported that branching along the entire stem was observed in 79% of the genotypes. Branching ability and number of branches have a positive effect in terms of ornamental perspective due to the different flowering times of genotypes, considering the long time period of flowering which can be achieved in landscape arrangements. Sandu et al. (1999)

investigated recessive branching trait by employing seven inbred lines with various branching types, observing that the trait displaying non-branching type in F1 populations was determined to be dominant over other branching types defined by seven specific alleles.

Observations for flower head attitude was recorded at F3.2 stage, using a scale of 1-horizontal, 2-inclined, 3-vertical, 4-half-turned down, 5-turned down, 6-over turned. Results regarding flower head attitude were presented at Table 4.6. The findings indicated that hybrids and cultivars differed significantly in their flower head attitude. Results indicated that the hybrids obtained exhibited a head attitude between a value of 2.22 (188), showcasing an attitude between inclined and vertical position, and a value of 3.31 (212), representing an attitude between vertical and half-turned down position (Table 4.6). Flower head attitude between vertical and inclined position was observed in the 90.32% of the hybrids. Commercial F1 hybrids evaluated varied between a value of 1.57 (Dwarf Teddy Bear) and 3.00 (Velvet Queen). In the diverse utilisation areas of ornamental sunflowers, including cut flowers and landscaping designs, the flower head position should represent a position between the vertical and inclined position for aesthetic appearance.

Mladenovic et al. (2017) observed the position of flower heads of ornamental sunflowers as 82.7% of vertical position, and the rest of the genotypes exhibited horizontal, inclined, and turned flower head attitude. Kováčik & Škaloud (1990) investigated the inheritance of four significantly important characteristics influencing yield in sunflower, such as flower head attitude, pollen fertility, branching, and the genetic determinants of these polygenic traits and reported that flower head attitude is governed by 12 genes. Kluza-Wieloch (2005), using common sunflower populations, examined several flower head traits including flower head attitude and diameter, disc flower diameter, thickness of the receptacle, and differences in flower head diameter during maturation in three consecutive years. He found that variations were great in hybrids, and that one of the hybrids exhibited the widest flower head attitude and the thickest receptacle, while the other hybrids performed an advantageous performance at an angle between 180° and 250°, exhibiting an angle between half-turned down and over-turned down positions, with a value between 3.63 and 4.23. However, such attitudes are more likely to be prevalent in common sunflower populations and known to be undesirable in ornamental sunflower varieties.

Table 4.6. The plant height, branching characteristics, and attitude of the inflorescence of the ornamental hybrids developed and commercial sunflower cultivars

Genotype	Plant Height (cm)	Branching Status	Position of Branching	Flower Head Attitude
129	146,80 ± 0,46 ^{abcd}	8,62 ± 0,38 ^a	4,48 ± 0,17 ^{d-i}	2,79 ± 0,12 ^{b-i}
185	137,70 ± 8,80 ^{a-g}	9,00 ± 0,00 ^a	4,16 ± 0,17 ^{e-i}	2,50 ± 0,00 ^{ghij}
186	132,60 ± 7,71 ^{b-i}	9,00 ± 0,00 ^a	3,62 ± 0,07 ^{h-j}	3,00 ± 0,00 ^{a-f}
187	154,68 ± 0,00 ^{ab}	6,33 ± 0,00 ^{cd}	5,33 ± 0,00 ^{abcd}	2,33 ± 0,00 ^{ijk}

(continues the next page)

Continuation of Table 4.6

188	116,72 ± 7,02 ^{c-m}	9,00 ± 0,00 ^a	3,15 ± 0,08 ^{ij}	2,22 ± 0,12 ^{jk}
189	94,44 ± 3,26 ^{i-o}	8,47 ± 0,53 ^{ab}	3,90 ± 0,65 ^{e-j}	2,89 ± 0,06 ^{a-i}
190	65,93 ± 4,45 ^{op}	8,67 ± 0,33 ^a	4,33 ± 0,41 ^{d-i}	2,83 ± 0,17 ^{a-i}
191	92,10 ± 3,71 ^{j-o}	9,00 ± 0,00 ^a	4,00 ± 0,39 ^{e-j}	2,61 ± 0,15 ^{e-j}
192	104,27 ± 0,37 ^{f-n}	9,00 ± 0,00 ^a	4,24 ± 0,04 ^{d-i}	3,00 ± 0,00 ^{a-f}
193	135,33 ± 15,30 ^{b-h}	6,33 ± 1,92 ^{cd}	5,00 ± 0,35 ^{abcde}	3,13 ± 0,18 ^{abcd}
194	141,00 ± 24,66 ^{a-f}	3,49 ± 1,39 ^e	5,58 ± 0,21 ^{abc}	3,00 ± 0,23 ^{a-f}
195	122,20 ± 9,18 ^{b-k}	9,00 ± 0,00 ^a	4,53 ± 0,29 ^{b-i}	3,07 ± 0,07 ^{abcde}
196	88,40 ± 7,00 ^{klmno}	9,00 ± 0,00 ^a	4,53 ± 0,29 ^{b-i}	2,67 ± 0,13 ^{d-j}
197	78,15 ± 6,49 ^{no}	9,00 ± 0,00 ^a	4,31 ± 0,34 ^{d-i}	2,74 ± 0,05 ^{c-i}
198	122,80 ± 8,01 ^{b-k}	9,00 ± 0,00 ^a	4,42 ± 0,21 ^{d-i}	2,97 ± 0,12 ^{a-g}
199	130,83 ± 10,24 ^{b-i}	9,00 ± 0,00 ^a	4,05 ± 0,46 ^{e-j}	2,89 ± 0,06 ^{a-i}
200	94,28 ± 9,76 ^{i-o}	9,00 ± 0,00 ^a	3,94 ± 0,48 ^{e-j}	2,57 ± 0,12 ^{f-j}
201	128,56 ± 8,92 ^{b-j}	8,55 ± 0,45 ^{ab}	4,55 ± 0,28 ^{b-i}	2,84 ± 0,09 ^{a-i}
203	115,82 ± 11,44 ^{d-m}	9,00 ± 0,00 ^a	4,06 ± 0,47 ^{e-j}	2,88 ± 0,06 ^{a-i}
205	97,90 ± 18,16 ^{i-o}	9,00 ± 0,00 ^a	4,34 ± 0,57 ^{d-i}	2,67 ± 0,18 ^{d-j}
206	121,48 ± 5,15 ^{b-l}	9,00 ± 0,00 ^a	4,87 ± 0,07 ^{bcdef}	2,47 ± 0,29 ^{hijk}
207	116,19 ± 7,84 ^{c-m}	9,00 ± 0,00 ^a	3,68 ± 0,41 ^{b-j}	2,66 ± 0,07 ^{d-j}
208	96,33 ± 6,18 ^{i-o}	9,00 ± 0,00 ^a	3,87 ± 0,37 ^{e-j}	2,87 ± 0,07 ^{a-i}
209	142,51 ± 16,48 ^{abcde}	8,47 ± 0,53 ^{ab}	4,74 ± 0,29 ^{b-h}	2,67 ± 0,44 ^{d-j}
210	121,02 ± 18,50 ^{b-l}	8,11 ± 0,89 ^{ab}	4,33 ± 0,56 ^{d-i}	2,86 ± 0,07 ^{a-i}
211	116,13 ± 11,20 ^{c-m}	7,04 ± 0,99 ^{bc}	4,86 ± 0,28 ^{b-g}	3,23 ± 0,05 ^{ab}
212	102,51 ± 13,43 ^{g-n}	9,00 ± 0,00 ^a	4,27 ± 0,47 ^{d-i}	3,31 ± 0,06 ^a
213	84,52 ± 15,17 ^{lmno}	9,00 ± 0,00 ^a	3,95 ± 0,55 ^{e-j}	2,53 ± 0,12 ^{f-j}
214	105,50 ± 11,99 ^{f-n}	9,00 ± 0,00 ^a	3,71 ± 0,21 ^{g-j}	3,11 ± 0,06 ^{abcd}
215	94,22 ± 8,18 ^{i-o}	9,00 ± 0,00 ^a	4,25 ± 0,41 ^{d-i}	2,54 ± 0,09 ^{f-j}
216	95,03 ± 9,22 ^{i-o}	9,00 ± 0,00 ^a	4,27 ± 0,37 ^{d-i}	2,69 ± 0,24 ^{d-j}
Mean	112,77	8,49	4,30	2,79
Min	65,93	3,49	3,15	2,22
Max	154,68	9,00	5,33	3,31
Commercial cultivars	Plant Height (cm)	Branching Status	Position of Branching	Flower Head Attitude
Earthwalker F1	143,47 ± 3,16 ^{abcd}	9,00 ± 0,00 ^a	3,68 ± 0,27 ^{b-j}	3,19 ± 0,12 ^{abc}
All Sort Mix F1	99,08 ± 34,75 ^{h-o}	7,58 ± 0,78 ^{abc}	4,09 ± 0,55 ^{e-j}	2,43 ± 0,23 ^{ijkl}
Autumn Beauty F1	172,72 ± 11,04 ^a	9,00 ± 0,00 ^a	3,73 ± 0,18 ^{f-j}	2,68 ± 0,22 ^{d-j}

(continues the next page)

Continuation of Table 4.6

Dwarf Big Smile F1	38,87 ± 2,57 ^p	9,00 ± 0,00 ^a	3,00 ± 0,42 ^j	2,40 ± 0,12 ^{ijk}
Dwarf Teddy Bear F1	42,03 ± 2,09 ^p	8,47 ± 0,53 ^{ab}	3,97 ± 0,33 ^{e-j}	2,02 ± 0,19 ^k
Dwarf Incredible F1	80,83 ± 3,33 ^{mno}	1,00 ± 0,00 ^f	6,00 ± 0,00 ^a	2,93 ± 0,07 ^{a-h}
Abendsonne Red F1	77,70 ± 1,73 ^{no}	7,93 ± 1,07 ^{ab}	3,57 ± 0,35 ^{ijj}	1,57 ± 0,23 ^l
Lemon Queen F1	153,17 ± 3,82 ^{abc}	9,00 ± 0,00 ^a	4,00 ± 0,10 ^{e-j}	3,00 ± 0,00 ^{a-f}
Dwarf Sunspot F1	73,80 ± 9,90 ^{no}	1,59 ± 0,51 ^f	5,61 ± 0,31 ^{ab}	3,19 ± 0,01 ^{abc}
Velvet Queen F1	144,00 ± 4,76 ^{abcd}	9,00 ± 0,00 ^a	3,89 ± 0,20 ^{e-j}	3,22 ± 0,05 ^{abc}
Evening Colors F1	143,74 ± 12,19 ^{abcd}	9,00 ± 0,00 ^a	3,71 ± 0,20 ^{g-j}	2,47 ± 0,10 ^{hijk}
Deep Orange F1	149,72 ± 8,14 ^{abcd}	1,00 ± 0,00 ^f	6,00 ± 0,00 ^a	2,50 ± 0,19 ^{ghijj}
Sunrich Orange F1	105,00 ± 0,00 ^{f-n}	1,00 ± 0,00 ^f	6,00 ± 0,00 ^a	3,00 ± 0,00 ^{a-f}
Strawberry Blonde F1	137,00 ± 0,00 ^{a-g}	9,00 ± 0,00 ^a	3,00 ± 0,00 ^j	3,00 ± 0,00 ^{a-f}
Suntastic Pink Bicolor F1	106,00 ± 0,00 ^{e-n}	5,00 ± 0,00 ^d	4,50 ± 0,00 ^{c-i}	3,00 ± 0,00 ^{a-f}
Junior F1	106,00 ± 0,00 ^{e-n}	9,00 ± 0,00 ^a	3,00 ± 0,00 ^j	3,00 ± 0,00 ^{a-f}
Mean	110,82	6,60	4,23	2,73
Min	38,87	1,00	3,00	1,57
Max	172,72	9,00	6,00	3,22

Characteristics of ray flowers including width, density, and overall profile and attitude are one of the most important traits concerning ornamental potential of sunflowers. The width in relation to length of ray flowers were recorded on a scale of 1-very narrow, 2-narrow, 3-broad, 4-very broad. Based on the results of the analyses, the differences observed in ray flower width among the hybrids were significant and the hybrids displayed a width ranging from 1.00, exhibiting very narrow (201) to 3.00, showing a broad shape of ray flowers (193) (Table 4.7). Out of 31 hybrids, 20 of them exhibited leaf width between narrow and broad and only one of them (193) exhibited broad shape. In the case of F1 commercial varieties, none of the varieties exhibited a very narrow shape in contrast to hybrids obtained. Out of 16 varieties evaluated, only two of the varieties (All Sort Mix, Earthwalker) displayed a ray flower between narrow and broad shape with a value of 2.33. Four of the varieties exhibited a broad shape (Autumn Beauty, Dwarf Big Smile, Deep Orange, Dwarf Teddy Bear). The rest of the varieties displayed a narrow shape. Remarkable variations was observed in ray flower width in this study. It was concluded that these results might differ from variety to variety in ornamental sunflowers.

Ray flower profile was evaluated on a scale of 1-flat, 2-rolled, 3-twisted, 4-strongly recurved. The results showed that 87% of the hybrids had a flat type ray flower profile. Among the hybrids, one genotype (194) exhibited a ray flower between rolled and twisted profile, while another genotype (212) showed a profile between flat and rolled. Out of 16 commercial varieties investigated, only “Abendsonne Red” exhibited a profile between flat and rolled, and rest of them had flat type ray flower profile (Table 4.7).

Density of the ray flowers was evaluated on a scale of 1-very sparse, 2-sparse, 3-medium, 4-dense, 5-very dense. The findings indicated that hybrids and cultivars differed significantly in their ray flower density except one hybrid (216). Ray flower density of hybrids varied between a value of 4.00 (187) and 4.95 (207), indicating dense to very dense structure respectively. It was concluded that these values were remarkably satisfactory in terms of determining the ornamental potential of sunflower hybrids. Commercial hybrids evaluated exhibited a ray flower density between 1.67 (Abendsonne Red) and 5.00 (Deep Orange, Dwarf Big Smile, Dwarf Teddy Bear).

Attitude of ray flowers' base in relation to head (ray flower attitude) were recorded on a scale of 1-erect, 2-semi-erect, 3-horizontal. In bouquets and floral arrangements, ornamental sunflowers are supposed to have a semi-erect ray flower attitude, which is the desired quality that vendors accept for use as cut flowers. According to the results of the analysis of variance, the differences in ray flower attitude among hybrids were significant and varied between 1.84 (194), representing a semi-erect ray flower attitude, and 2.93 (192), showcasing an horizontal attitude in relation to head. 20 out of 31 hybrids (65%) represented a semi-erect attitude in ray flowers. In contrast to hybrids no variation was observed among the commercial cultivars in terms of ray flower attitude and all of them displayed a semi-erect ray flower attitude, with a value of 2.00 (Table 4.7).

The variation in ray flower characteristics among sunflower cultivars and in other ornamentals were also reported by other researchers. Dowell et al. (2019) using 288 ornamental sunflower inbred lines investigated 14 morphological traits including the density, width, length, and number of the ray flowers, in both greenhouse and field conditions for association mapping studies and found great variations for these traits. They reported that the length of the ray flowers ranged between 1.4 and 7.1 cm, the width ranged between 0.5 and 4.6 cm, the number of ray flowers for each inflorescence was between 16 and 49.3, and the ray flower density was estimated to be 0.39-4.55 ray flowers in each cm of disc radius under greenhouse conditions. Similarly, Elisheba & Sudhagar (2021) investigated 50 sunflower genotypes for various morphological traits including ray flower density, which varied greatly from sparse to dense. Tanajiaro (2019) studied ray flower characteristics including shape (profile) and density in 13 ornamental sunflower cultivars. The researcher reported that 12 out of 13 genotypes exhibited ovate ray flower shape, while only "Lemon Queen" variety showed lanceolate ray flower shape. In terms of the ray flower density, "Lemon Queen" showed the best results out of all commercial varieties, while "Autumn Beauty" exhibited very low results. Similarly, in a study of Patil (2018) that investigated which ornamental sunflower cultivars were the most suitable for open field cultivation, it was found that ray flower density varied among the cultivars and "Lemon Queen", "Large Bloom Sunflower", "Velvet Queen", "Moonwalker", and "Mammoth Russian" varieties produced the most dense ray flowers. However, there were no discernible differences between F1 hybrids and parental lines in the study by Divita et al. (2012) that examined the density of ray flowers in hybrids and parental inbred sunflower lines. Kale (2002) investigated ray flower density in *Gaillardia pulchella* genotypes and reported great variations. Nair & Shiva (2003) investigated 25 *Gerbera jamesonii* genotypes to evaluate morphological performances and reported that number of ray flowers had a correlation with flower yield. In contrast to the study of Tanajiaro (2019), the profile of ray flowers displayed both ovate and lanceolate shapes,

particularly in lemon colored flowers developed. This trait varied depending on the width in relation to length of ray flowers.

Table 4.7. The ray flower characteristics of the ornamental hybrids and commercial sunflower cultivars

Genotype	Ray Flower Width	Ray Flower Profile	Ray Flower Density	Ray Flower Attitude
129	1,87 ± 0,24 ^{g-j}	1,00 ± 0,00 ^c	4,36 ± 0,23 ^{abc}	2,59 ± 0,23 ^{abcde}
185	2,33 ± 0,17 ^{bcdef}	1,17 ± 0,17 ^{bc}	4,72 ± 0,20 ^{ab}	2,67 ± 0,10 ^{abcd}
186	2,27 ± 0,27 ^{cdefg}	1,00 ± 0,00 ^c	4,57 ± 0,23 ^{ab}	2,38 ± 0,07 ^{a-f}
187	2,68 ± 0,00 ^{ab}	1,00 ± 0,00 ^c	4,00 ± 0,00 ^{bcde}	2,00 ± 0,00 ^{ef}
188	2,02 ± 0,13 ^{d-j}	1,00 ± 0,00 ^c	4,23 ± 0,38 ^{abcd}	2,87 ± 0,13 ^{ab}
189	2,05 ± 0,13 ^{d-i}	1,00 ± 0,00 ^c	4,39 ± 0,10 ^{abc}	2,40 ± 0,20 ^{a-f}
190	2,24 ± 0,18 ^{c-h}	1,00 ± 0,00 ^c	4,54 ± 0,07 ^{ab}	2,72 ± 0,17 ^{abcd}
191	2,05 ± 0,15 ^{d-i}	1,00 ± 0,00 ^c	4,34 ± 0,20 ^{abc}	2,50 ± 0,10 ^{abcde}
192	2,56 ± 0,18 ^{bc}	1,00 ± 0,00 ^c	4,31 ± 0,17 ^{abcd}	2,93 ± 0,07 ^a
193	3,00 ± 0,12 ^a	1,00 ± 0,00 ^c	4,73 ± 0,07 ^{ab}	2,67 ± 0,18 ^{abcd}
194	2,36 ± 0,16 ^{bcde}	2,29 ± 0,35 ^a	4,69 ± 0,17 ^{ab}	1,84 ± 0,26 ^f
195	2,13 ± 0,13 ^{d-i}	1,00 ± 0,00 ^c	4,47 ± 0,29 ^{abc}	2,67 ± 0,24 ^{abcd}
196	1,73 ± 0,18 ^{ij}	1,00 ± 0,00 ^c	4,47 ± 0,29 ^{abc}	2,40 ± 0,42 ^{a-f}
197	2,11 ± 0,05 ^{d-i}	1,00 ± 0,00 ^c	4,43 ± 0,07 ^{abc}	2,31 ± 0,08 ^{bcdef}
198	2,08 ± 0,13 ^{d-i}	1,00 ± 0,00 ^c	4,69 ± 0,10 ^{ab}	2,25 ± 0,14 ^{cdef}
199	2,21 ± 0,12 ^{c-i}	1,00 ± 0,00 ^c	4,58 ± 0,10 ^{ab}	2,80 ± 0,12 ^{abc}
200	1,82 ± 0,19 ^{hij}	1,00 ± 0,00 ^c	4,44 ± 0,08 ^{abc}	2,47 ± 0,29 ^{abcde}
201	1,00 ± 0,00 ^k	1,00 ± 0,00 ^c	4,67 ± 0,17 ^{ab}	2,44 ± 0,06 ^{abcde}
203	2,19 ± 0,10 ^{c-i}	1,00 ± 0,00 ^c	4,47 ± 0,03 ^{abc}	2,03 ± 0,17 ^{ef}
205	2,13 ± 0,07 ^{d-i}	1,00 ± 0,00 ^c	4,23 ± 0,28 ^{abcd}	2,62 ± 0,02 ^{abcd}
206	1,93 ± 0,07 ^{e-j}	1,00 ± 0,00 ^c	4,65 ± 0,13 ^{ab}	2,18 ± 0,32 ^{def}
207	2,10 ± 0,10 ^{d-i}	1,00 ± 0,00 ^c	4,95 ± 0,05 ^a	2,23 ± 0,03 ^{cdef}
208	1,80 ± 0,12 ^{ij}	1,00 ± 0,00 ^c	4,73 ± 0,18 ^{ab}	2,33 ± 0,47 ^{bcdef}
209	2,22 ± 0,25 ^{c-i}	1,00 ± 0,00 ^c	4,48 ± 0,25 ^{abc}	2,24 ± 0,35 ^{cdef}
210	1,93 ± 0,07 ^{e-j}	1,00 ± 0,00 ^c	4,52 ± 0,08 ^{ab}	2,59 ± 0,24 ^{abcde}
211	2,41 ± 0,05 ^{bcd}	1,00 ± 0,00 ^c	4,87 ± 0,13 ^a	2,30 ± 0,15 ^{bcdef}
212	2,32 ± 0,08 ^{bcdef}	1,37 ± 0,19 ^b	4,52 ± 0,19 ^{ab}	2,43 ± 0,12 ^{a-f}

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Continuation of Table 4.7

213	1,90 ± 0,05 ^{f-j}	1,00 ± 0,00 ^c	4,69 ± 0,10 ^{ab}	2,81 ± 0,10 ^{abc}
214	1,94 ± 0,11 ^{e-j}	1,00 ± 0,00 ^c	4,61 ± 0,15 ^{ab}	2,55 ± 0,22 ^{abcde}
215	1,61 ± 0,06 ^j	1,12 ± 0,12 ^{bc}	4,42 ± 0,14 ^{abc}	2,45 ± 0,21 ^{abcde}
216	2,12 ± 0,06 ^{d-i}	1,00 ± 0,00 ^c	3,73 ± 0,23 ^{cdef}	2,69 ± 0,17 ^{abcd}
Mean	2,10	1,06	4,50	2,46
Min	1,00	1,00	3,73	1,84
Max	3,00	2,29	4,95	2,93
Commercial cultivars	Ray Flower Width	Ray Flower Profile	Ray Flower Density	Ray Flower Attitude
Earthwalker F1	2,33 ± 0,33 ^{bcdef}	1,00 ± 0,00 ^c	4,67 ± 0,33 ^{ab}	2,00 ± 0,00 ^{ef}
All Sort Mix F1	2,33 ± 0,18 ^{bcdef}	1,00 ± 0,00 ^c	3,60 ± 0,31 ^{def}	2,00 ± 0,00 ^{ef}
Autumn Beauty F1	3,00 ± 0,00 ^a	1,00 ± 0,00 ^c	3,73 ± 0,37 ^{cdef}	2,00 ± 0,00 ^{ef}
Dwarf Big Smile F1	3,00 ± 0,00 ^a	1,00 ± 0,00 ^c	5,00 ± 0,00 ^a	2,00 ± 0,00 ^{ef}
Dwarf Teddy Bear F1	3,00 ± 0,00 ^a	1,00 ± 0,00 ^c	5,00 ± 0,00 ^a	2,00 ± 0,00 ^{ef}
Dwarf Incredible F1	2,00 ± 0,00 ^{d-j}	1,00 ± 0,00 ^c	2,60 ± 0,40 ^g	2,00 ± 0,00 ^{ef}
Abendsonne Red F1	2,00 ± 0,00 ^{d-j}	1,33 ± 0,33 ^b	1,67 ± 0,67 ^h	2,00 ± 0,00 ^{ef}
Lemon Queen F1	2,00 ± 0,00 ^{d-j}	1,05 ± 0,05 ^c	3,73 ± 0,57 ^{cdef}	2,00 ± 0,00 ^{ef}
Dwarf Sunspot F1	2,00 ± 0,00 ^{d-j}	1,00 ± 0,00 ^c	4,77 ± 0,23 ^{ab}	2,00 ± 0,00 ^{ef}
Velvet Queen F1	2,00 ± 0,00 ^{d-j}	1,00 ± 0,00 ^c	3,00 ± 0,00 ^{fg}	2,00 ± 0,00 ^{ef}
Evening Colors F1	2,00 ± 0,00 ^{d-j}	1,00 ± 0,00 ^c	3,33 ± 0,18 ^{ef}	2,00 ± 0,00 ^{ef}
Deep Orange F1	3,00 ± 0,00 ^a	1,00 ± 0,00 ^c	5,00 ± 0,00 ^a	2,00 ± 0,00 ^{ef}
Sunrich Orange F1	2,00 ± 0,00 ^{d-j}	1,00 ± 0,00 ^c	3,00 ± 0,00 ^{fg}	2,00 ± 0,00 ^{ef}
Strawberry Blonde F1	2,00 ± 0,00 ^{d-j}	1,00 ± 0,00 ^c	3,00 ± 0,00 ^{fg}	2,00 ± 0,00 ^{ef}
Suntastic Pink Bicolor F1	2,00 ± 0,00 ^{d-j}	1,00 ± 0,00 ^c	3,00 ± 0,00 ^{fg}	2,00 ± 0,00 ^{ef}
Junior F1	2,00 ± 0,00 ^{d-j}	1,00 ± 0,00 ^c	3,00 ± 0,00 ^{fg}	2,00 ± 0,00 ^{ef}
Mean	2,29	1,02	3,63	2,00
Min	2,00	1,00	1,67	2,00
Max	3,00	1,33	5,00	2,00

Flower head diameter was measured across the tips of the ray flowers from one end to the other end at F3.2 stage with a digital caliper. Based on the results obtained in the Table 4.8, the flower head diameters of the hybrids ranged from 16.39 cm (188) to 10.44 cm (208) and these differences were statistically significant. The variety with the largest flower head displayed a diameter of 15.08 cm (Sunrich Orange) and the variety with the smallest head diameter was recorded as 6.18 cm (Abendsonne Red). Several researchers have suggested to use cut sunflowers with a head diameter of 10-15 cm for floral arrangements and those with a head diameter of 7-8 cm for bouquets (Carrillo-Ávila et al., 2015; Melgares, 2001). Sloan & Harkness (2006) also stated 8-15 cm of flower head diameter is recommended by florists for use as cut flower varieties. Results indicate that the hybrids developed in this study possess a potential for use as cut flowers in respect to flower diameter. Tanajiaro (2019) experimented several morphological traits in 13 ornamental sunflower genotypes, including flower head diameter which varied from 5.8 cm to 15.2 cm which is in agreement with results found in this study. The significant variation in flower head diameter of ornamental sunflowers has also been reported by other researchers. Vuppalapati (2005) reported variability in flower head diameter ranging from 8 cm to 28 cm. Mladenović et al. (2017) reported that flower head diameter was between 4.5-14 cm. Kluza-Wieloch (2005) reported that flower head diameter in three cultivars of common sunflower ranged between 15.5 and 17.3 cm in three consecutive years of observations. Sloan & Harkness (2010) experimented three varieties of ornamental sunflowers and found that flower head diameter ranged between 16-21 cm. In addition, in a study comparing commercial sunflower cultivars in terms of their suitability for cut flower purposes, the variety “Sunbright Supreme” was found to be unacceptable with a flower diameter of 4.94 cm, while the F1 “Vincent’s Choice” was found to be suitable with 13.45 cm (Sloan & Harkness, 2006). Apart from genetic conditions, cultivation conditions including planting space and fertilization might have a significant effect on flower size. Cadeac (1988) investigated the size of the inflorescence in common sunflower and reported that the diameter ranged between 16.9 and 20.7 cm, and nitrogen fertilizer application resulted in a decrease in the size of the inflorescence. Süzer (1998) determined that an increase in phosphorus fertilizer dose had no significant impact on flower head diameter.

Disc flowers, also known as the sexual flowers, are only located in the centre of the flower head with a rounded shape. The diameter of disc flower region was measured from one end to the other, excluding ray flowers. The diameter of the disc flowers exhibited significant differences among hybrids and commercial cultivars. Among hybrids, disc flower diameters ranged from 6.52 cm (186) and 4.17 cm (206). In commercial varieties evaluated, this value varied between 2.42 cm (Abendsonne Red) and 6.06 cm (Lemon Queen) in fertile varieties, while in sterile varieties it ranged from 5.16 cm (Suntastic Pink Bicolor) to 7.10 cm (Sunrich Orange). The variation in diameter of disc flower has also been reported by Cadeac (1988) who investigated the size of the inflorescence in common sunflower and reported that the disc flower diameter ranged between 5.60 and 7.40 cm. Silva et al. (2018) evaluated the disc diameter of ornamental sunflowers which varied between 1.9 cm and 6 cm. Terbea & Stoenescu (1984) noticed an increase in disc flower diameter as the planting density increased, however in the study of Kluza-Wieloch (2005), this effect was not confirmed. Tanajiaro (2019) investigated important characteristics of numerous ornamental sunflower genotypes including disc flowers which varied between 3.1 cm and 9.3 cm. Wien (2016a; 2017) categorized disc

flowers in three groups; where the small size of disc flowers having 4-6 cm, a medium size having 6-8 cm and the large size of disc flowers having more than 8 cm and decided that disc flowers having less than 3.81 cm were undesirable in terms of ornamental perspectives (Wien, 2012; 2014). According to this statement, hybrids obtained in this study can be categorised into two groups as small and medium-sized disc flowers and all of which is considered desirable for ornamental industry.

Cut sunflowers must be harvested at the longest possible length. Therefore, stem length of ornamental sunflowers partially determines the cut flower longevity considering that recutting was recommended to extend the vase life of cut flowers. In this study, stem length was measured from the base of the plant to the top of the flower head. Based on the results of the analysis, the average stem length of the hybrids varied between 42.1 cm (190) and 129.7 cm (187). The shortest and longest stem lengths of commercial checks were recorded as 25.5 cm (Dwarf Big Smile), and 152.7 cm (Autumn Beauty), respectively, for fertile cultivars and 85.0 cm (Sunrich Orange) and 129.7 cm (Deep Orange), respectively, for sterile varieties (Table 4.8). The variations in stem length and diameter were also reported in previous researchers. In the study by Sloan & Harkness (2006), stem size of cut sunflowers ranged from 27.9 cm to 91.0 cm in length. Tanajiaro (2019) observed stem length out of 13 sunflower genotypes which varied from 2.1 cm to 44.1 cm with a significant variations. Sakata (2014) reported that stems length of commercial hybrid “Sunbright” ranged between 100-150 cm and stated that longer sunflower stems increased diversity in the preparation of arrangements. Burnett (2017) studied “Pro Cut Gold” variety to determine the effects of pinching application on stem length. He found that pinching created a big variation in stem length, which varied between 57.98 cm and 122.81 cm. Grieve & Poss (2010) conducted a study to investigate the effects of salinity on sterile “Moonbright” and “Sunbeam” ornamental sunflower cultivars under greenhouse conditions. They observed that the stem lengths of the cultivars were between 60 and 175 cm, which were in the acceptable range of the stem length recommended by florists.

Stem diameter was measured 40 cm below the flower receptacle in both branching and non-branching types. As a result of the analysis, it was found that the hybrids with the thinnest and thickest stem displayed 0.85 cm and 1.11 cm diameter. These results indicate that the hybrids are within the ideal diameter range recommended for use as cut flowers (Sloan & Harkness, 2006). Significant variations in stem diameter were also observed among commercial hybrids. The variety with the thinnest stem exhibited 0.76 cm (Abendsonne Red) in diameter, while the thickest stem diameter was observed to be 1.31 cm (Dwarf Sunspot). The results are in agreement with reports of Neves et al. (2005) who observed that the stem diameter of ornamental sunflower varieties ranged between 0.8 cm and 1.3 cm. However, in the study of Neves et al. (2005), results were considerably different than those of Sloan (2003). In another study by Sloan & Harkness (2006) stem diameter of cut sunflowers ranged from 1.40 cm to 2.40 cm. The stem diameter variation across four sunflower genotypes was also examined by Mladenovic et al. (2016), who found that it ranged from 0.54 cm to 0.58 cm. Sloan et al. (2003) investigated ornamental sunflower varieties in terms of stem diameter and reported that it varied between 0.72 cm and 0.78 cm. Silva et al. (2018) reported that stem diameters of sunflower cultivars varied between 1.33 cm and 1.80 cm. Burnett (2017) evaluated “Pro Cut Gold” variety under different pinching treatments and reported that stem diameter varied between 0.51 cm and

1.42 cm. These large differences in stem diameter can be attributed to the different sunflower cultivars used in the aforementioned studies and thus to genetic influence.

Table 4.8. Flower head diameter, disc flower diameter, and stem length and diameter of the ornamental hybrids developed and commercial sunflower cultivars

Genotype	Flower Head Diameter (mm)	Disc Diameter (mm)	Stem Length (cm)	Stem Diameter (mm)
129	154,44 ± 3,26 ^{ab}	59,37 ± 0,97 ^{b-h}	121,89 ± 0,38 ^{abcde}	9,85 ± 0,24 ^{b-h}
185	136,37 ± 4,89 ^{b-g}	56,42 ± 1,87 ^{c-k}	112,83 ± 8,71 ^{b-i}	10,48 ± 0,75 ^{b-g}
186	154,18 ± 1,85 ^{ab}	65,17 ± 0,64 ^{abc}	108,05 ± 7,50 ^{b-i}	10,99 ± 0,61 ^{a-g}
187	148,86 ± 0,00 ^{abcd}	54,25 ± 0,00 ^{d-k}	129,68 ± 0,00 ^{abc}	9,75 ± 0,00 ^{c-h}
188	163,88 ± 7,16 ^a	62,20 ± 2,32 ^{abcd}	92,27 ± 7,04 ^{d-n}	11,09 ± 0,55 ^{a-f}
189	137,62 ± 3,97 ^{b-g}	52,86 ± 1,43 ^{d-l}	70,34 ± 3,24 ^{j-r}	8,88 ± 0,18 ^{fgh}
190	110,45 ± 7,61 ^{h-m}	47,42 ± 1,60 ^{klm}	42,14 ± 5,06 ^{rst}	8,50 ± 0,25 ^{gh}
191	116,70 ± 2,78 ^{g-l}	51,11 ± 0,89 ^{e-m}	68,83 ± 3,37 ^{k-r}	8,89 ± 0,81 ^{fgh}
192	138,83 ± 0,87 ^{b-g}	50,55 ± 1,54 ^{e-m}	80,31 ± 0,62 ^{h-p}	9,40 ± 0,16 ^{defgh}
193	148,93 ± 12,23 ^{abcd}	60,63 ± 4,58 ^{bcdef}	110,33 ± 15,3 ^{b-i}	10,08 ± 0,51 ^{b-h}
194	148,59 ± 1,13 ^{abcd}	60,94 ± 3,90 ^{bcde}	116,33 ± 24,39 ^{b-h}	10,14 ± 0,42 ^{b-g}
195	121,67 ± 3,18 ^{f-l}	51,38 ± 0,66 ^{e-m}	97,27 ± 9,13 ^{b-m}	9,14 ± 0,50 ^{defgh}
196	117,21 ± 7,97 ^{g-l}	42,40 ± 2,92 ^{lm}	64,13 ± 6,63 ^{l-r}	8,91 ± 0,85 ^{efgh}
197	119,17 ± 5,84 ^{g-l}	47,57 ± 1,94 ^{jklm}	54,84 ± 6,54 ^{oprst}	9,41 ± 0,36 ^{defgh}
198	128,32 ± 1,50 ^{c-i}	56,54 ± 1,81 ^{c-k}	97,80 ± 8,01 ^{b-l}	10,00 ± 0,52 ^{b-h}
199	129,29 ± 5,96 ^{c-i}	51,78 ± 2,69 ^{d-m}	106,60 ± 9,47 ^{b-j}	10,65 ± 1,12 ^{b-g}
200	127,33 ± 3,32 ^{d-j}	47,03 ± 3,09 ^{klm}	69,96 ± 9,82 ^{j-r}	10,95 ± 0,28 ^{a-g}
201	127,57 ± 0,67 ^{d-i}	48,67 ± 0,37 ^{i-m}	103,72 ± 8,86 ^{b-k}	10,79 ± 0,10 ^{a-g}
203	126,72 ± 11,93 ^{d-k}	54,99 ± 5,09 ^{c-k}	90,82 ± 11,44 ^{d-o}	10,67 ± 1,30 ^{b-g}
205	130,59 ± 7,97 ^{c-i}	49,38 ± 5,40 ^{h-m}	73,32 ± 17,95 ^{i-r}	9,04 ± 0,96 ^{efgh}
206	110,38 ± 4,55 ^{h-m}	41,74 ± 2,61 ^{mn}	96,48 ± 5,15 ^{c-m}	9,71 ± 0,69 ^{c-h}
207	138,93 ± 15,58 ^{b-g}	54,86 ± 4,02 ^{c-k}	91,42 ± 7,77 ^{d-o}	10,06 ± 0,47 ^{b-h}
208	104,43 ± 4,41 ^{klm}	49,52 ± 6,14 ^{g-m}	71,73 ± 5,78 ^{i-r}	9,76 ± 1,05 ^{c-h}

(continues the next page)

Continuation of Table 4.8

209	143,95 ± 3,99 ^{a-f}	54,50 ± 1,92 ^{d-k}	117,51 ± 16,48 ^{bcdef}	9,92 ± 1,08 ^{b-h}
210	134,29 ± 7,41 ^{b-g}	58,75 ± 5,16 ^{c-i}	96,63 ± 18,19 ^{c-m}	9,40 ± 0,82 ^{defgh}
211	138,43 ± 5,75 ^{b-g}	54,71 ± 4,37 ^{d-k}	91,43 ± 11,18 ^{d-o}	10,46 ± 1,44 ^{b-g}
212	124,41 ± 12,60 ^{e-l}	48,10 ± 6,80 ^{jklm}	77,73 ± 13,22 ^{i-r}	9,43 ± 1,38 ^{defgh}
213	131,93 ± 6,05 ^{b-i}	50,09 ± 5,55 ^{f-m}	61,14 ± 13,88 ^{l-s}	8,86 ± 1,40 ^{fgh}
214	132,91 ± 4,91 ^{b-h}	49,13 ± 1,71 ^{h-m}	80,89 ± 11,61 ^{g-p}	8,98 ± 0,40 ^{efgh}
215	121,30 ± 11,12 ^{f-l}	48,69 ± 2,32 ^{i-m}	70,54 ± 8,11 ^{j-r}	8,94 ± 0,38 ^{efgh}
216	118,39 ± 3,52 ^{g-l}	48,24 ± 3,22 ^{i-m}	71,34 ± 8,78 ^{j-r}	9,33 ± 0,30 ^{defgh}
Mean	131,81	52,55	88,33	9,76
Min	104,43	41,74	42,14	8,50
Max	163,88	65,17	129,68	11,09
Commercial cultivars	Flower Head Diameter (mm)	Disc Diameter (mm)	Stem Length (cm)	Stem Diameter (mm)
Earthwalker F1	104,63 ± 9,32 ^{jklm}	46,49 ± 3,62 ^{klm}	123,47 ± 3,16 ^{abcd}	10,50 ± 0,17 ^{b-g}
All Sort Mix F1	90,41 ± 1,52 ^m	46,57 ± 2,00 ^{klm}	79,08 ± 34,75 ^{i-p}	10,38 ± 1,12 ^{b-g}
Autumn Beauty F1	132,35 ± 3,97 ^{b-i}	54,95 ± 1,77 ^{c-k}	152,72 ± 11,04 ^a	11,42 ± 0,23 ^{abcde}
Dwarf Big Smile F1	102,99 ± 2,88 ^{lm}	42,77 ± 0,77 ^{lm}	25,53 ± 0,77 ^t	8,95 ± 0,29 ^{efgh}
Dwarf Teddy Bear F1	69,48 ± 1,77 ⁿ	33,37 ± 0,59 ⁿ	28,70 ± 2,12 st	10,20 ± 1,42 ^{b-g}
Dwarf Incredible F1	120,37 ± 5,29 ^{g-l}	59,10 ± 3,01 ^{b-i}	60,83 ± 3,33 ^{m-s}	12,01 ± 0,35 ^{abc}
Abendsonne Red F1	61,88 ± 8,16 ⁿ	24,15 ± 1,73 ^o	57,70 ± 1,73 ^{n-t}	7,60 ± 0,28 ^h
Lemon Queen F1	143,68 ± 14,19 ^{a-f}	60,57 ± 1,72 ^{bcdef}	133,17 ± 3,82 ^{ab}	10,75 ± 0,27 ^{a-g}
Dwarf Sunspot F1	124,23 ± 5,56 ^{e-l}	58,15 ± 6,35 ^{c-j}	53,80 ± 9,90 ^{prst}	13,09 ± 0,45 ^a
Velvet Queen F1	134,57 ± 9,07 ^{bg}	51,98 ± 0,87 ^{d-m}	124,00 ± 4,76 ^{abcd}	10,89 ± 0,41 ^{a-g}
Evening Colors F1	106,33 ± 5,23 ^{ijklm}	50,29 ± 1,18 ^{f-m}	123,74 ± 12,19 ^{abcd}	10,12 ± 1,32 ^{b-g}
Deep Orange F1	145,40 ± 9,22 ^{abcde}	68,95 ± 2,09 ^{ab}	129,72 ± 8,14 ^{abc}	10,75 ± 0,33 ^{a-g}
Sunrich Orange F1	150,82 ± 0,00 ^{abc}	71,03 ± 0,00 ^a	85,00 ± 0,00 ^{f-p}	10,47 ± 0,00 ^{b-g}
Strawberry Blonde F1	135,51 ± 0,00 ^{b-g}	60,52 ± 0,00 ^{bcdef}	117,00 ± 0,00 ^{b-g}	11,6 ± 0,00 ^{abcd}
Suntastic Pink Bicolor F1	109,67 ± 0,00 ^{i-m}	51,56 ± 0,00 ^{e-m}	86,00 ± 0,00 ^{e-p}	12,33 ± 0,00 ^{ab}
Junior F1	129,81 ± 0,00 ^{c-i}	60,02 ± 0,00 ^{b-g}	86,00 ± 0,00 ^{e-p}	10,84 ± 0,00 ^{a-g}
Mean	116,38	52,53	91,65	10,74
Min	61,88	24,15	25,53	7,60
Max	150,82	71,03	152,72	13,09

The presence of pollen in ornamental sunflower hybrids was evaluated on a scale of 1 to 9, with 1 indicating that pollen production is absent, and 9 indicating that pollen is 100% present in sexual flowers. In this study, four (129, 194, 195, 196) out of 31 hybrids displayed Rfrf genotype in the nucleus of male parents, which resulted in 50% fertile and 50% sterile. However, 27 hybrids (87%) were observed to be 100% male-sterile, as expected. Pollen was observed in all commercial fertile varieties (9.00) and none of the commercial sterile variety (1.00) exhibited pollen in their sexual flowers (Table 4.9).

Mladenović et al. (2017) observed that 90% out of 81 ornamental sunflower varieties were sterile, while in the 10% of the genotypes, pollen was present. Sharypina et al. (2008) demonstrated that the genes controlling traits such as ray flower color, branching, and pollen fertility in sunflowers were inherited independently and showed that both the branching and restoration of pollen fertility traits were under monogenic control with following segregation ratios of 9:3:3:1 and 27:9:12:9:3:4.

The vase life performance was considered as the number of days from the date the flowers are placed in the vase to the date the quality of each flower begins to deteriorate. The results indicated that hybrids and cultivars differed significantly in their vase life. The vase life of the hybrids obtained in this study varied between 9.2 days and 14 days (Table 4.9). The average vase life of sterile 27 and fertile 4 hybrids developed in this study were 11.9 (ranging from 9.2 to 14 days) and 10.6 (ranging from 9.3 to 11.8 days), respectively. Results indicate that being male-sterile might extend vase life of ornamental sunflower. These results were in agreement with reports of Armitage (1993), indicating sterile varieties had a longer vase life in contrast to fertile varieties. In contrast to the studies carried out to evaluate the vase life performances of ornamental sunflower varieties, these results were obtained without the use of any vase solution. The results reported here were quite similar with findings of Shchori & Steinitz (1980).

Furthermore, in our study, out of 16 commercial ornamental sunflower cultivars, sterile ones had a vase life between 8 (Suntastic Pink Bicolor) and 11.06 days (Deep Orange) (avg. 9.9 days), while the vase life performance of fertile varieties ranged from 8.55 (Evening Colors) to 10.48 days (Earthwalker) (avg. 9.6 days). Similar results were reported by Armitage & Laushman (2003), in the investigation of overall performances of ornamental sunflower varieties. Gast (1995) reported that a vase life of 10 days is considered desirable in cut sunflowers. The average vase life of commercial cultivars used and hybrids developed in this study was 9.7 and 11.3 days, respectively 11.28. According to the results, hybrids with longer vase lives have been developed and they may have a lot of potential for usage as cut flowers.

Table 4.9. The pollen presence and vase life of the hybrids and commercial sunflower cultivars (* represents the fertile hybrid candidates; ** represents the sterile hybrid candidates)

Genotype	Pollen Presence	Vase Life (days)
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Continuation of Table 4.9

129*	$2,98 \pm 0,62^c$	$11,81 \pm 0,22^{bcdef}$
185**	$1,00 \pm 0,00^d$	$11,45 \pm 0,15^{b-h}$
186**	$1,00 \pm 0,00^d$	$11,47 \pm 0,29^{b-h}$
187**	$1,00 \pm 0,00^d$	$14,00 \pm 0,00^a$
188**	$1,00 \pm 0,00^d$	$10,00 \pm 0,64^{g-l}$
189**	$1,00 \pm 0,00^d$	$10,87 \pm 0,29^{d-i}$
190**	$1,00 \pm 0,00^d$	$10,18 \pm 0,32^{f-l}$
191**	$1,00 \pm 0,00^d$	$10,63 \pm 0,86^{e-j}$
192**	$1,00 \pm 0,00^d$	$11,00 \pm 0,31^{c-i}$
193**	$1,00 \pm 0,00^d$	$11,67 \pm 1,11^{b-g}$
194*	$4,56 \pm 1,45^b$	$11,47 \pm 0,47^{b-h}$
195*	$5,36 \pm 1,48^b$	$9,80 \pm 0,60^{h-l}$
196*	$9,00 \pm 0,00^a$	$9,33 \pm 0,33^{i-m}$
197**	$1,00 \pm 0,00^d$	$11,50 \pm 0,50^{b-h}$
198**	$1,44 \pm 0,44^d$	$12,83 \pm 0,60^{ab}$
199**	$1,00 \pm 0,00^d$	$11,93 \pm 0,41^{bcde}$
200**	$1,00 \pm 0,00^d$	$12,67 \pm 0,44^{abc}$
201**	$1,00 \pm 0,00^d$	$11,52 \pm 0,25^{b-h}$
203**	$1,00 \pm 0,00^d$	$11,48 \pm 0,88^{b-h}$
205**	$1,00 \pm 0,00^d$	$11,77 \pm 0,15^{bcdef}$
206**	$1,00 \pm 0,00^d$	$9,20 \pm 0,12^{ijklm}$
207**	$1,00 \pm 0,00^d$	$12,50 \pm 0,06^{abcd}$
208**	$1,00 \pm 0,00^d$	$10,67 \pm 0,44^{e-j}$
209**	$1,00 \pm 0,00^d$	$10,67 \pm 0,17^{e-j}$
210**	$1,00 \pm 0,00^d$	$12,77 \pm 1,12^{ab}$
211**	$1,00 \pm 0,00^d$	$13,10 \pm 0,67^{ab}$
212**	$1,00 \pm 0,00^d$	$10,60 \pm 1,14^{e-j}$
213**	$1,00 \pm 0,00^d$	$11,83 \pm 0,60^{bcdef}$
214**	$1,00 \pm 0,00^d$	$10,83 \pm 0,33^{d-i}$
215**	$1,00 \pm 0,00^d$	$10,83 \pm 0,33^{d-i}$

(continues the next page)

Continuation of Table 4.9

216**	$1,00 \pm 0,00^d$	$10,83 \pm 0,60^{d-i}$
Mean	1,59	11,33
Min	1,00	9,20
Max	9,00	14,00
Commercial cultivars	Pollen Presence	Vase Life (days)
Earthwalker F1*	$9,00 \pm 0,00^a$	$10,48 \pm 0,25^{e-k}$
All Sort Mix F1*	$9,00 \pm 0,00^a$	$9,51 \pm 0,64^{i-m}$
Autumn Beauty F1*	$9,00 \pm 0,00^a$	$8,80 \pm 0,46^{klm}$
Dwarf Big Smile F1*	$9,00 \pm 0,00^a$	$10,00 \pm 0,12^{g-l}$
Dwarf Teddy Bear F1*	$9,00 \pm 0,00^a$	$9,82 \pm 0,01^{h-l}$
Dwarf Incredible F1*	$9,00 \pm 0,00^a$	$9,69 \pm 0,06^{ijkl}$
Abendsonne Red F1*	$9,00 \pm 0,00^a$	$8,67 \pm 0,33^{lm}$
Lemon Queen F1*	$9,00 \pm 0,00^a$	$9,33 \pm 0,82^{i-m}$
Dwarf Sunspot F1*	$9,00 \pm 0,00^a$	$10,16 \pm 0,24^{f-l}$
Velvet Queen F1*	$9,00 \pm 0,00^a$	$10,44 \pm 0,39^{e-k}$
Evening Colors F1*	$9,00 \pm 0,00^a$	$8,55 \pm 0,28^{lm}$
Deep Orange F1**	$1,00 \pm 0,00^d$	$11,06 \pm 0,45^{c-i}$
Sunrich Orange F1**	$1,00 \pm 0,00^d$	$11,00 \pm 0,00^{c-i}$
Strawberry Blonde F1**	$1,00 \pm 0,00^d$	$9,00 \pm 0,00^{jklm}$
Suntastic Pink Bicolor F1**	$1,00 \pm 0,00^d$	$8,00 \pm 0,00^m$
Junior F1**	$1,00 \pm 0,00^d$	$10,50 \pm 0,00^{e-j}$
Mean	6,50	9,69
Min	1,00	8,00
Max	9,00	11,06



Figure 4.10. Images from the vase life trial of the hybrid "187"



Figure 4.11. Images from the vase life trial of the hybrid "211"



Figure 4.12. Images from the vase life trial of the hybrid “210”

Patil (2018) experimented the vase life performance of 20 ornamental sunflower varieties, and reported that results ranged between 4.2 days and 9 days without any treatment. Stevens et al. (1993) evaluated the vase life of numerous ornamental sunflower cultivars using preservative solutions and observed that the results varied from 5.3 to 14.7 days. AbdelRahman (2022) studied the effect of preservative solutions on vase life of ornamental sunflowers and found that NST (Nano-silver thiosulphate) application extended vase life until 16.6 days. However, groups with no treatment had an average vase life of 9 days. Furthermore, Devecchi (2005) reported that the vase life of “Sunrich Orange” sunflowers in different preservative solutions was between 10.8-11 days. Kılıç et al. (2020) also evaluated the “Sunrich Orange” cultivar in different vase solutions and reported that the vase life of controls was 8.9 days, while the addition of STS (Silverthio sulfate) in solution extended it to 12.3 days.



Figure 4.13. Images from the vase life trial of the hybrid “207”



Figure 4.14. Images from the vase life trial of the hybrid “215”

Clark et al. (2010) examined 26 ornamental sunflower cultivars and suggested that preservative solutions increased vase life in 16 cultivars and determined that the combination of hydrator and holding preservative solutions increased the vase life in one cultivar, whereas the use of hydrator alone had a negative effect on vase life in three cultivars. Mensuali-Sodi & Ferrante (2005) stated that citric acid solution improved the vase life of “Sunrich Orange” sunflowers and indicated that the longer stem lengths (70 cm versus 50 cm) resulted in a longer vase life.



Figure 4.15. Images from the vase life trial of the hybrid “216”

Carlson & Dole (2013) studied the effects of various pH solutions and found out that acidic pH solutions had significant positive effects on the vase life of “Sunbright” cultivars which ranged from 10.2 days and 11.3 days. Similar results were obtained by Ezz et al. (2021) in the vase life evaluation of “Sunbright Supreme” cultivars in pulsing

solutions. The same cultivar was tested by Nascimento et al. (2019), however in his study, it was found that stems harvested at the stage after inflorescence opened, displayed a vase life of only 6 days, while stems harvested at the stage prior to the R5 stage exhibited the best performance with 12.4 days.

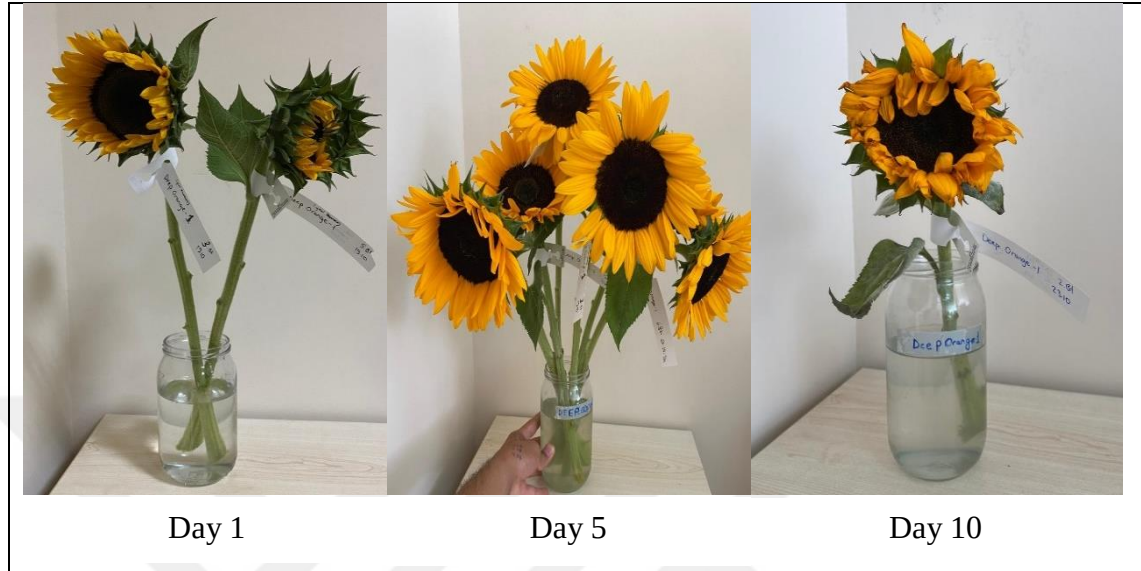


Figure 4.16. Images from the vase life trial of “Deep Orange F1” cultivar

Kalinowski et al. (2023) reported that at 20°C after 3 days storage at 5°C the longest vase life obtained by “Sunbright” cultivar with 13.2 days. Redman & Dole (1994) studied the vase life of *Helianthus maximillianii* and they found that without any vase solutions vase life was only 6.3 days, while 8- Hydroxyquinone (8-HQS) increased it. The proper stage of harvesting and the length of the stems at the harvest time might affect vase life as they in turn affect how much water ornamental sunflower stems can absorb. Naik et al. (2018) studied the effects of different post-harvest parameters on the vase life of cut sunflower cultivars. The best results were obtained when stems harvested at the stage where ray flowers were positioned at 90-degree. In addition, results have shown that tight bud stage and the stage where ray flowers were fully opened had a negative effect on vase life of cut sunflowers. Similarly, in this study, the stems were harvested at the stage in which the ray flowers were positioned at an angle of 90-degree.



Figure 4.17. Images from the vase life trial of “Sunrich Orange F1” cultivar



Figure 4.18. Images from the vase life trial of “Earthwalker F1” cultivar

Some of hybrids especially ones encoded by 187, 198, 200 and 211 developed in this study, performed exceptionally well with a vase life of 13-14 days and outperformed the commercial cultivars used as control in the study. These hybrids possess significant advantages, as well as market potential for use as cut flowers.

The CIELAB color space is defined by three parameters: L^* , a^* , and b^* . L^* describes lightness, or the perceived brightness of the color on a scale from black (0) to white (100). The a^* represents the green-red shift (negative values for green, positive values for red), and the b^* determines the blue-yellow shift (negative values for blue, positive values for yellow) (Granato & Masson, 2010). Chroma (C^*) refers to the saturation or intensity of the color, with higher values reflecting more saturated colors. Hue (h^*) is the actual color, with specific angles for the different hues i.e. red at 0° or

360°, yellow at 90°, green at 180° and blue at 270°. The RGB color space is an additive color space on the basis of the three primary colors red, green, and blue. Within the evaluation of the floral color trait in ornamental sunflower hybrids, L*, a*, and b* values of ray (petal) and disc flower colors of each individual plant were recorded with a Chromameter device (Konica Minolta CR-400). After which the L*, C*, and h* values were calculated, subsequently converted into RGB color spaces (Table 4.10).

Based on the results of the ray flower color analyses, the highest L* value was observed in “Lemon Queen” variety with a value of 80.31 and the lowest value was determined in hybrid ‘209’ with as value of 32.78. In disc flowers, the highest and lowest L* values were found in “Dwarf Sunspot” variety (43.2) and in hybrid ‘214’(8.1), respectively. In the evaluation of ray flower colors, the highest and the lowest c* values were determined as 110.96 (201) and 50.12 (216). The highest disc flower c* value was 56.19 and found in “Dwarf Sunspot” while the lowest value was 9.92 (213). The highest and lowest ray flower colors h* values were 88.65 (203) and 53.67 (209), respectively. In disc flowers, the highest and the lowest h* values were 91.78 in “Dwarf Incredible” and 39.44 in “Strawberry Blonde”, respectively. According to these results, hybrids displayed a significant variation in a broad spectrum of floral color including, orange and yellow backgrounds with red color suffused on the center (199, 206, 197), tile-red (198, 213, 214, 215), lemon (191), purple gaillardia (216), and red colors (209) other than usual yellow tones (Table 4.10). Similarly, orange-yellow (Dwarf Teddy Bear, Dwarf Big Smile), reddish brown (Earthwalker), maroon (Abendsonne Red, Evening Colors), lemon (Lemon Queen), and apricot (Deep Orange) colors were detected among commercial varieties. Yellow color tones were observed frequently in the hybrids. Similar results were reported by Tanajiaro (2019). Lemon gaillardia color is defined as the combination of the central purple color with background lemon color. Observations showed that as the central purple color became darker, the background lemon color appeared lighter. In plants with darker purple centers, the background color appeared whitish (Table 4.12). The color of disc florets in hybrids ranged from dark brown, dark red, brown, dark maroon, and black to bronze colors (Table 4.11). It was determined that a wider range of disc color tones was present in commercial varieties resulting in brown, light brown, mustard yellow, black, orange and yellow colors, exhibiting lighter tones in sexual flowers.

Tanajiaro (2019) examined the ray flower colors of ornamental sunflower genotypes and divided 13 genotypes into four categories as yellow, yellow-orange, orange-red, and red, with yellow group being the majority. Similarly, Patil (2018) divided 20 ornamental sunflower genotypes into six categories and observed yellow color as the majority. Mladenović et al. (2017) examined 81 ornamental sunflower genotypes and observed different variations in ray flower colors such as lemon-yellow, orange, orange-yellow, maroon, with the majority of the genotypes (32%) being yellow ray flower color. In addition, color variations in disc flowers were also observed as yellow, orange, red anthocyanin, maroon, black, purple anthocyanin, or yellow anthocyanin with 55.5% of the genotypes having anthocyanin pigmentation. Cvejić et al. (2016) observed the variations in disc flowers and stated that anthocyanin coloration in disc flowers was dominant over yellow and lemon-yellow color, showed monohybrid inheritance. In another study, similar results were obtained by Divita et al. (2012), which stated that purple anthocyanin coloration in disc flowers of F1 hybrids was dominant. Mladenović et al. (2016) stated that various combinations can be achieved in landscape arrangements

and cut flower arrangements with different colored genotypes. Ferguson et al. (2012) evaluated several ornamental sunflower varieties mostly preferred by customers in terms of floral color and observed light yellow, red/orange, intense burgundy, golden yellow, pale yellow, and burgundy.

Table 4.10. The color parameters (CIELCH), and resulting ray flower colors and RGB values of the hybrids and commercial cultivars

Genotype	Color of the Ray flowers			Color	R	G	B
	L*ab	c*ab	h*ab				
129	67,89 ± 0,97 ^{bcdef}	97,66 ± 2,13 ^{abcd}	80,91 ± 0,84 ^{a-h}		215	155	0
185	73,39 ± 2,88 ^{abcde}	103,49 ± 3,16 ^{abc}	82,62 ± 0,93 ^{abcde}		230	170	0
186	76,22 ± 0,91 ^{abc}	110,48 ± 0,81 ^{ab}	84,15 ± 0,72 ^{abcd}		235	178	0
187	76,22 ± 0,00 ^{abc}	110,48 ± 0,00 ^{ab}	84,15 ± 0,00 ^{abcd}		235	178	0
188	71,32 ± 1,28 ^{a-f}	106,93 ± 5,53 ^{ab}	81,51 ± 1,09 ^{a-g}		226	162	0
189	72,84 ± 2,89 ^{abcde}	103,62 ± 0,85 ^{abc}	82,96 ± 1,40 ^{abcde}		226	168	0
190	73,58 ± 2,34 ^{abcde}	89,68 ± 7,38 ^{de}	84,50 ± 0,53 ^{abcd}		220	170	0
191	71,38 ± 1,81 ^{a-f}	57,39 ± 6,70 ^{ij}	86,32 ± 2,38 ^{abc}		202	170	64
192	73,67 ± 0,10 ^{abcde}	106,39 ± 0,20 ^{ab}	80,60 ± 0,14 ^{a-h}		235	165	0
193	74,49 ± 0,21 ^{abcd}	110,03 ± 2,24 ^{ab}	80,05 ± 0,59 ^{b-i}		235	165	0
194	75,85 ± 1,38 ^{abc}	109,68 ± 0,69 ^{ab}	82,32 ± 1,86 ^{a-f}		237	172	0
195	70,59 ± 3,19 ^{a-f}	103,09 ± 1,68 ^{abc}	80,27 ± 1,26 ^{a-i}		225	157	0
196	58,58 ± 4,08 ^{ghij}	91,22 ± 4,19 ^{cde}	77,57 ± 2,16 ^{d-i}		191	124	0
197	64,80 ± 4,20 ^{defgh}	72,33 ± 7,94 ^{fighi}	72,11 ± 4,50 ^{ijkl}		211	139	3
198	45,42 ± 3,95 ^{lmn}	77,01 ± 1,94 ^{fgh}	64,69 ± 4,15 ^{lmn}		168	81	0
199	54,52 ± 3,17 ^{ijk}	82,59 ± 2,02 ^{ef}	73,58 ± 1,73 ^{ghij}		183	111	0
200	73,19 ± 0,93 ^{abcde}	108,53 ± 1,02 ^{ab}	83,19 ± 0,16 ^{abcd}		228	168	0
201	76,41 ± 1,13 ^{abc}	110,96 ± 1,88 ^a	83,91 ± 0,31 ^{abcd}		238	176	0

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Continuation of Table 4.10

203	77,41 ± 1,08 ^{ab}	81,65 ± 8,82 ^{ef}	88,65 ± 1,62 ^a		222	186	0
205	73,96 ± 0,33 ^{abcde}	109,47 ± 1,49 ^{ab}	82,15 ± 0,55 ^{af}		231	167	0
206	62,96 ± 3,70 ^{fghi}	100,24 ± 4,66 ^{abcd}	76,85 ± 2,22 ^{d-j}		209	132	0
207	64,64 ± 3,27 ^{efgh}	91,96 ± 1,92 ^{cde}	78,03 ± 2,09 ^{c-i}		207	141	0
208	67,07 ± 3,64 ^{cdefg}	97,20 ± 5,40 ^{bcd}	80,99 ± 1,89 ^{a-g}		214	150	0
209	32,78 ± 4,28 ^o	60,64 ± 3,14 ^{ij}	53,67 ± 4,85 ^o		132	46	0
210	74,13 ± 0,65 ^{abcde}	108,18 ± 2,86 ^{ab}	83,05 ± 0,31 ^{abcd}		231	171	0
211	73,42 ± 1,37 ^{abcde}	108,56 ± 2,75 ^{ab}	82,17 ± 0,48 ^{a-f}		231	167	0
212	74,43 ± 0,90 ^{abcde}	103,22 ± 7,10 ^{abc}	77,73 ± 4,50 ^{d-i}		245	164	0
213	47,08 ± 0,80 ^{klmn}	72,25 ± 0,74 ^{fghi}	68,89 ± 0,57 ^{jklm}		166	92	0
214	48,87 ± 5,08 ^{jklm}	75,08 ± 2,46 ^{fgh}	65,57 ± 2,30 ^{klmn}		175	90	0
215	50,63 ± 2,71 ^{ijkl}	59,29 ± 6,70 ^{ij}	63,22 ± 7,14 ^{mn}		173	99	22
216	68,80 ± 3,34 ^{bcdef}	50,12 ± 4,78 ^j	77,29 ± 3,79 ^{d-i}		203	157	75
Mean	66,66	92,56	78,18				
Min	32,78	50,12	53,67				
Max	77,41	110,48	88,65				
Commercial cultivars	L*ab	c*ab	h*ab	Color	R	G	B
Earthwalker F1	51,61 ± 4,97 ^{ijkl}	66,98 ± 4,77 ^{hii}	68,90 ± 2,07 ^{jklm}		174	104	0
All Sort Mix F1	54,88 ± 3,66 ^{ijk}	75,06 ± 2,80 ^{fgh}	74,57 ± 1,24 ^{e-j}		179	114	0
Autumn Beauty F1	67,53 ± 4,55 ^{cdefg}	91,77 ± 6,47 ^{cde}	79,24 ± 2,73 ^{c-i}		214	150	0
Dwarf Big Smile F1	72,53 ± 0,73 ^{abcde}	102,55 ± 0,41 ^{abc}	78,31 ± 0,28 ^{c-i}		236	160	0
Dwarf Teddy Bear F1	56,62 ± 1,75 ^{hiij}	81,87 ± 3,29 ^{ef}	72,61 ± 0,32 ^{hiijk}		236	160	0
Dwarf Incredible F1	74,86 ± 0,75 ^{abc}	108,06 ± 3,01 ^{ab}	81,27 ± 0,37 ^{a-g}		237	169	0

(continues the next page)

Continuation of Table 4.10

Abendsonne Red F1	39,88 ± 1,47 ^{no}	53,85 ± 1,95 ^j	59,92 ± 2,10 ^{no}		141	72	11
Lemon Queen F1	80,31 ± 1,67 ^a	67,86 ± 1,50 ^{ghij}	88,42 ± 0,82 ^{ab}		228	195	63
Dwarf Sunspot F1	73,88 ± 1,37 ^{abcde}	105,21 ± 1,09 ^{ab}	80,66 ± 0,78 ^{a-h}		235	165	0
Velvet Queen F1	44,72 ± 1,53 ^{lmn}	66,95 ± 4,16 ^{hij}	65,56 ± 1,80 ^{klmn}		158	84	0
Evening Colors F1	55,96 ± 9,08 ^{hijk}	49,69 ± 7,46 ^j	70,38 ± 7,69 ^{ijklm}		173	120	49
Deep Orange F1	69,47 ± 2,51 ^{bcdef}	103,26 ± 4,74 ^{abc}	73,90 ± 1,21 ^{f-j}		239	145	0
Sunrich Orange F1	74,00 ± 0,00 ^{abcde}	104,39 ± 0,00 ^{abc}	84,44 ± 0,00 ^{abcd}		224	170	0
Strawberry Blonde F1	73,67 ± 0,00 ^{abcde}	105,32 ± 0,00 ^{ab}	84,00 ± 0,00 ^{abcd}		224	170	0
Suntastic Pink Bicolor F1	40,20 ± 0,00 ^{mno}	56,20 ± 0,00 ^{ij}	77,99 ± 0,00 ^{c-i}		126	86	0
Junior F1	67,57 ± 0,00 ^{b-g}	80,03 ± 0,00 ^{efg}	79,24 ± 0,00 ^{c-i}		211	151	0
Mean	62,36	82,44	76,21				
Min	39,88	49,69	59,92				
Max	80,31	108,06	88,42				

Table 4.11. The color parameters (CIELCH), and resulting disc flower colors and RGB values of the hybrids and commercial cultivars

Genotype	Color of the Disc Flowers			Color	R	G	B
	L*ab	c*ab	h*ab				
129	11,86 ± 1,75 ^{ijk}	15,93 ± 3,14 ^{klmn}	54,48 ± 3,70 ^{i-o}		44	25	11
185	10,35 ± 0,55 ^{ijk}	12,62 ± 1,38 ^{lmn}	48,85 ± 4,46 ^{kp}		40	23	14
186	10,85 ± 1,25 ^{ijk}	18,29 ± 2,82 ⁱ⁻ⁿ	41,96 ± 2,32 ^{op}		47	19	8
187	10,03 ± 0,00 ^{ijk}	14,22 ± 0,00 ^{lmn}	64,97 ± 0,00 ^{d-j}		39	24	6
188	8,84 ± 0,84 ^{jk}	17,15 ± 1,07 ^{klmn}	43,02 ± 3,56 ^{nop}		42	16	2
189	11,62 ± 0,35 ^{ijk}	17,79 ± 1,06 ⁱ⁻ⁿ	59,14 ± 3,18 ^{h-m}		45	25	5

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Continuation of Table 4.11

190	15,48 ± 1,25 ^{ghij}	19,83 ± 1,35 ^{h-m}	69,90 ± 4,49 ^{b-i}		52	34	11
191	16,17 ± 0,06 ^{fehi}	19,55 ± 0,38 ^{h-n}	68,28 ± 3,74 ^{c-i}		54	36	14
192	10,95 ± 0,47 ^{ijk}	12,73 ± 2,24 ^{lmn}	49,12 ± 1,44 ^{k-p}		40	23	14
193	11,46 ± 0,77 ^{ijk}	21,69 ± 3,13 ^{f-l}	45,43 ± 7,50 ^{mnop}		51	20	5
194	21,76 ± 7,62 ^{defg}	30,43 ± 7,83 ^{defg}	68,43 ± 12,81 ^{c-i}		72	44	5
195	14,92 ± 1,51 ^{hijk}	18,12 ± 3,73 ⁱ⁻ⁿ	61,92 ± 5,22 ^{f-l}		51	31	12
196	10,09 ± 1,43 ^{ijk}	12,24 ± 1,18 ^{lmn}	55,77 ± 3,48 ^{h-o}		39	24	13
197	10,03 ± 1,07 ^{ijk}	13,61 ± 2,13 ^{lmn}	59,59 ± 8,23 ^{g-m}		39	24	10
198	10,34 ± 1,18 ^{ijk}	13,32 ± 1,06 ^{lmn}	52,27 ± 5,10 ^{j-p}		41	23	12
199	14,68 ± 2,52 ^{hijk}	18,75 ± 1,21 ⁱ⁻ⁿ	66,81 ± 7,69 ^{d-j}		50	31	10
200	10,44 ± 1,41 ^{ijk}	15,76 ± 3,67 ^{klmn}	61,60 ± 2,12 ^{f-l}		41	23	5
201	14,05 ± 1,09 ^{ijk}	21,74 ± 2,07 ^{f-l}	68,60 ± 3,61 ^{c-i}		51	31	5
203	14,16 ± 2,98 ^{ijk}	19,34 ± 2,93 ⁱ⁻ⁿ	63,64 ± 7,99 ^{e-k}		51	31	9
205	14,60 ± 0,60 ^{hijk}	24,04 ± 0,74 ^{e-k}	63,18 ± 3,99 ^{e-k}		55	29	0
206	12,88 ± 0,19 ^{ijk}	15,08 ± 1,66 ^{klmn}	68,67 ± 3,36 ^{c-i}		43	28	10
207	14,99 ± 2,56 ^{hijk}	21,43 ± 0,42 ^{g-l}	58,93 ± 6,28 ^{h-m}		54	29	8
208	10,82 ± 0,87 ^{ijk}	11,46 ± 1,01 ^{mn}	52,37 ± 2,23 ^{j-p}		39	24	15
209	8,39 ± 1,56 ^{jk}	14,00 ± 1,23 ^{lmn}	52,94 ± 6,36 ^{j-p}		38	19	3
210	9,71 ± 1,62 ^{ijk}	16,33 ± 1,75 ^{klmn}	57,64 ± 10,14 ^{h-n}		40	21	0
211	11,75 ± 2,85 ^{ijk}	19,55 ± 6,08 ^{h-n}	55,54 ± 2,49 ^{i-o}		47	23	3
212	9,97 ± 1,99 ^{ijk}	15,78 ± 3,03 ^{klmn}	51,80 ± 4,06 ^{j-p}		41	20	5
213	9,44 ± 1,13 ^{ijk}	9,92 ± 1,06 ⁿ	47,97 ± 2,84 ^{lmnop}		35	22	16
214	8,10 ± 1,01 ^k	10,35 ± 1,20 ^{mn}	45,06 ± 3,60 ^{mnop}		35	20	12
215	9,15 ± 1,44 ^{ijk}	10,62 ± 0,92 ^{mn}	49,64 ± 1,49 ^{k-p}		36	22	14

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Continuation of Table 4.11

216	14,21 ± 0,86 ^{ijk}	17,09 ± 1,78 ^{klmn}	74,97 ± 1,84 ^{bcdef}		47	33	10
Mean	12,00	16,73	57,50				
Min	8,10	9,92	41,96				
Max	21,76	30,43	74,97				
Commercial cultivars	L*ab	c*ab	h*ab	Color	R	G	B
Earthwalker F1	19,47 ± 2,47 ^{efghi}	24,47 ± 3,40 ^{e-j}	75,61 ± 1,90 ^{bcdef}		61	42	10
All Sort Mix F1	32,65 ± 1,13 ^b	40,55 ± 4,48 ^{bc}	82,74 ± 1,35 ^{abc}		95	71	2
Autumn Beauty F1	23,44 ± 3,78 ^{de}	30,91 ± 6,36 ^{de}	78,54 ± 0,96 ^{abcd}		74	53	9
Dwarf Big Smile F1	26,97 ± 2,14 ^{bcd}	39,91 ± 2,64 ^{bc}	74,05 ± 1,89 ^{b-g}		85	55	0
Dwarf Teddy Bear F1	30,83 ± 1,52 ^{bc}	34,67 ± 2,37 ^{cd}	76,80 ± 0,22 ^{bcde}		92	65	16
Dwarf Incredible F1	39,61 ± 2,31 ^a	46,26 ± 3,46 ^b	91,78 ± 0,41 ^a		105	91	0
Abendsonne Red F1	22,51 ± 2,59 ^{def}	26,66 ± 3,05 ^{d-i}	70,61 ± 0,92 ^{b-h}		72	47	15
Lemon Queen F1	26,17 ± 4,12 ^{cd}	28,68 ± 2,88 ^{defgh}	82,23 ± 1,54 ^{abc}		76	59	17
Dwarf Sunspot F1	43,20 ± 1,58 ^a	56,19 ± 1,21 ^a	83,93 ± 2,73 ^{ab}		127	96	0
Velvet Queen F1	22,43 ± 2,82 ^{def}	30,71 ± 4,41 ^{def}	77,90 ± 0,38 ^{abcde}		70	48	4
Evening Colors F1	21,61 ± 2,04 ^{defg}	21,26 ± 2,60 ^{h-l}	77,79 ± 0,88 ^{abcde}		63	48	20
Deep Orange F1	9,60 ± 0,16 ^{ijk}	13,66 ± 0,50 ^{lmn}	57,78 ± 2,76 ^{h-n}		38	22	7
Sunrich Orange F1	21,07 ± 0,00 ^{defgh}	27,95 ± 0,00 ^{d-i}	84,15 ± 0,00 ^{ab}		62	48	6
Strawberry Blonde F1	8,66 ± 0,00 ^{jk}	15,62 ± 0,00 ^{klmn}	39,44 ± 0,00 ^p		40	17	7
Suntastic Pink Bicolor F1	9,17 ± 0,00 ^{ijk}	10,81 ± 0,00 ^{mn}	54,7 ± 0,00 ^{io}		36	22	13
Junior F1	9,87 ± 0,00 ^{ijk}	14,55 ± 0,00 ^{klmn}	52,63 ± 0,00 ^{j-p}		40	21	6
Mean	22,95	28,93	72,54				
Min	8,66	10,81	39,44				
Max	43,20	56,19	91,78				

The RGB values were classified and 10 different color groups were defined according to Fick's study (1976) to evaluate the dominance status of the hybrids obtained. Based on this classification, the color groups and RGB values are named and presented in Table 4.12. This process allowed more detailed evaluation of the ray flower color inheritance and contributed to a more precise analysis of the phenotypic characteristics of the hybrids.

Table 4.12. Color classification of ornamental sunflower hybrids based on L*, c*, and h* values (Fick, 1976)

Color name	Color	R	G	B	Color Definition	Color Group
Sun		240	175	0	Light yellow, Medium yellow, Intense yellow, Orange yellow	Yellow
Lightning yellow		240	180	0		
Amber		248	188	0		
Galliano		227	173	0		
Intense yellow		255	205	0		
Buddha gold		197	158	0		
Fuel yellow		255	183	62		
Web orange		242	157	0	Orange	Orange
Ronchi		230	202	70	Lemon-yellow	Lemon-yellow
Apache		215	192	110	Lemon	Lemon
Tacha		219	198	89		
Energy yellow		234	208	76		
Earls green		205	184	44		
Sahara		196	173	25		
California		241	153	0	Apricot	Apricot
Peru tan		132	56	0	Brownish gaillardia with yellow tips (tile-red)	Yellow or Orange Gaillardia
Ochre		208	126	33		
Saddle brown		82	50	0		
Reno sand		150	90	0		
Pickled bean		105	62	28		
Korma		140	65	0		
Chealsea gem		153	82	0		
Meteor		195	117	0	Brownish gaillardia with orange tips	(Gaillardia with red suffused on orange and yellow backgrounds)
Kumera		125	89	28		
Indochine		187	105	0		
Mai Tai		170	100	0		

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Continuation of Table 4.12

Matrix		180	90	100		
Tosca		140	60	60	Brownish gaillardia with yellow tips (almost red stripes)	
Solid pink		120	40	50		
Rusty nail		140	85	0	Dark brown gaillardia with yellow tips	
Pirate gold		190	130	0		
Pizza		192	136	0		
Golden grass		216	162	0	Light brownish gaillardia with yellow tips	
Gamboge		219	156	0		
Dixie		213	142	0		
Geebung		200	140	0		
Golden Bell		210	130	0		
Oregon		147	64	0	Red-brown (tile-red)	Reddish brown
Pumpkin skin		179	89	0		
Red berry		140	0	0	Reddish maroon	
Nutmeg wood finish		114	57	7		
Mahogany		83	8	5		
Dark tan		96	5	0		
Cedar wood finish		105	20	0	Dark reddish maroon	Red
Rustic red		75	0	0		
Kenyan copper		130	35	0		
Red beech		125	50	0		
Cape palliser		160	100	65	Light purple gaillardia with lemon tips	
Sepia skin		155	95	70		
Luxor gold		175	140	60		
Tussock		200	160	85		
Twine		200	160	95	Pale purple gaillardia with lemon tips	Lemon Gaillardia
Muddy waters		190	145	90		(Gaillardia with purple suffused on lemon background)
Driftwood		180	135	70		
Antique brass		185	135	95		
Dallas		125	80	40		
Iron stone		155	85	70	Purple gaillardia with lemon tips	
Persian plum		120	35	45		
Bordeaux		90	0	25	Purple with white tips	Purple

Using the color classification developed by Fick (1976), phenotypes of the F1 generations developed in this study were examined to investigate the ray flower color inheritance of the ornamental sunflower hybrids. The ray flower colors of the A and B lines in each crossing combinations, and the color in the F1 phenotypes are presented in Table 4.13.

In this context, it was observed that yellow ray flower coloration was dominant in F1 plants derived from the yellow x lemon-yellow (Table 4.22), yellow x lemon (Table 4.15), and orange x yellow crosses (Table 4.21). The results are in agreement with reports by Fick (1976), Miller & Fick (1997), Cvejić et al. (2016) and Sharypina et al. (2008). In addition, Cvejić et al. (2016) demonstrated that monohybrid inheritance was observed in F2 generations when yellow x lemon-yellow ray flowers were crossed. Skaloud & Kovacik (1978) and Šećerov-Fišer & Škorić (1988) reported that yellow ray flower color was controlled by a single dominant gene and that yellow was dominant over lemon and orange. However, Fick (1976) and Yue et al. (2008) observed 9:3:4 segregation ratios in F2 populations resulting from crosses between yellow and lemon ray flower colors, indicating the epistatic effect of two independent genes, and reported that yellow and lemon-yellow ray flower colors were controlled by two genes. Sharypina et al. (2008) illustrated inbred lines with yellow ray flowers as *LLOOLyLyApAAp*, lemon-yellow as *lLOOLyLyApAp*, orange as *LlooLyLyApAp*, apricot as *LLOOLyLyap*, and light-yellow as *LLOOLyApAp*, identifying the colors associated with recessive alleles from which it was concluded that lemon-yellow ray flower color showed recessive epistatic effect over orange and light-yellow colors.

Fick (1976) observed that crossing parental lines with yellow and red ray flowers resulted in a “gaillardia” pattern in the F1 population which was defined as the red central color with the background color determined by the nonred parent. Therefore, crossing lemon and red ray flower color resulted in the “lemon gaillardia”, while crossing orange and red ray flower color resulted in the “orange gaillardia” phenotype in the F1 generation (Fick, 1976). In this study, gaillardia patterns with yellow peripheral was detected in yellow x reddish brown crosses in the F1 populations (Table 4.16). Additionally, it was determined by Fick (1976) and Cvejić et al. (2016) that in orange x red and lemon x red crosses, a single dominant gene was responsible for the expression of the red ray flower color in the F2 generation with a segregation ratio of 3:1, whereas in yellow x red cross, red ray flower color was controlled by two independent complementary genes, suggesting that when both genes were dominant, the color of the ray flowers was red, whereas in other cases ray flowers appeared as yellow, with a segregation ratio of 9:7.

In this study, when lines having yellow colors in ray flowers were crossed with yellow gaillardia colors, resulting F1 phenotypes showed that yellow gaillardia was dominant in two crossing combinations, while yellow color was dominant in three crossing combinations. Similarly, in yellow x lemon gaillardia crosses, one of the combinations exhibited yellow gaillardia patterns in the F1 populations, whereas in one combination yellow color was dominant, and lemon-yellow color was observed to be dominant in other combination. Fick (1976) reported no data on the F1 phenotypes when crossing gaillardia color with yellow color, however, it was explained as digenic inheritance in F2 backcross populations, identifying 3 yellow and 1 red segregation ratio. It was determined that yellow color was dominant in lemon x yellow gaillardia cross. Meanwhile, in lemon-yellow x yellow gaillardia cross, resulting F1 populations displayed

yellow gaillardia patterns in ray flowers. It was assumed that conflicting and varying results observed in the crossing combinations were due to the different backcross generations of the A and B-lines, the genetic composition of the parental lines used in the crosses during the breeding process, and the insufficient number of progeny. It was observed that several color variations were obtained in lemon x orange gaillardia and orange gaillardia x yellow crosses, from which it was determined that yellow coloration of ray flowers was dominant in F1 generations of all the crossing combinations. When yellow gaillardia x orange gaillardia, yellow gaillardia x red, and yellow gaillardia x reddish brown colors were crossed, it was observed that yellow gaillardia color was dominant in F1 populations. It was reported by Cvejić et al. (2016) that red ray flower color was partially dominant over yellow and lemon-yellow colors, and this trait was controlled by one or two independent genes, based on the colors used in previous crosses of the other parent. In lemon-yellow x lemon cross, resulting F1 populations exhibited mostly lemon colors, suggesting that for the recessive lemon color to be phenotypically expressed, both parents must carry the genotypes of these colors. As a result of crossing two parental lines having different yellow gaillardia tones, the resulting F1 phenotype exhibited lemon gaillardia color and several color variations were detected (Table 4.39). Similarly, the crossing of two parental lines with different lemon gaillardia tones resulted in lemon, apricot, and yellow colors with lemon gaillardia being the majority (Table 4.40). Although the inheritance of yellow, red, orange, lemon, apricot, and light-yellow ray flower colors was studied thoroughly, little attention was given to the inheritance of gaillardia colors.

Table 4.13. Dominant ray flower colors in F1 hybrid sunflower populations of crossing combinations

Color Group		
Hybrids Obtained	AxB (ray flower petal color of the parental lines)	F1 phenotype
129	Yellow x Reddish Brown	Yellow Gaillardia
186	Yellow x Lemon	Yellow
188	Yellow x Reddish Brown	Yellow Gaillardia
189	Yellow x Lemon Gaillardia	Yellow Gaillardia
190	Yellow x Lemon Gaillardia	Yellow
191	Yellow x Lemon Gaillardia	Lemon-yellow
192	Yellow x Yellow Gaillardia	Yellow
193	Orange x Yellow	Yellow

(continues the next page)

Continuation of Table 4.13

194	Yellow x Lemon-yellow	Yellow
195	Yellow x Yellow Gaillardia	Yellow
196	Yellow x Yellow Gaillardia	Yellow Gaillardia
197	Lemon x Yellow Gaillardia	Yellow
198	Yellow Gaillardia x Red	Yellow Gaillardia (darker tones)
199	Yellow x Orange Gaillardia	Yellow Gaillardia (darker tones)
201	Lemon-yellow x Yellow	Yellow
203	Lemon-yellow x Lemon	Lemon
205	Orange Gaillardia x Yellow	Yellow
206	Yellow x Yellow Gaillardia	Yellow Gaillardia
207	Lemon x Orange Gaillardia	Yellow
208	Lemon-yellow x Yellow Gaillardia	Yellow Gaillardia
210	Yellow x Lemon-yellow	Yellow
211	Yellow Gaillardia x Yellow	Yellow
212	Orange Gaillardia x Yellow	Yellow
213	Yellow Gaillardia x Reddish Brown	Yellow Gaillardia (darker tones)
214	Yellow Gaillardia x Orange Gaillardia	Yellow Gaillardia (darker tones)
215	Yellow Gaillardia x Yellow Gaillardia	Lemon Gaillardia
216	Lemon Gaillardia x Lemon Gaillardia	Lemon Gaillardia

The inheritance of ray flower color was examined in 27 out of 31 hybrids, and the resulting color variations were identified. In this context, the highest number of color variations was observed in crosses between yellow x lemon gaillardia, lemon x yellow gaillardia, lemon x orange gaillardia, and crosses between different gaillardia tones. The

images representing the ray flower colors of the parental lines, color variations, and the ray flower color tones of the hybrids are presented in Table 4.14-4.40.

Table 4.14. Color variations in the F1 populations of “129” and ray flower colors of the lines involved in the crosses

Hybrid 129			Petal color tones of hybrids
A (CMS) line (♀)	x	B (maintainer) line (♂)	
	x		
Light Yellow		Red-brown (tile red)	
F1 phenotype			
11 gaillardia patterns with red suffused on orange and yellow backgrounds			4 yellow

Table 4.15. Color variations in the F1 populations of “186” and ray flower colors of the lines involved in the crosses

Hybrid 186		Petal color tones of hybrids
A (CMS) line (♀)	B (Maintainer) line (♂)	
		
Medium Yellow	Lemon	
F1 phenotype	14 yellow	

Table 4.16. Color variations in the F1 populations of “188” and ray flower colors of the lines involved in the crosses

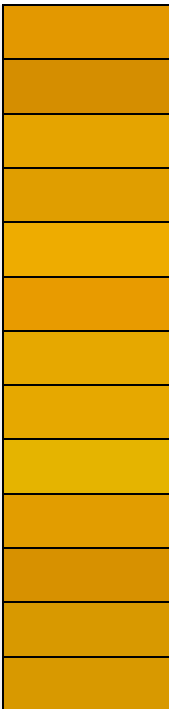
Hybrid 188			Petal color tones of hybrids	
A (CMS) line (♀)	x	B (Maintainer) (♂)		
	x			
Medium yellow		Red-brown (tile-red)		
F1 phenotype				
8 gaillardia patterns with red suffused on orange and yellow backgrounds				
5 yellow				

Table 4.17. Color variations in the F1 populations of “189” and ray flower colors of the lines involved in the crosses

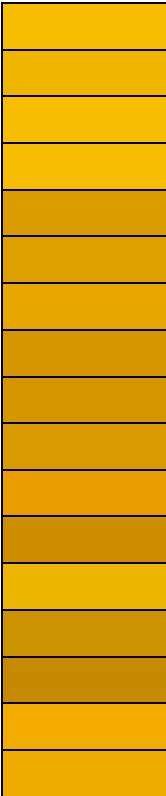
Hybrid 189			Petal color tones of hybrids
A (CMS) line (♀)	x	B (Maintainer) (♂)	
	x		
Yellow		Purple gaillardia with lemon background	
F1 phenotype	9 gaillardia patterns with red suffused on orange and yellow backgrounds	8 yellow	

Table 4.18. Color variations in the F1 populations of “190” and ray flower colors of the lines involved in the crosses

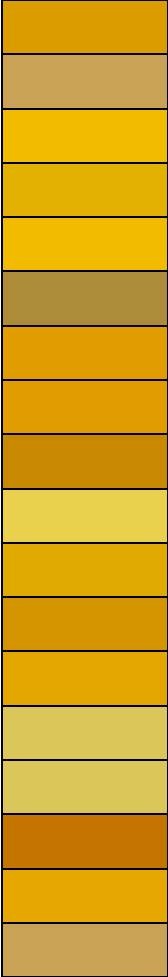
Hybrid 190				Petal color tones of hybrids
A (CMS) line (♀)	x	B (maintainer) line (♂)		
	x			
Medium Yellow		Purple gaillardia with lemon background		
F1 phenotype	7 yellow	3 lemon	3 gaillardia patterns with purple suffused on lemon background	5 gaillardia patterns with red suffused on orange and yellow backgrounds

Table 4.19. Color variations in the F1 populations of “191” and ray flower colors of the lines involved in the crosses

Hybrid 191				Petal color tones of hybrids
A (CMS) line (♀)		x	B (Maintainer) line (♂)	
		x		
Intense yellow			Gaillardia patterns with purple suffused on lemon background	
F1 phenotype				
4 lemon yellow		3	1 gaillardia patterns with purple suffused on lemon background	
		lemon	1 gaillardia patterns with red suffused on orange and yellow backgrounds	

Table 4.20. Color variations in the F1 populations of “192” and ray flower colors of the lines involved in the crosses

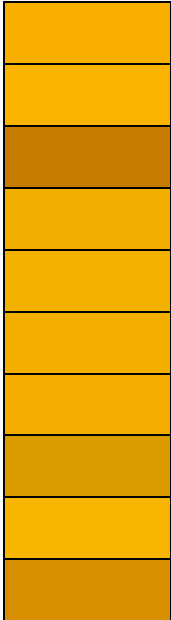
Hybrid 192			Ray flower color tones of hybrids
A (CMS) line (♀)	x	B (Maintainer) (♂)	
	x		
Yellow		Brownish gaillardia with yellow tips (red-brown)	
F1 phenotype	7 yellow	3 gaillardia patterns with red suffused on orange and yellow backgrounds	

Table 4.21. Color variations in the F1 populations of “193” and ray flower colors of the lines involved in the crosses

Hybrid 193		Petal color tones of hybrids
A (CMS) line (♀)	B (maintainer) line (♂)	
		
Orange	Intense yellow	
F1 phenotype	14 yellow	

Table 4.22. Color variations in the F1 populations of “194” and ray flower colors of the lines involved in the crosses

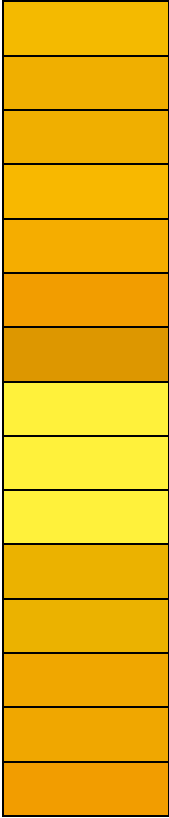
Hybrid 194			Petal color tones of hybrids
A (CMS) line (♀)	x	B (maintainer) line (♂)	
	x		
Intense yellow		Lemon-yellow	
F1 phenotype	10 yellow	3 lemon-yellow	2 orange

Table 4.23. Color variations in the F1 populations of “195” and ray flower colors of the lines involved in the crosses

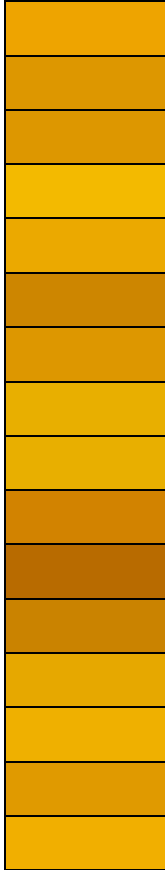
Hybrid 195			Petal color tones of hybrids	
A (CMS) line (♀)	x	B (maintainer) line (♂)		
	x			
Yellow		Brownish gaillardia with yellow tips (red-brown)		
F1 phenotype				
	8 yellow	7 gaillardia with red suffused on orange and yellow backgrounds		1 reddish brown

Table 4.24. Color variations in the F1 populations of “196” and ray flower colors of the lines involved in the crosses

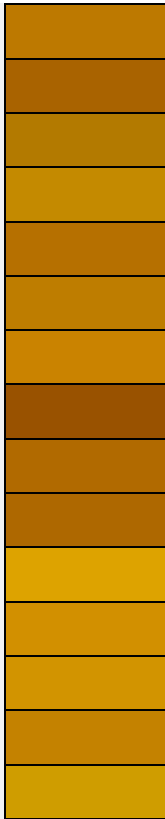
Hybrid 196			Petal color tones of hybrids
A (CMS) line (♀)	x	B (maintainer) line (♂)	
	x		
Yellow		Brownish gaillardia with yellow tips	
F1 phenotype	15 gaillardia patterns with red suffused on orange and yellow backgrounds		

Table 4.25. Color variations in the F1 populations of “197” and ray flower colors of the lines involved in the crosses

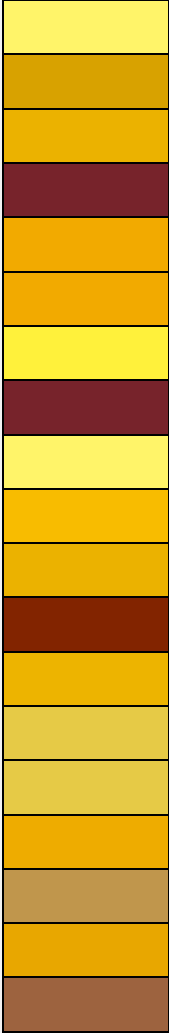
Hybrid 197		Petal color tones of hybrids	
A (CMS) line (♀)	x B (maintainer) line (♂)		
			
Lemon	Dark red gaillardia with yellow tips		
F1 phenotype	8 yellow		
	4 gaillardia patterns with purple suffused on lemon backgrounds		
	3 lemon-yellow		
	2 lemon		
	1 gaillardia patterns with red suffused on orange and yellow backgrounds		
	1 red		

Table 4.26. Color variations in the F1 populations of “198” and ray flower colors of the lines involved in the crosses

Hybrid 198			Petal color tones of hybrids
A (CMS) line (♀)	x	B (Maintainer) (♂)	
	x		
Red gaillardia with yellow tips		Red	
F1 phenotype	10 gaillardia patterns with red suffused on orange and yellow backgrounds	4 red	1 yellow

Table 4.27. Color variations in the F1 populations of “199” and ray flower colors of the lines involved in the crosses

Hybrid 199			Petal color tones of hybrids
A (CMS) line (♀)	x	B (maintainer) line (♂)	
	x		
Medium yellow		Brownish gaillardia with orange tips (almost red stripes)	
F1 phenotype		13 gaillardia patterns with red suffused on yellow and orange backgrounds	
		3 reddish brown	

Table 4.28. Color variations in the F1 populations of “201” and ray flower colors of the lines involved in the crosses

Hybrid 201		Petal color tones of hybrids
A (CMS) line (♀)	B (maintainer) line (♂)	
		
Lemon Yellow	Medium yellow	
F1 phenotype	16 yellow	

Table 4.29. Color variations in the F1 populations of “203” and ray flower colors of the lines involved in the crosses

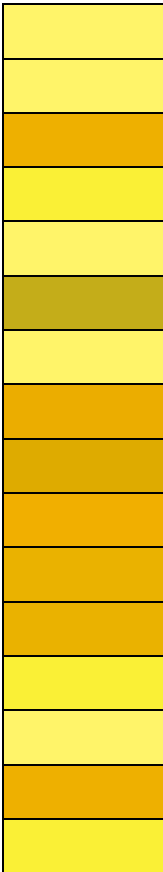
Hybrid 203			Petal color tones of hybrids	
A (CMS) line (♀)	x	B (maintainer) line (♂)		
	x			
Lemon-yellow		Lemon		
F1 phenotype				
	9 lemon	7 yellow		

Table 4.30. Color variations in the F1 populations of “205” and ray flower colors of the lines involved in the crosses

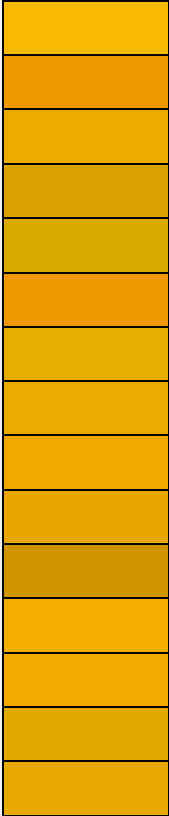
Hybrid 205			Petal color tones of hybrids
A (CMS) line (♀)	x	B (maintainer) line (♂)	
	x		
Brownish gaillardia with orange tips		Intense yellow	
F1 phenotype	11 yellow	2 gaillardia patterns with red suffused on orange and yellow backgrounds	

Table 4.31. Color variations in the F1 populations of “206” and ray flower colors of the lines involved in the crosses

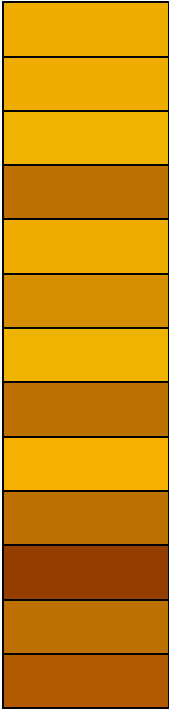
Hybrid 206			Petal color tones of hybrids
A (CMS) line (♀)	x	B (maintainer) line (♂)	
	x		
Medium yellow		Brownish gaillardia with yellow tips (tile-red)	
F1 phenotype	7 gaillardia patterns with red suffused on orange and yellow backgrounds		6 yellow

Table 4.32. Color variations in the F1 populations of “207” and ray flower colors of the lines involved in the crosses

Hybrid 207			Petal color tones of hybrids
A (CMS) line (♀)	x	B (maintainer) line (♂)	
	x		
Lemon		Brownish gaillardia with orange tips	
F1 phenotype	10 yellow	4 gaillardia with red suffused on orange and yellow backgrounds	4 reddish brown

Table 4.33. Color variations in the F1 populations of “208” and ray flower colors of the lines involved in the crosses

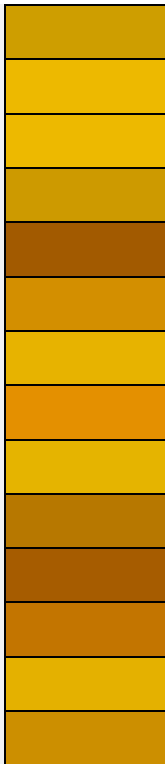
Hybrid 208			Petal color tones of hybrids
A (CMS) line (♀)	x	B (maintainer) line (♂)	
	x		
Lemon-yellow		Brownish gaillardia with yellow tips (tile-red)	
F1 phenotype	7 gaillardia patterns with red suffused on orange and yellow backgrounds	6 yellow	1 reddish brown

Table 4.34. Color variations in the F1 populations of “210” and ray flower colors of the lines involved in the crosses

Hybrid 210			Petal color tones of hybrids
A (CMS) line (♀)	x	B (maintainer) line (♂)	
	x		
Orange yellow		Lemon yellow	
F1 phenotype	13 yellow	2 gaillardia patterns with red suffused on orange and yellow backgrounds	

Table 4.35. Color variations in the F1 populations of “211” and ray flower colors of the lines involved in the crosses

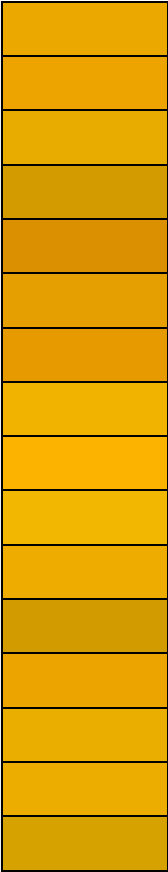
Hybrid 211			Petal color tones of hybrids
A (CMS) line (♀)	x	B (maintainer) line (♂)	
	x		
Brownish gaillardia with yellow tips (red-brown)		Intense yellow	
F1 phenotype	10 yellow	6 gaillardia patterns with red suffused on orange and yellow backgrounds	

Table 4.36. Color variations in the F1 populations of “212” and ray flower colors of the lines involved in the crosses

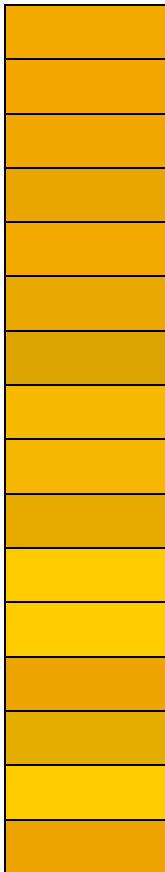
Hybrid 212			Petal color tones of hybrids	
A (CMS) line (♀)	x	B (maintainer) line (♂)		
	x			
Brown and yellow (almost orange)		Intense yellow		
F1 phenotype				
	14 yellow	2 gaillardia patterns with red suffused on orange and yellow backgrounds		

Table 4.37. Color variations in the F1 populations of “213” and ray flower colors of the lines involved in the crosses

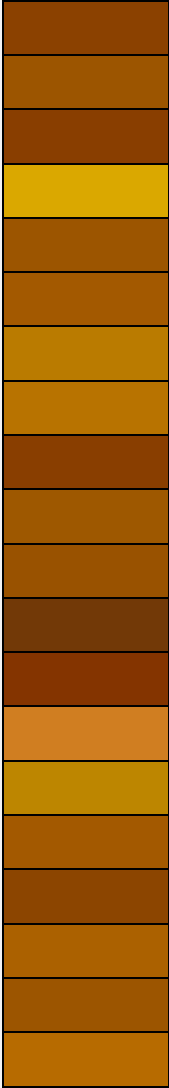
Hybrid 213			Petal color tones of hybrids
A (CMS) line (♀)	x	B (maintainer) line (♂)	
	x		
Dark brown gaillardia with yellow tips		Red-brown (tile-red)	
F1 phenotype	19 gaillardia patterns with red suffused on orange and yellow backgrounds	1 dark reddish maroon	

Table 4.38. Color variations in the F1 populations of “214” and ray flower colors of the lines involved in the crosses

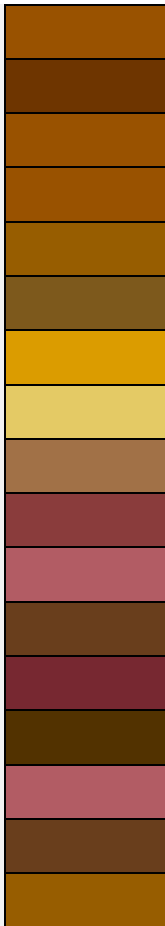
Hybrid 214					Petal color tones of hybrids
A (CMS) line (♀)	x	B (Maintainer) line (♂)			
	x				
Brownish gaillardia with yellow tips		Brownish gaillardia with orange tips			
F1 phenotype	13 gaillardia patterns with red suffused on yellow backgrounds	1 gaillardia patterns with orange suffused on orange backgrounds	1 dark reddish maroon	1 lemon	1 gaillardia patterns with purple suffused on lemon background

Table 4.39. Color variations in the F1 populations of “215” and ray flower colors of the lines involved in the crosses

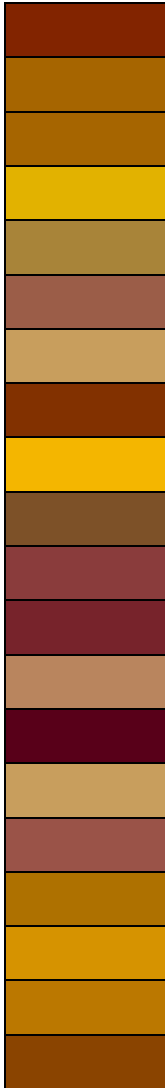
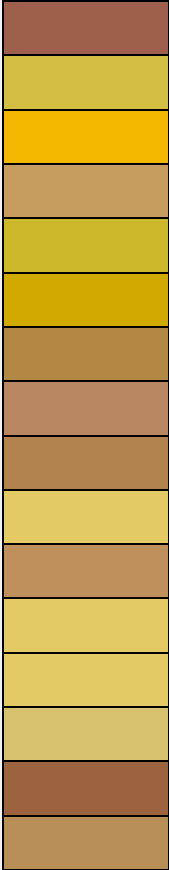
Hybrid 215			Petal color tones of hybrids		
A (CMS) line (♀)	x	B (maintainer) line (♂)			
	x				
Dark brown gaillardia with yellow tips		Brownish gaillardia with yellow tips			
F1 phenotype	9 gaillardia patterns with purple suffused on lemon background	7 gaillardia patterns with red suffused on orange and yellow backgrounds	2 yellow	1 red	1 purple

Table 4.40. Color variations in the F1 populations of “216” and ray flower colors of the lines involved in the crosses

Hybrid 216				Petal color tones of hybrids
A (CMS) line (♀)	x	B (Maintainer) line (♂)		
	x			
Light purple gaillardia with lemon tips		Pale purple gaillardia with lemon tips		
F1 phenotype	8 gaillardia with purple suffused on lemon backgrounds	6 lemon	1 apricot	1 yellow

5. CONCLUSION AND FUTURE PROSPECTS

The aim of this study was to investigate male-sterile SU group herbicide resistant ornamental sunflower hybrids with different floral colors to determine their vase life, ray flower color inheritance and the ornamental potential. For this purpose, SU resistant A (CMS) and B (maintainer) lines with advanced backcross generations developed by CMS method within the scope of the TUBITAK, were used as plant materials.

A total of 947 seeds belonging A and B lines were sown in the spring season of 2024, and 68.4% of them germinated successfully. The seedlings were subjected to selection in terms of their resistance to SU herbicide when they are at 6-8 leaf stage. It was determined that 188 plants in A-lines, and 196 plants in B-lines were observed to be resistant to SU-group herbicides. Segregation of resistant and susceptible plants in each line fit the expected ratio of 1:1, respectively. To determine the B-lines with homozygous (*rfrf*), which will be used in AxB crossing combinations, DNA was isolated from SU resistant B lines. B lines having homozygous (*rfrf*) genotype in the nucleus were identified using SCAR markers to obtain male-sterile hybrids. Then A and B-lines having different ray flower colors and suitable for various ornamental purposes were crossed to create sterile hybrids. In total 31 F1 hybrid variety candidates were obtained. Seeds were harvested at the physiological maturity stage, and sown in the next growing season, in which 73.6% of them were germinated properly. Then the seedlings were transplanted into field and grown for morphological observations and vase life determination.

The use of pollen-free ornamental sunflowers as cut flowers has recently become a market demand in order to prevent allergic reactions in individuals with pollen allergies and to avoid unwanted stains in the floral arrangements (Cvejić & Jocić, 2010). Ethylene production results with reduced longevity and senescence in ethylene-sensitive flowers. Since ethylene production is reduced in pollen-free cultivars, CMS cultivars potentially extend the vase life of cut sunflowers and various other cut flowers. The fact that the ornamental sunflower hybrids developed in this study were male-sterile, i.e. do not produce pollen, they might well respond to market demands. In this context, several morphological characteristics influencing the market potential and the vase life of the 31 hybrids were investigated in the fall season of 2024 and compared with 16 commercial ornamental sunflower checks consisting of 11 fertile and five sterile cultivars with high market potential.

Morphological observations of the hybrids included flowering time, germination time and rate, branching status and position, flower head attitude, plant height, stem length, flower head diameter, stem diameter, disc diameter, ray flower characteristics, pollen fertility, leaf size and color, the color of the ray flowers (petal) and disc flowers (sexual flowers). The vase life of minimum 10 days is desirable criterion in ornamental sunflower cut cultivars (Gast 1995). The average vase life of the hybrids was found to be superior to commercial checks and ranged from 9.2 days to 14 days. The results showed that the hybrids obtained displayed longer vase life performances, exhibiting high market potential, high quality and robust plant structures compared to commercial varieties.

These results were obtained without the use of any vase solution, indicating the genetic superiority of the lines developed and the commercial potential of the F1 hybrids created from them. The vase life of commercial fertile varieties varied between 8.5 days

and 10.5 days, while commercial sterile varieties ranged from 8 days to 11.1 days. Similarly, the average vase life of sterile 27 and fertile 4 hybrids were 11.9 (ranging from 9.2 to 14 days) and 10.6 (ranging from 9.3 to 11.8 days), respectively. Results indicate that male sterility might extend vase life of ornamental sunflower.

In the use of sunflower as an outdoor ornamental plant, genotypes with 50-170 cm and 100-150 cm plant height, branched, compact and strong plant structure, and disease resistant genotypes are preferred. Based on these criterias, it was determined that 15 variety candidates (129, 185, 186, 187, 188, 193, 194, 195, 198, 199, 201, 206, 209, 210, 214) can be used as outdoor ornamental plants. These variety candidates had a flowering time of 44.4-56.4 days, a plant height varying between 105.50-154.68 cm, and exhibiting branching in the whole stem and mostly at the top. These varieties, having a larger flower head diameter compared to cut flower criterias, were observed to be more suitable for use in parks and gardens as border plants, both in terms of leaf size and variability in the size of ray flowers. In addition, the variation in flowering times can provide the opportunity for planting at regular intervals in outdoor areas with the possibility of appealing the eye for a long time. Variety candidates considered suitable for outdoor use were found to exhibit a wide range of color variation ranging from red, tile-red, various shades of gaillardia, orange yellow, and several tones of yellow color.

According to the reports published by Sloan & Harkness (2006), sunflowers with a flower head diameter of 8-15 cm, a stem length of 60-90 cm and a stem diameter of 0.5-1.5 cm are preferred for use as cut sunflowers by florists. Considering these recommendations, it was determined that 12 variety candidates (189, 191, 192, 203, 205, 207, 208, 211, 212, 213, 215, 216) are suitable for use as cut sunflower. It was determined that these varieties exhibited a very dense ray flowers and had a vase life of 10.6-13.1 days, and determined as 100% male-sterile. In addition, these varieties corresponded to the 90°-135° flower head posture angle, which is a very important feature in the cut flower sector. It was also observed that varieties had a shorter flowering times compared to the variety candidates suitable for outdoor use. This results in shorter harvest times and an increased number of harvests during the year, leading to higher profits for cut flower growers. The disc diameter of the candidates varied between 4.81 cm and 5.49 cm. In addition, the attitude of ray flowers was determined to be in the range between semi-erect and horizontal, indicating that these cut sunflower variety candidates might provide convenience in the transportation phase and have an aesthetic presence in bouquets and floral arrangements. These cut sunflower variety candidates displayed a wide range of colors such as lemon, gaillardia patterns, orange yellow, and tile-red.

In the use of sunflower as a potted ornamental plant, it is desired that the genotypes should have a short flowering period, a compact structure, small leaves, and a plant height between 50-100 cm. Among the hybrids developed in this study four of the variety candidates (190, 196, 197, 200) are suitable for use as potted plants indoors or in small gardens. These variety candidates exhibited a flowering period of 41.5-50 days, plant height of 65.9-94.2 cm, branching position on the upper sides of the flower stem, with very small to small leaf sizes and medium-dark green leaf colors. The flower head attitude was observed to be between inclined and vertical position as opposed to commercial dwarf varieties exhibiting an attitude between horizontal and vertical position. Duration of flowering period, which is a very important trait in potted ornamental sunflowers, should be observed in future field trials. The dwarf-type variety candidates was observed

to display no significant color variations. However, as a result of crossing parental lines with lemon and yellow gaillardia ray flower colors, a wide spectrum of color variations was detected such as lemon-yellow, yellow and orange gaillardia patterns, with the majority being yellow color.

Ray flower colors of the hybrids derived from the crosses were compared with that of the parental lines and the variations in different colors and tones were determined. The results revealed the dominant colors and which parental combinations should be used in crosses to obtain the desired ray flower color. In this context, it was observed that yellow ray flower color was dominant over orange and lemon colors. In the crosses of yellow and reddish brown colors, resulting F1 populations exhibited yellow gaillardia patterns. It was observed that yellow gaillardia color tones were dominant in F1 populations of yellow gaillardia x reddish brown crosses. As a result of crossing parental lines having different tones of yellow gaillardia colors, purple, red, yellow, lemon gaillardia and orange gaillardia colors were obtained. In addition, as a result of crossing parental lines having different tones of lemon gaillardia colors, lemon, yellow, and apricot colors were detected, with lemon gaillardia being the majority. In lemon x orange gaillardia crosses, reddish brown and orange gaillardia colors were obtained, with yellow being the majority. In orange gaillardia x yellow crosses, yellow color was determined to be dominant, and yellow gaillardia and apricot colors were obtained in the F1 populations. Moreover, yellow gaillardia color tones were found to be dominant, and lemon, dark reddish maroon, lemon gaillardia and orange gaillardia color tones were obtained in yellow gaillardia x orange gaillardia crosses. Within the scope of the investigation of ray flower color inheritance, it was concluded that the contradictory findings in the F1 populations may be due to the lack of sufficient progeny and the parental lines used in crossbreeding were not homozygous enough. However, these conflicting results, which can be considered as advantageous, demonstrated that wider color variations can be achieved in ornamental sunflower genotypes and that such selection in breeding studies can be addressed to different purposes. The results demonstrated that a variety of colors can be achieved from crosses of heterozygous A (CMS) and B (maintainer) lines with different ray flower colors, and resulting genotypes can be employed with a wide spectrum of colors in landscaping areas, bouquets and floral arrangements, balconies and gardens.

In contrast, in the crossing studies, the segregation of ray flower colors followed a certain pattern according to the dominant and recessive traits in the parental combinations. Yellow color was dominant and was frequently observed in hybrids. Other color groups such as red, orange, lemon and reddish brown colors were genotypically recessive and phenotypically less frequent in most hybrids. The results demonstrated that the selection of parental lines is important for achieving the desired ray flower color in hybrids. The involvement of lines carrying yellow color for yellow ray flower color target in hybrids will ensure the genetic transmission of a dominant trait. On the other hand, for recessive colors such as purple, lemon and brown, both parents should carry the genotypes of these colors to be phenotypically expressed. This study revealed important aspects of the inheritance of ray flower color trait in ornamental sunflowers and provided useful informations for achieving the desired color variations in ornamental plants. In further studies, dominant color trait in ornamental sunflower hybrids can be identified more accurately by providing more progenies. The interaction of genes and the genes

controlling the color trait can be revealed in detail through determination of segregation ratios in F₂ populations. In addition, chromosomal location of the genes controlling ray flower color can be integrated into marker studies, which could eventually provide more detailed investigation of color inheritance.

In future studies, the hybrids developed should be examined under fertilization regimes and planting densities to investigate morphological characteristics influencing the ornamental potential such as flower head diameter, stem diameter, flowering time, disc diameter, stem length, and plant height by establishing greenhouse and open field trials. Future studies should focus on the performance of potted ornamental sunflower hybrids candidates under different pot sizes, fertilization rates, and irrigation regimes to maintain its ongoing value in the potted plant sector. Furthermore, studies performed in both greenhouse and open field conditions may be utilized to evaluate its resistance to diseases, and pests. In addition, the effects of post-harvest treatments such as pulsing solutions, preservative solutions should be investigated to identify which treatments are the most effective in extending the shelf life of the cut flower hybrid candidates. A detailed investigation into different storage conditions and temperature levels can also provide a better understanding of the positive and negative factors influencing post-harvest longevity in these ornamental sunflower hybrids.

Currently, all of the ornamental sunflower cultivars subject to trade in Türkiye are imported. In this study, Turkish ornamental sunflower variety candidates with long post-harvest life, resistant to Sulfonylurea (SU) group herbicides, suitable for ornamental use in different color tones were developed. Male-sterile variety candidates developed using CMS method, introduced for the first time in an ornamental plant sector, is expected to reduce the dependence on imports in ornamental sunflower cultivars in Türkiye. With the utilisation of variety candidates resistant to SU herbicides, it is expected that weed control in cut flower production will become more manageable, reducing the cost of open field cultivation for growers, while providing more cost-effective weed control in our country.

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