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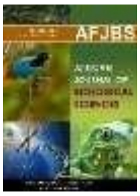

Exploring the Strange world of Strawberry: from their Origins to the Art of Cultivation and Propagation

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Abstract

This extensive study explores the many aspects of strawberries, including its historical roots, contemporary cultivation practices, and methods of propagation. The tale chronicles the migration of *Fragaria* species throughout continents, starting with their ancient origins in Pliny's writings. It emphasizes important breeding events that resulted in the creation of *Fragaria ananassa*. A comprehensive elucidation of the botanical characteristics of the strawberry plant is provided, including its root system, stem, foliage, and reproductive organs. The conversation covers a range of cultivars, with a particular focus on their reactions to distinct photoperiods and significant agronomic characteristics. This text provides a clear explanation of the important aspects related to soil and climate that are essential for effective cultivation. It also offers valuable insights into how environmental factors affect crop output and the quality of fruits. This study provides a comprehensive examination of several propagation techniques, such as stolon propagation, crown division, and micropropagation, with a focus on their practical implications and significant contributions to the field of strawberry farming. In summary, this publication offers a comprehensive examination of strawberries, making it a great reference for researchers, cultivators, and enthusiasts in the horticulture industry.

Keywords: Strawberries, Cultivation, Propagation, Botanical Description, Cultivars

ORIGIN AND DISTRIBUTION

Strawberries, scientifically known as *Fragaria*, are a part of the Rosaceae family. An early account of strawberries dates back to Pliny's writings in 23-79 AD (Darrow, 1966). In North America, pioneers cultivated *Fragaria virginiana* (*F. virginiana*) for its native characteristics and resilience in the face of drought and severe weather conditions. This was introduced to Europe during the early 17th century, when different species like *Fragaria vesca* (*F. vesca*) were grown in France and Northern Europe. In Russia, *Fragaria moschata* (*F. moschata*) was primarily cultivated. One significant event in the history of strawberries occurred 300 years ago, when a French Navy sailor returned to France from Chile and Peru with several specimens of *Fragaria chiloensis* (*F. chiloensis*). Afterward, the plants were carefully propagated and brought into close proximity with *F. virginiana*, allowing them to be cultivated side by side. A fortuitous crossbreeding yielded a more resilient plant with larger and more flavorful fruits. This particular hybrid, *Fragaria* × *ananassa*, has been widely disseminated across the globe. The ploidy of *Fragaria* × *ananassa* is octoploid, while wild strawberries have a diploid ploidy. This difference in ploidy leads to enhanced fruit production and larger fruits. In contrast, this particular crossing resulted in lower organoleptic qualities. However, the fruits displayed a vibrant red color and a succulent texture (Khoshnevian *et al.,* 2013). Strawberries are highly sought after due to their popularity and the high demand for both fresh consumption and use in the fruit processing industry.

BOTANY AND TAXONOMY

The strawberry (*Fragaria* × *ananassa*) is a common plant that is known for its hardiness, perennial nature, and beautiful rose-like appearance. It is taxonomically classified as a species with: The world of plants Order: Rosales Belonging to the Rosaceae family Subfamily: Rosoideae Plant Type: *Fragaria* Plant species: *Fragaria* sp.

ROOT SYSTEM

Strawberry plants possess fasciculated roots that consist of a significant proportion of volume specifically allocated to providing support to the plant and other components. These rootlets are responsible for absorbing nutrients and water necessary for the plant's development (Strand, 2008). According to Flórez Faura and Mora Cabeza (2010) and Ruíz and Piedrahita (2012), the set in question is affixed to the stem using threads of uniform dimensions. It is spread at depths of up to 30 cm, however it has been seen that roots may extend up to 80 cm. On an annual basis, the main root undergoes replacement by subsequent roots located at more elevated heights on the crown.

Fig 1: A) Habit. B) Stolon. C) Stipules. D) Lateral leaflet. E) Indument of the abaxial surface of the leaflets. F) Peduncle. G) Flower, front view. H) Flower, lateral view. 1) Bracteole. J) Sepal. K) Petal. L) Stamen. M) Longitudinal section of the gynoecium. N) Carpel. 0) Accesory fruit. P) Achene. an: anther, aq: achene, br: bracteole, cp: carpel, eg: stigma, ep: stipules, es: stamen, et: style, fi: filament, gi: gynoecium, ov: ovary, pe: petal, re: receptacle, ri: rhizome, se: sepal.

STEM (CROWN)

The strawberry stalk, also known as a crown, features a rosette shape adorned with basal leaves. These leaves house axillary buds that have the remarkable ability to produce various plant organs such as leaves, stolons, flowers, or even new crowns. They develop in the crop based on the nutritional and environmental conditions (Ruíz and Piedrahíta, 2012).

STOLON

It's fascinating how the stem grows horizontally from the crown and eventually gives rise to a new crown, giving birth to a new plant in just three weeks. It is fascinating to observe how a single plant can give rise to up to 15 stolon systems, each with its own unique vigor compared to the mother plant (Flórez Faura and Mora Cabeza, 2010; Ruíz and Piedrahíta, 2012).

LEAVES

Just take a look at the leaves of the strawberry plant - they're made up of three leaflets with jagged edges and two stipules. The leaves are arranged in a spiral phyllotaxis pattern, with the fifth leaf positioned above the first one. With its strategic arrangement, the strawberry plant maximizes sunlight interception. Additionally, the leaves boast a remarkable stomata density on their lower surface, enabling the plant to efficiently absorb carbon dioxide from the atmosphere. Nevertheless, this increased stomatal density can pose challenges when dealing with water scarcity.

FLOWER AND FRUIT

The flower of a strawberry typically consists of five green sepals (sometimes more), five white petals, multiple stamens, and a receptacle, commonly referred to as a torus, which supports a large number of pistils. Only hermaphrodite flowers are found in cultivated varieties (Ruíz and Piedrahíta, 2012). Just as a microbiologist would observe, the pistil of a flower undergoes development and transforms into a tiny fruit known as an achene, which contains a solitary seed. Similar to a microbiologist, one can observe the achenes as tiny and rigid structures that are scattered throughout the juicy strawberry. Consequently, the strawberry "fruit" is not considered a fruit on its own, but rather an aggregate fruit. Then, the fruit can be described as a complex structure, formed by the fusion of numerous small achenes that develop from the fertilized ovum and contain the edible part. Following fertilization, the receptacle undergoes growth and development, resulting in a variety of fruit shapes, including oval, conical, or balloon-shaped. The color of the receptacle ranges from pale red to intense red and bright red. This parameter serves as a quality indicator during the commercialization process (Perkins-Veazie, 1995).

CULTIVARS

There are approximately 1000 different types of strawberries found across the globe. Variations among cultivars stem from their vigor, ability to resist pathogens, and the characteristics of their fruits (such as size, color, shape, and flavor). (López-Aranda *et al.*, 2011). Different cultivars can be categorized based on their response to different photoperiods, such as short-day, long-day, and neutral-day plants (Hummer and Hancock, 2009; Serçe and Hancock, 2005). Strawberry's short-day plants, also known as June-bearing plants, bloom during periods of less than 12 hours of light. Several cultivars fall into this category, including Allstar, Cavendish, Chandler, Sparkle, and Wendy. Strawberry plants that require longer days are also known as eve-bearing strawberry plants. These plants produce two harvests annually, one in the spring and another in late summer. Most June-bearing strawberry cultivars belong to the *Fragaria* × *ananassa* variety, while the ever-bearing strawberry cultivars belong to the *F. vesca* variety. The third class consists of day-neutral strawberries, which bloom regardless of the hour of light. Plants in this class exhibit superior fruit quality and productivity compared to other classes, making them ideal for cultivation as annual plants. Albion is a well-known cultivar that falls into this category. There are an immense number of varieties, with new ones emerging annually. Providing a comprehensive list of all the different types of strawberries would be quite challenging. Thankfully, there is a tool that enables us to understand the key attributes of numerous varieties. There is an interactive list that can be found at https://strawberryplants.org/strawberry-varieties/. There are several notable varieties available, including Alba, Albión, Allstar, Antilla, Atlas, Benton, bolero, Camarosa, Cambridge Favourite, Candonga, Cavendish, Chandler, Charlotte, Earlyglow, Flair, Florentina, Fortuna, Kent, Lucía, Monterey, Pandora, Primoris, Rainier, Royal Sovereing Sabrina, San Adreas, Splendor, Sweet Ann, and Ventana.

BREEDING AND CROP IMPROVEMENT

Fragaria ananassa is widely recognized as the predominant strawberry crop, while other species include *F. chiloensis*, *F. vesca*, *F.* viridis, *F. moschata*, and *F. virginiana* have comparatively little significance. *F. vesca*, a strawberry native to alpine forests, had significant popularity throughout the 16th and 17th centuries until it was supplanted by a variety originating from America. At now, *F. vesca* is being planted in domestic gardens owing to the little but very delectable fruits it produces. During the late 15th and 16th centuries, *F. moschata* was cultivated, and its fruits had a distinct musky taste. In contrast, *F. viridis*, characterized by its pale green fruit, was mostly used for decorative reasons. *F. virginiana*, often referred to as a wild strawberry, is distributed in North America, Canada, and Alaska. The fruit is very fragrant although diminutive. Both of these species are presently not commercially significant. The Mapuche, an indigenous tribe residing in the southern region of present-day Chile, were responsible for domesticating *F. chiloensis*. *F. chiloensis* was brought to Europe during the time of Spanish colonialism. During the 18th century, a fortuitous hybridization occurred in France between *F. chiloensis* and *F. virginiana*, resulting in the emergence of *Fragaria ananassa*. *F. vesca* is a diploid species with 14 chromosomes, whereas *Fragaria ananassa* is an octoploid species with 56 chromosomes. Table 1 presents a comprehensive list of many species worldwide, including information on their ploidy and key agronomic traits. Strawberry is a very diverse crop, with over 100 new varieties being registered year (UPO, 2019). Nevertheless, the genetic foundation for acquiring such a vast array of contemporary cultivars is limited. Until 1990, a limited number of 10 parental genotypes were used in the development of new cultivars. Despite the limited number of genotypes, this species has managed to maintain a significant level of genomic variability due to its octoploid nature. This has been exemplified through the utilization of randomly amplified polymorphic DNA, as demonstrated by Gambardella *et al.* (2000) and further supported by Gil-Ariza *et al.* (2009).

Over the course of more than two centuries of breeding, only a limited number of genetic variations have been generated. The use of wild germplasm has played a substantial role in the preservation of genetic diversity. Presently, a plethora of breeding schemes exist. Certain programs get funding from public sources, while others are funded by private enterprises. The objective of all these initiatives is to enhance *Fragaria ananassa*. The primary breeding programs in Europe are concentrated in France, the Netherlands, the United Kingdom, Italy, and Spain. In America, the main breeding programs are conducted in the United States (specifically California, Florida, and Maryland) and Canada (specifically Ontario and Quebec). Additionally, in Chile, a breeding program involving *F. chiloensis* is implemented in Talca.

Table 1: Global Strawberry Species: Ploidy and Key Agronomic Features

Species	Ploidy	Main Characteristic	Distribution
F. moschata	6×	Fruit dark to light red, with a musky European Siberia flavor; plant tolerant to flood soil, cold, and shade; resistant to mildew	European Siberia
F. chiloensis	8×	uit dark red and internal flesh white; Chile and West; much tolerant to a wide range of North America conditions due to rusticity	Chile and West- North America
F. virginiana		Fruit dark red or scarlet, with internal flesh white, very aromatic; soft to deep red or scarlet fruit; much tolerant to a wide range of adverse conditions	North America, including Canada and Alaska
F. × ananassa		Fruits spherical or oblong, very big, and red	Worldwide
F.× bringhurstii	5×	Intermediate characteristics of *F. vesca* and *F. chiloensis*	California
F. moupinensis		Orange–red fruits, with less flavor	North China
F. orientali	4×	Slight aromatic and soft fruits	East Russia and West China
F. nipponica		Fruit unpleasant; plant tolerant to cold weather; self-incompatible	Japan
F. daltoniana		Fruits red brilliant but tasteless; self-compatible	The Himalayas
F. nilgerrensis		Fruits are tasteless but pink; self compatible; and resistant to pests like aphids and a lot of diseases	South eastern Asia
F. viridis		Self-incompatible with bearing fruits of color greenish pink, firm, and aromatic	Asia and Europe
F. vesca	2×	Fruits are red, soft, long and aromatic. Self-compatible; tolerant to adverse conditions such as drought, cold, heat; and resistance to several diseases	Worldwide

SOIL AND CLIMATE

SOIL

Proper soil preparation is crucial for the successful growth of strawberries. It thrives best in loose soils, particularly sandy or loamy sand, that have excellent drainage (Tagliavini *et al.,* 2005). To ensure successful planting of mother plants, a specific procedure is followed. It begins by making a careful cut to encourage new shoots to grow. The plant is then treated with a solution containing fungicides and insecticides to eliminate any potential threats. Finally, the plant is transplanted directly into the prepared holes, as described by Roussos *et al.* (2012). It is important to consider that when applying nutrients to these soils, it is done in small amounts and with a higher frequency (Horneck *et al.,* 2011). Strawberries thrive in soil that has a slightly acidic pH, typically ranging from 5.5 to 6.5 (Tagliavini *et al.,* 2005). Acidic soils have the potential to limit microbial activity, decrease the accessibility of vital nutrients, and lead to aluminum toxicity in the soil. This can result in delayed root growth and hinder the absorption of water and nutrients. Furthermore, it is essential to perform electrical conductivity (EC) tests to assess the impact of salt content in the soil. Given the delicate nature of strawberry crops, it is crucial to maintain a low electrical conductivity (EC) level of less than 1 dS/m to ensure their optimal growth and development. The crop thrives in soils with high cation exchange capacity, indicating their ability to retain and exchange essential nutrients. These factors have a significant impact on the soil's stability, nutrient content, pH levels, and how it responds to fertilizers and amendments. In addition, it is important to have a higher percentage of organic matter, ideally around 2% to 3%, and a carbon-nitrogen ratio (C/N) that is close to 10. When it comes to most crops, it's important to keep an eye on the ideal values. For nitrates, the range should be around 10-50 mg/kg, while ammonia should be kept between 0-5 mg/kg. (Hochmuth and Albregts, 1994). When it comes to the phosphorus content in soil, it's worth noting that a concentration of 60 ppm is considered quite high for strawberries. In the case of using P_2O_5 (phosphoric anhydride), it is advisable to have values higher than 50 ppm for strawberries, as suggested by Peverill *et al.* in 1999. Soil microorganisms are crucial in the process of mineralizing organic sulfur. The rate at which sulfur becomes available for plants is determined by the biological activity and various factors that affect microbial populations, such as temperature and humidity (Peverill *et al.,* 1999). Typically, for most crops, a sulfur level of 37 to 78 ppm is considered sufficient. Anything below 23 ppm is considered low, while anything above 116 ppm is considered high (Hochmuth and Albregts, 1994).

CLIMATE

The growth of strawberries is influenced by various environmental and physiological factors. Factors such as light intensity, light quality, photoperiod, temperature, and soil moisture levels all play a significant role in determining the growth of various plant parts, including leaves, crowns, roots, stolons, inflorescences, flowers, and fruits. Ultimately, these factors have a direct impact on the overall crop yield and fruit quality. However, the response of different genotypes can vary significantly, depending on the specific conditions and the environment in which they are grown (Darnell *et al.,* 2003; Darrow, 1966; Hancock, 1999). At certain times of the year, the weather conditions can be less than ideal for planting fruit-producing plants. This can be due to extreme temperatures and heavy rainfall towards the end of summer, or chilly temperatures in late winter and early spring, which can hinder the growth of newly transplanted crops. During certain instances, the manifestations occur when plants are in the midst of blooming and bearing fruit, coinciding with periods of intense heat, heavy rainfall, spring and autumn frosts, or strong winds and hail (Demchak 2009; Demchak & Hanson, 2013; Hancock, 1999; Herrington *et al.*, 2011; Hummer and Hancock, 2009; Singh *et al.*,2012). The ideal temperature range for strawberry growth falls between 10 °C and 26 °C. This finding is supported by the research conducted by Ledesma *et al.* (2008), which aligns with the results obtained by Verheul *et al.* (2007) indicating diurnal temperatures of 18 °C and nocturnal temperatures of 12 °C.

PROPAGATION

Stolons are the predominant mechanism used for propagation in strawberries. According to Bish *et al.* (1997), the process of propagation occurs organically, with a preference for the establishment of root systems in organs such as stolons, crowns, and meristem culture. In the context of breeding procedures, the reproduction of strawberry plants via the use of seeds is employed as a means to acquire hybrid plants (Frankel and Galun, 2012). In cases when certain species or cultivars exhibit sexual infertility, cloning emerges as the only viable solution. The utilization of horizontal aerial stems, characterized by the presence of alternating long and short internodes, facilitates the development of adventitious roots, commonly referred to as stolons (Davies *et al.*, 1994; Wilk *et al.*, 2009). This enables the novel plant to independently explore soils beyond the confines of the mother plant's root system (Husaini and Neri, 2016). Stolons are used for the cultivation of mother plants in nurseries located in temperate zones, mostly because to the prevailing conditions of extended daylight hours and elevated temperatures (Bish *et al.*, 2001; Cantliffe *et al.*, 2003). The offspring plants achieve self-sufficiency during a span of two to three weeks, while they remain connected to the parent plant with stoloniferous filaments. According to Holzapfel and Alpert (2003), the daughter plants have the ability to engage in vascular transport, facilitating the interchange of carbon, water, mineral fertilizers, and biochemical components. Following the cutting process, the newly acquired plant from the mother plant is kept in cold chambers at a temperature of -2 °C until the time of seeding. The plant's cold accumulation during this period enables it to produce the first blooming, which is often feeble, as well as a substantial number of stolons that need to be pruned to enhance vigor and crown formation (Lieten *et al.*, 1995).

PROPAGATION BY CROWN DIVISION

This technique is mostly used in cultivars characterized by limited stolon production but substantial secondary crown production. Due to this rationale, the implementation is limited to mother plants that possess fully grown crowns. To encourage the growth of secondary roots in each crown, it is necessary to use fertilizers with high levels of nitrogenous sources, provide enough hydration, and maintain consistent conditions.

USE OF ROOTING TRAYS

Stolons measuring 1 cm in length are carefully removed from the mother plant using precise pruning shears. These stolons are then placed in plastic rooting trays filled with substrates like peat and coconut fiber. After 30-40 days, the plants can be transferred to the field, as suggested by Durner *et al.* (2002) and Lieten (1998).

MICROPROPAGATION

Strawberry micropropagation was first introduced in 1974 and quickly gained popularity among European seed companies. This method proved effective in reducing the occurrence of soil-borne diseases like *Verticillium*, *Phytophtora cactorum*, and *Phytophthora Fragarie*. Additionally, it led to a significant increase in the number of stolons produced by the mother plant (Boxus, 1974; Boxux and Larvor, 1987; Boxus *et al.,* 1984). This technique involves the cultivation of plant tissues and relies on principles such as cellular totipotency, which allows a single cell to develop into a whole new plant through in vitro multiplication. This type of in vitro culture is presented as a viable option for obtaining pathogen-free plants, while also achieving a rapid multiplication rate.

PHASES OF MICROPROPAGATION

In 1974, Murashige introduced a method for efficiently generating healthy plants in a short period of time. This method involves three stages: Stage I involves establishing a sterile crop, Stage II focuses on multiplying propagules, and Stage III prepares the plants for reintroduction into the soil (Murashige, 1974). On the other hand, a more advanced method, inspired by Murashige's model, was primarily suggested for use in a commercial setting (Debergh and Maene, 1981). This procedure involves several stages. First, mother plants are prepared under hygienic conditions. Then, aseptic cultures are established. Next, viable propagules are produced. After that, preparations are made for field growth. Finally, the plants are transferred to the field. It is advisable for the initial two stages that the "mother" plant possesses the typical traits of the variety and is disease-free (George *et al.,* 2008). Furthermore, it is crucial to remove any contaminated culture medium before or after sowing. The work area should be thoroughly disinfected or sterilized during the process of cutting and extracting explants, as well as when sowing them into the culture medium. It is important to ensure that this disinfection does not cause any harm to the plants (Sathyanarayana and Varghese, 2007). When extracting tissues from explants, it is recommended to make cuts on the differentiated organs to obtain new explants (George *et al.,* 2008). Ensuring the rooting and elongation of plant structures is crucial in the third stage. It is strongly advised to carry out elongation in vitro and rooting ex vitro. This approach offers several benefits, including cost reduction and improved physiological and structural root formation compared to in vitro development. Additionally, it helps prevent damage to the roots during transplantation to the field (Sathyanarayana & Varghese, 2007). For strawberries, researchers performed an experiment where they elongated the aerial part in vitro using specific substances. They used a combination of 6-benzylaminopurine, benzyl adenine, and indole-3-butyric acid in specific amounts for a duration of three weeks (Moradi *et al.,* 2011). After the plants have finished this stage, they are ready to be moved to the field.

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