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AKDENIZ UNIVERSITY

INVESTIGATION OF GENOTYPIC AND ENVIROMENT EFFECTS ON KINKING CHARACTER IN TOMATO (*Lycopersicon esculantum L.*)

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MASTER DEGREE THESIS

Bu tez 16/07/2021 tarihinde jüri tarafından oy birliği ile Kabul edilmiştir.

Prof. Dr. Faik KANTAR
Prof. Dr. Nedim MUTLU
Assoc. Prof. Dr. Hasan PINAR

ÖZET

DOMATESTE (*Lycopersicon esculantum L.*) SAP KIRILMASI KARAKTERİ ÜZERİNDEKİ GENOTİPİK VE ÇEVRESEL ETKİLERİN İNCELENMESİ

Egemen AKINCI

Yüksek Lisans Tezi, Tarımsal Biyoteknoloji Bölümü

Danışman : Prof. Dr. Faik KANTAR

Temmuz 2021; 58 sayfa

Bu çalışma domateste *(Lycopersicon esculantum L.)* sap kırılma problemini araştırmıştır. Kinking, domates saplarının kırılmasına verilen isimdir. Bu sorun domates meyvelerinin küçük kalmasına ve verim kaybına neden olur.

Bu çalışmada kinking sorununun genetik, çevresel ve fiziksel nedenleri araştırılmıştır. Literatürde bu konuda çok fazla çalışma bulunmamaktadır. Bu çalışma, kırılma problemini azaltarak uğranılan hasarı en aza indirmeyi amaçlamaktadır. Bu problemin gen havuzundaki hibritlerdeki oluşum sıklığı, hatlarda görülme sıklığı ve aynı hatların farklı çevre koşullarında değişkenliği incelenmiştir.

2019 yılı ilkbahar, sonbahar ve kış mevsimlerinde yapılan denemelerde fenotipik gözlemler yapılmış ve kinking karakterinin görülme sıklığı ölçülmüştür. 3508 hibrit ve 346 hat dahil olmak üzere toplam 3854 materyal analiz edilmiştir. Frekans analizleri, kinking karakterinin frekansının çok yüksek olduğunu göstermiştir. Bu analizlerde 2019 kış hatlarının kırılma karakterinin sıklığının diğer mevsimlere göre daha düşük olduğu gözlemlenmiştir.

Tüm gözlemler analiz edildiğinde, kinking ile salkım sapı uzunluğu arasında pozitif ve anlamlı bir ilişki bulunmuştur. Aynı zamanda, zor hasat edilen hibritlerle, kinking karakteri arasında ile negatif fakat anlamlı bir ilişki bulunmuştur ancak diğer özellikler arasında anlamlı bir ilişki bulunamamıştır.

Ayrıca kinking karakterinin kalıtsal özelliği hakkında herhangi bir yorum yapılamamış olup, kırılma karakterinin sıcaklık, ışık ve nem gibi çevresel faktörlerden etkilendiği düşünülmektedir. Bu nedenle ıslah programlarında kısa saplı ve kırılması zor domates materyalleri üzerinde seleksiyonlar yapılarak bu materyallerden melezler elde edilebilir. Bu karakterin kalıtımının daha iyi anlaşılması için GWAS çalışması ve QTL analizleri önerilir.

ANAHTAR KELİMELER: Çevresel Faktörler, Domates, Kalıtım, Kinking

JÜRİ: Prof. Dr. Faik KANTAR

Prof. Dr. Nedim MUTLU

Doç. Dr. Hasan PINAR

ABSTRACT

INVESTIGATION OF GENOTYPIC AND ENVIROMENT EFFECTS ON KINKING CHARACTER IN TOMATO (*Lycopersicon esculantum L.*)

Egemen AKINCI

Master Thesis; Department of Agricultural Biotechnology

Supervisor: Prof. Dr. Faik KANTAR

July 2021; 58 pages

This study investigated the stem breakage problem in tomato *(Lycopersicon esculantum L.).* Kinking (nicking) is the name given to the breaking of tomato stems. This problem causes tomato fruits to remain small and yield loss. The genetic, environmental and physical causes of the nicking problem affecting tomatoes were investigated.

This study aims to minimize the damage by reducing the nicking problem. The frequency of occurrence of this problem in the hybrids in the gene pool, the frequency of its occurrence in the lines and the variability of the same lines in different environmental conditions were investigated. Phenotypic observations were taken in the trials conducted in the spring, autumn and winter seasons of 2019. A total of 3854 materials were analyzed including 3508 hybrids and 346 lines. Frequency analyzes showed that the frequency of the kinking character was very high. In these analyzes, it was observed that the frequency of the kinking character of the 2019 winter lines were lower than in other seasons.

When all materials analyzed, a positive and significant relationship was found between kinking and truss stem length. At the same time, there was a negative but significant relationship with harvest difficulty character. No significant relationship was found between kinking and other traits.

In addition, no comment could be made on the hereditary feature of the kinking character, and it is thought that the kinking character is affected by environmental factors such as temperature, light and humidity. Therefore, hybridisation programs are suggested using these materials and selections should be made for short and strong peduncles in breeding programs. GWAS studies and , QTL analyzes are recommended for a better understanding of the inheritance of this character.

KEYWORDS: Tomato, Correlations, Environment, Genetic, Kinking

COMMITTEE: Prof. Dr. Faik KANTAR

Prof. Dr. Nedim MUTLU

Assoc. Prof. Dr. Hasan PINAR

PREFACE

The tomato cultivation is a very important place for Turkey and one of the most important products in human nutrition. In the fields, it was seen as a great advantage in the support of our country requirement in greenhouses and hydrophonic culture production. Kinking (nicking) problem reduce yields and quality in tomatoes. This study attempted to investigate the extend of kinking problem in tomatoes.

I would like to thank to the Nunhems Seed Company for their support during the experiment between 2019-2020. I am grateful also for Prof. Dr. Faik KANTAR for his guidance and consultancy whole of the duration of the study and staffs at the Department of Agricultural Biotechnology.

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ACADEMIC DECLARATION

I state that this study titled Investigation Of Genotypic And Environment Effects On Kinking Character In Tomato (Lycopersicon esculantum L.), which I submitted as a Master Thesis, was written in accordance with academic rules and ethical values, and I declare that I have cited the source of all information that does not belong to me in this thesis.

16/07/2021

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1. INTRODUCTION

The tomato came to Europe for the first time probably with Christopher Columbus in 1493, but it was the Spanish Hernán Cortéswy that sees this resort in Tenochtítlan and brought his seeds to Europe. The Spanish government, who realizes that tomatoes can grow in the Mediterranean climate, began to introduce its production in both Europe and far colonies. The tomato was started to be raised in the Spanish areas in 1540s and used as a common meal in the early 17th century. Other European countries did not accept tomatoes as food. Although the Italian nobles and scientists discover tomatoes from 1548 (tomato and ketchup industry), they used it as a fruit in the early 17th century and until the early 18th century. They cared about color and beauty. Thanks to the selective correction, many colors and different ways managed to develop tomatoes. The tomato fell to a similar place in England in 1597. This changed with many developments from Spain in the middle of the 18th century. At the end of the 19th century there were tomato in Asia. British consuls in Syria reached John Barker's guidance. In the mid-19th century tomato became very common in Syria and China. The American Scientist was alexander W. Livingston who grew tomatoes for commercial purposes. He spent his life on tomatoes.

In 2009, the world tomato production increased to 158.3 million tons up by 3.7% by the previous year. China is the largest tomato manufacturer by meeting 24% of world production. After that, the United States, Turkey, India, comes to Egypt and Italy.

In the greenhouses, the stem strength of tomato plants are not sufficient to support the weight of the fruits. Hence cluster stems break under the weight of fruits and 'Kinking problem' reduces the fruit size and quality by preventing the assimilates from being moved to fruits, thus reduces crop yields. Different factors may cause it. First, some varieties have a weaker stem (flowers and fruit stalks) than other varieties. Conditions in the greenhouse may be conducive to this situation. In hot period, plants exhibit a more vegetative development. This reduces the flowering of the plant, but does not stop all, and plants reveal different growth states of the vegetative and general periods. When a tomato is in a more vegetative condition, the stem of the cluster extends in the steep angle; and continues with fruit attitude. This may cause more kinking. The growing tissue under low light intensity is more tender than one under high light intensity, which simply bends under fruit weight. There are several ways to prevent this problem. Firstly controlling the environment in which plants grow is important. If you have higher air temperatures or low light, try cooling or increasing the light intensity. However, some factors cannot be controlled. For example, despite all the cooling measures, ambient air may stay warmer during hot summer seasons. It may not be practical and over expensive to provide extra light under cloudy winter periods. However, in practice farmers can use plastic clips to support cluster stems and prevent kinking. Although this is only practical way to prevent kinking of peduncle stems, it is cumbersome process and costly in terms of labor requirements. This is the best way to minimize the quality and efficiency reduction resulting from the bending of the stalk stem. The other option requires additional labor, time and cost but it is very efficient.

There are clips of different shapes produced to prevent this situation. The purpose of the clips is to prevent kinking by supporting the clusters. We can use a clip for supporting the stem of the clusters when they flowering. Thus the stem carries more weight, the fruits develop easily and become productive.

In this study, the frequency of kinking character in hybrids and lines, environmental effects were investigated. This study helps to understand the reasons for kinking problem in tomatoes and help to determine the varieties which have less kinking problem for reduce yield and quality loss. High yield and quality tomato varieties will provide farmers more profits and contribute to consumers and manufacturers positively.

2. LITERATURE REVIEW

2.1. Characteristics And History

Tomato *(Solanum Lycopersicum L.)* is shown in the world's most important and popular fruit vegetables. It is an annual self-pollinate plant. Solanaceae have 2n = 24 chromosome (Jenkins 1948; Peralta et al., 2008). The classification of the Solanaceae family changed in the last days and the new naming of Lycopersicon has turned into genus Solanum (Peralta et al 2008). Solanum genus and Lycopersicon are combined. Lycopersicon types consists of Lycopersicum L. and wild relatives in the cultured tomato (Peralta et al. 2005; Peralta et al. 2008). The origin of the tomato is the region in the United States, Bolivia, Chile, Colombia, Ecuador and Peru (Peralta et al. 2008; Blanca et al. 2012. The discovery of America opened the door to bring tomato to Europe and then spread rapidly in the world (Heiser 1969; Blanca et al. 2012; Lin et al. 2014). The use of tomatoes widely reached the 20th century by the spread of private seed companies developing the F1 hybrid method (BAI and Lindhout 2007).

Figure 2.1. Some tomato types

2.2. Importance And Consumptions

Currently, the tomato is the highlight of the horticultural industry and is growing worldwide either for the fresh market or processing (Nowicki et al. 2013). Tomato is a versatile vegetable. In the production of a wide variety of processed products such as tomato paste, powder, ketchup, sauce, soup and canned whole fruits, together with the consumption of fresh tomato fruit; Unripe green fruit is used for pickling, canned and consumed after cooking. It is an important source of lycopene, a phytochemical that protects cells from cancer-related oxidative damage (Giovannucci et al. 1995). This crop is grown around the world for wide purposes.

Approximately 70% of total tomato production in Turkey is consumed fresh and the remainder is processed. Of the 30% of the crop that is processed, 85% is used to produce tomato paste, 10% is canned, and the remainder is used to produce dried tomatoes and other products. Over the period of 1995 to 2007 production increased by 2.7 million tons to almost 10 million tons in 2007. Exports increased by 300,000 tons to reach 400,000 tons in 2020. Imports are insignificant over the whole period. Tomato exports from Turkey are highly seasonal and generally take place between February and June (Gülşen et al., 2007). Turkey exported 1.023.000 tons of fresh vegetables in 2009. Tomatoes have a significant place in total exports with a share of 53% (IGEME, 2009).

The need for collection, evaluation and characterization of native and exotic tomato germplasm as self-hybridization is a prerequisite. Evaluation of phenotypic characteristics such as fruit morphology, color density, nutritional quality, hardness, flavor and aroma are difficult and time consuming due to the quantitative nature of the traits (Fiorani & Schurr 2013). In addition, study on phenotypic traits is necessary because these criteria are widely used to evaluation the genetic diversity, reproductive value and yield potential of the crop (Lopez et al. 1994; Singh and Sahu 1998; Agong et al. 2001; Dharmatti et al. 2001; Mohanty and Pusti 2001; Parthasarathy and Aswath 2002).

2.3. Kinking Problem

The stems of clusters of tomato plants is too weak for supporting of the truss weight. They tend to bending in the winter, autumn, spring seasons. The term for bending of the stem "Kinking" (or Nicking) and this twisting adversely affects the transport of nutrients to the fruit, thus reducing crop yields. Although there is some evidence for this, little attention has been paid to the possibility that bending of the stems may also lead to "compensatory growth" in the clusters. When a full cluster was plucked from tomato plants at early stage of development, the fruit yield increased in those clusters just above and below the detached cluster (Slack and Calvert 1977). Obviously, the growth of the remaining trusses compensated to some extent the loss of the removed truss, and the compensation was more complete as the number of the removed truss increased. Similarly, when some distal fruit was removed from the first three clusters of the tomato at an early stage of fruit development, there was a compensatory increase in the weight of the remaining proximal fruit and the weight of the fruit in the below clusters. (Hurd et al. 1979; Koning 1994). Removing some fruit from a cluster increased the weight of the remaining fruit. Thus, there is strong evidence that competition for assimilates occurs between trusses and between fruits of individual clusters, and that this competition leads to redistribution of assimilation if all clusters or individual fruits are removed. Therefore, if the flow of assimilate into cluster is limited by the kinking, a similar distribution of assimilate seemed likely to occur. If so, the efficiency of the affected stem and the compensatory growth of other trusses would likely be affected by the severity of the kinking. The stage of development of the fruit and vascular tissue very important whether kinking occurs suddenly or over a long period of time.

Figure 2.2. Non-kinking truss

Figure 2.3. Kinking truss

3. MATERIAL VE METHOD

3.1. Material

3.1.1. Research Location

This study was carried out in Nunhems Tohumculuk Antalya Station under greenhouse conditions between 2019-2021. The observations in relation to plant growth and the occurrence of kinking problem were made in different seasons on parental lines and their hybrids.

3.1.2. Genetic Materials

In the experiment, 150 to 200 tomato lines and 300 to 1200 tomato hybrids were used as research material depending on season and experiment.

3.2. Method

Kinking trait was investigated in relation to other phenological and morphological plant characteristics in 6 different plantings with a number of lines and hybrids in the seasons of spring, autumn and winter period in 2019 and 2020 under greenhouse conditions (Trials 1-6). A further separate hybridization program (Trial 7) was set up in the green house in the growth season of 2020-2021 with the lines showing no kinking and severe kinking phenotype selected from the previous six experiments.

3.2.1. Spring season experiment with parental lines 2019

An experiment was set up in greenhouse with 103 lines of various generations (F1-F9). The seeds of the lines were sown in seedling unit of the company on 05.01.2019. Seedlings were then transplanted in the the plots as 12 plants per plot in the greenhouse on 10.02.2019. Standard cultural practices such as fertilization, pesticide applications and irrigations were made according to company's internal standard procedures. Plant observations were made at generative and harvest stages according to UPOV criteria and The company's internal applications (Table 3.1).

3.2.2. Spring season experiment with hybrids 2019

An experiment was set up in greenhouse with 1253 hybrids (F1). The seeds of the hybrids were sown in seedling unit of the company on 05.01.2019. Seedlings were then transplanted into the plots as 12 plants per plot in the greenhouse on 10.02.2019. Standard cultural practices such as fertilization, pesticide applications and irrigations were made according to company's internal standard procedures. Plant observations were made at generative and harvest stages according to UPOV criteria and The company's standard applications (Table 3.1).

3.2.3. Autumn season experiment with parental lines 2019

An experiment was set up in greenhouse with 164 lines of various generations (F1-F9). The seeds of the lines were sown in seedling unit of the company on 25.07.2019. Seedlings were then transplanted into the plots as 12 plants per plot in the greenhouse on 25.08.2019. Standard cultural practices such as fertilization, pesticide applications and irrigations were made according to Company's internal standard procedures. Plant observations were made at generative and harvest stages according to UPOV criteria and the company's internal procedures (Table 3.1).

3.2.4. Autumn season experiment with hybrids 2019

An experiment as set up in greenhouse with 1057 hybrids (F1). The seeds of the hybrids were sown in seedling unit of the company on 27.07.2019. Seedlings were transplanted into the plots at a seedling density of 12 plants per plot in the greenhouse on 28.08.2019. Standard cultural practices such as fertilization, pesticide applications and irrigations were made. Plant observations were made at generative and harvest stages according to UPOV criteria and company's internal procedures (Table 3.1).

3.2.5. Winter season experiment with parental lines 2019/2020

An experiment was set up in greenhouse with 182 lines of various generations (F1-F9). The seeds of the lines were sown in seedling unit of the company on 15.08.2019. Seedlings were then transplanted into the plots with 12 plants per plot in the greenhouse on 22.09.2019. Standard cultural practices such as fertilization, pesticide applications and irrigations were made. Plant observations were made at generative and harvest stages according to UPOV criteria and company's internal procedures (Table 3.1).

3.2.6. Winter season experiments with hybrids 2019/2020

An experiment was set up in greenhouse with 1230 hybrids (F1). The seeds of the hybrids were sown in seedling unit of the company on 17.08.2019. Seedlings were transplanted into the plots with 12 plants per plot in the greenhouse on 25.09.2019. Standard cultural practices such as fertilization, pesticide applications and irrigations were made. Plant observations were made at generative and harvest stages according to UPOV criteria and company's internal procedures (Table 3.1).

3.2.7. Hybridization Experiments 2020/2021

An experiment involving hybridization between the lines with or without kinking problem was set up in the growing season of 2020 and 2021 in greenhouse. In the spring of 2020, a total 4 F7 lines were selected from the autumn of 2019, 2 with a severe kinking problem and 2 without a kinking problem. These parent lines were planted in the greenhouse on 15.02.2020 with 12 plants for each plot. Crossings were made on these lines (Table 3.3). Detailed observations were made at harvest on 3th 4th and 5th truss in 5 plants per line. A list of observations made are given in Table 3.2.

3.2.8. Cultivation

Stored in the cold storage (5^0C), tomato seeds were made ready for planting in the seedling nursery. This period is 30-35 days for autumn, 35-40 days for winter and 30-35 days for spring. After planting, the growing conditions were kept in optimum condition. Fertilization, spraying and cultural treatments were applied in expert procedures. The greenhouses were heated when the ambient temperatures fell below 10^0C in the cold period, and the necessary irrigation regimes were applied to cool them in summer. The EC value was strictly monitored during the ripening and harvest periods. Plants were routinely sprayed against diseases and pests. Different lines and hybrids in each period were planted in the greenhouses. Labels were used to distinguish different types and lines. For fertilization; vibration technique was used in lines and bees were used as vectors in hybrids.

Figure 3.1. Soil preparation before transplanting in the green house

Figure 3.2. Tomato seedlings growing in the green house

Figure 3.3. A view of Tomato plants grown in the greenhouse

Figure 3.4. A view of Tomato truss and fruits in the green house

3.2.9. Observations and measurements on kinking and phenotypic traits in lines and hybrids

Plants and fruits were observed on a plot basis. First, phenotypic observations were done during autumn, winter and spring lines. The aim of this was to evaluate scale of the kinking problem and its correlation with other phenotypic characters.

In plant observations, UPOV criteria were used; Peduncle length, kinking presence, plant shape, plant strength, phytosanitary, plant coverage were measured. At harvest, observations were made on harvest difficulty, earliness, fruit shape, fruit color, fruit set, yield and cracking in fruits.

Table 3.1. Morphological traits investigated on the tomato parental lines and hybrids

	Trait Codes	Trait name	Scores	Explanations				
1	Vig	Plant Vigor	1-9		1 = Weak	5 = Medium Vigor	9 = Vigorous	
2	Cov	Cover	1-9		1 = Covered Plant	9 = Medium Cover	9 = Open Plant	
3	PHlt	Plant Health	1-9		1 = Diseased	5 = Medium Diseased	9 = Healthy	
4	Erl	Earliness	1-9		1 = Very Late	5 = Medium Harvest	9 = Very Early	
5	Ltn	Number of clusters	1-9					
6	HrvDif	Harvest difficulty	1-5-9		1 = Difficult	5 = Medium	9 = Easy	
7	Shp	Fruit Shape	1-2-3-4-5	1 = Flattened	2 = Flat-round	3 = Round	4 = High-Round	5 = Heart shape
8	FSizVis_nr	Fruit Size	100-400 (Gr)					
9	Uni	Uniformity	1-9		1 = Segregating	5 = Medium Uniform	9 = Uniform	
10	Firm	Firmness	1-9		1 = Very Soft Fruits	9 = Medium Firm	9 = Very Firm Fruits	
11	Col	Color	1-9		1 = Very Light Color	5 = Medium Green	9 = Very Dark Color	
12	Gsh	Green shoulder	0-6	0 = Absent	6 = Present			
13	Kg	Kinking	1-5-9	1 = Absent	5 = Medium	9 = Present		
14	Clx	Calyx	1-9		1 = Thin Calyx	9 = Thick Calyx		
15	Bss	Blossom end scar	0-6	0 = Absent	6 = Present			
16	StmSca	Stem end scar	0-6	0 = Absent	6 = Present			
17	Blo	Blotchy	0-6	0 = Absent	6 = Present			
18	Crk	Cracking	0-6	0 = Absent	6 = Present			
19	Yvis	Visual Yield	1-9		1 = Low Yield	5 = Medium Yield	9 = High Yield	
20	Cvp	General point	1-9		1 = Weak Hybrid	5 = Medium Quality	9 = Good Hybrid	
21	TL	Truss Stem Length	3-4-5-6-7	3 = Short	4 = Short to Medium	5 = Medium	6 = Medium to Long	7 = Long

3.2.10. Measurements on kinking and phenotypic traits in hybridization trial

Plants and fruits were observed on a plot basis. Phenotypic observations were done on autumn, winter and spring lines in order to investigate frequency of kinking problem and its relationship with other plant growth related traits.

Plant morphological traits set by UPOV criteria such as peduncle length, kinking presence, plant shape, plant strength, phytosanitary and plant coverage were measured. At harvest stage, harvest difficulty, earliness, fruit shape, fruit color, fruit set, yield and cracking in fruits were recorded (Table 3.2).

Table 3.2. Observations of morphological traits and kinking on the lines and F1 hybrids

Row Number	Trait Code	Trait explanation	Scores/Value	
1	MST	Main stem thickness	(mm)	
2	Kg	The presence of Kinking	0 = Absent	1 = Present
3	TST	Truss Stem Thickness	mm	
4	WTL	Whole Truss Length (Length of truss stem starting from main stem to the peduncle of the last fruit)	cm	
5	HTL	Half Truss Length from main stem to the peduncle of the first fruit (length of the	cm	
6	TLFL	Truss Length from peduncle of First Fruit to the Peduncle of the Last fruit	cm	
7	TFW	Total Fruit Weight/truss	g	
8	FNPT	Fruit Number Per Truss		
9	AZOTS	Abscission Zone on Truss Stem	0 = Absent	1 = Present
10	AZOFP	Abscission zone on Fruit Peduncle	0 = Absent	1 = Present

Table 3.3. Tomato parental lines used in the hybridization program at F7 stage

			Tomato Parental Lines			
	Trait Codes	**Trait name**	N20_002667	N20_002668	N20_002688	N20_002691
1	Vig	Plant Vigor	7	7	5	6
2	Cov	Cover	6	7	6	6
3	PHlt	Plant Health	7	7	4	6
4	Erl	Earliness	5	4	4	4
5	Ltn	Number of clusters	6	7	4	7
6	HrvDif	Harvest difficulty	9	5	5	5
7	Shp	Fruit Shape	3	3	3	3
8	FSizVis	Fruit Size	150	170	180	160
9	Uni	Uniformity	6	6	5	6
10	Firm	Firmness	7	7	7	7
11	Col	Color	6	6	7	6
12	Kg	Kinking	1	1	9	9
13	Clx	Calyx	7	6	7	6
14	Bss	Blossom end scar	0	0	0	0
15	StmSca	Stem end scar	0	0	0	0
16	Blo	Blotchy	0	0	0	0
17	Crk	Cracking	0	0	0	0
18	Yvis	Visual Yield	5	5	3	5
19	Cvp	General point	7	7	6	5
20	TL	Truss Stem Length	6	5	7	5

Table 3.4. Hybridization program using the parental lines with or without kinking trait

Hybridisation no	Maternal Parent	Trait		Paternal parent	Trait
1	N20_002667	Non-Kinking	X	N20_002668	Non-Kinking
2	N20_002668	Non-Kinking	X	N20_002691	Kinking
3	N20_002688	Kinking	X	N20_002691	Kinking

Figure 3.5. A view of hybrids in the greenhouse

Figure 3.6. Truss and fruits of Hybrids made

3.2.11. Data analysis

Data made from each experiment were analyzed using SPSS statistical program (Version 23 IBM Statistics). Means were separated by Duncan's Multiple Range Test.

4. RESULTS AND DISCUSSION

4.1. Spring season experiments with lines 2019

Descriptive statistics including minimum, mean and maximum values of plant growth parameters from the observations of 95 lines growth in the green house in the spring of 2019 were given in table 4.1. In this experiment, kinking trait was not measured, but general plant growth especially of truss stem length was investigated (Figure 4.1). Mean truss stem length ranged between a minimum of short (3) and very long (7) with an average of medium (5,06) (Table 4.1). Truss stem length that may be related to kinking problem was measured in 95 lines (Figure 4.1). Out of 95 lines investigated, 11 lines had short stem length (TL=3), 9 lines had short to medium (TL=4), 47 lines had medium (TL=5), 19 lines had medium to long (TL=6) and 9 lines had long truss stem lengths (TL=7) (Figure 4.1.1). Therefore, 49.5 % of lines had medium stem length while 20.0 % had medium to long stems. Other characteristics were not discussed here to concentrate on kinking problem. Their correlations and relations with kinking problem were discussed in section 4.7.

Table 4.1. Plant growth parameters and traits investigated of 95 lines in the spring growth season in 2019

Row no	Trait Code	Trait Explanation	Min.	Max.	Mean	SE	Std. Dev.	Variance
1	Vig	Vigor	4	8	5,87	,084	,815	,665
2	Cov	Cover	4	7	5,89	,078	,765	,585
3	PHlt	Plant Health	5	7	6,64	,054	,524	,275
4	Erl	Earliness	4	8	5,95	,091	,892	,795
5	Ltn	Number of Clusters	5	8	6,44	,077	,754	,568
6	Shp	Fruit shape	1	3	2,61	,062	,607	,368
7	Size	Fruit Size	130	400	191,37	4,670	45,514	2071,512
8	Uni	Uniformity	5	7	5,86	,038	,375	,141
9	Firm	Firmness	4	8	6,53	,082	,797	,635
10	Col	Color	5	8	6,16	,077	,748	,560
11	Clx	Calyx	5	8	6,23	,081	,792	,627
12	TL	Truss Stem Lenght	3	7	5,06	,110	1,070	1,145
13	Bss	Blossom Scar	0	7	4,95	,287	2,800	7,838
14	Ber	Blossom End Rot	0	0	,00	,000	,000	,000

Continuation of the **Table 4.1.**

15	Stm	Stem End Scar	0	7	2,62	,297	2,896	8,387
16	Blo	Blotchy	0	0	,00	,000	,000	,000
17	Crk	Cracking	0	6	,60	,182	1,771	3,136
18	Skn	Skin	0	0	,00	,000	,000	,000
19	Drp	Fruit Dropping	0	5	,05	,053	,513	,263
20	Lcol	Leaf Color	3	8	6,33	,111	1,086	1,180
21	Lrol	Leaf Rolling	5	7	6,38	,067	,655	,429
22	Yvis	Visual Yield	4	7	5,46	,075	,727	,528
23	Cvp	General Point	2	7	5,00	,083	,812	,660

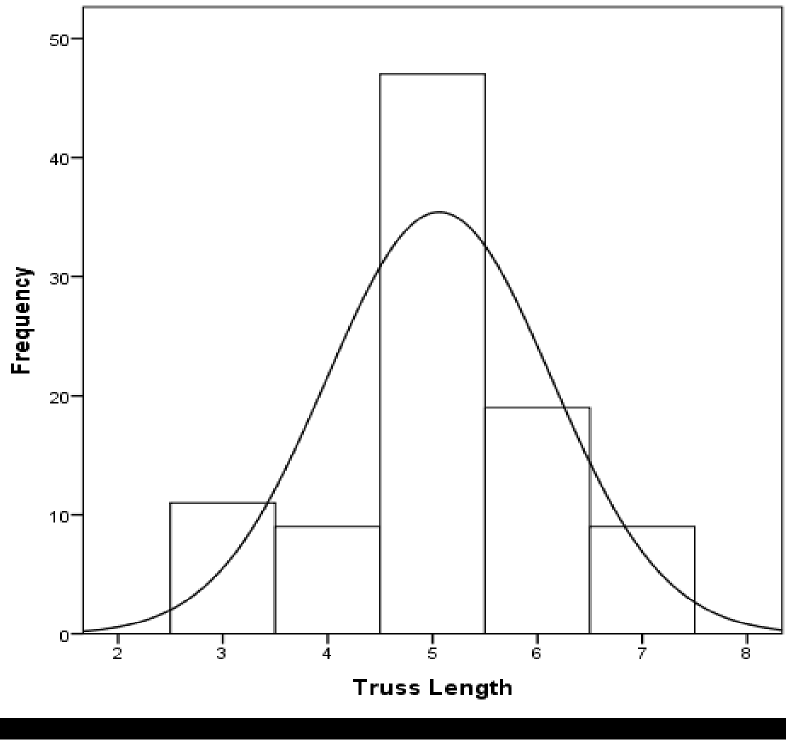

Figure 4.1. Frequency of truss length in the lines investigated on spring season 2019

4.2. Spring season experiments with hybrids 2019

Descriptive statistics including minimum, mean and maximum values of plant growth parameters from the observations of 1222 hybrids growth in the green house in the spring of 2019 were given in Table 4.2. In this experiment, general plant growth especially of kinking trait was investigated (Figure 4.2). Mean kinking ranged between a minimum of absent (1), medium level (5) and present (9) with an average of present (8,802) (Table 4.2). Kinking trait problem was investigated in 1222 hybrids (Figure 4.2). 17 hybrids had no kinking problem (Kg=1), 10 hybrids had medium level kinking trait (Kg=5), 1195 hybrids had kinking problem (Kg=9). (Figure 4.2). Therefore, 1,4% of hybrids had no kinking problem, %1 of medium kinking problem and %97,6 of had kinking problem. The field codes which had no kinking problem of hybrids were N18_014824, N18_014952, N18_015105, N18_015139, N18_015215, N18_015315, N18_015451, N18_015556, N18_015626, N18_015710, N18_015768, N18_015842, N18_015854, N18_015938, N18_015997, N18_016043, N18_016223. The correlations and seasonal effects with kinking trait were discussed in section 4.7.

Table 4.2. Plant growth parameters and traits investigated of 1222 hybrids in the growth season in 2019

Row No	Trait Code	Trait Explanation	Min.	Max.	Mean	S.E	Std. Deviation	Variance
1	Vig	Vigour	4	8	6,554	,0188	0,6603	,436
2	PHlt	Plant health	4	8	6,489	,0166	0,5813	,338
3	Cov	Plant Cover	4	7	6,467	,0168	0,5875	,345
4	Ltn	Number of Clusters	5	8	6,414	,0160	0,5621	,316
5	Erl	Earliness	4	8	6,62	,0191	0,6689	,447
6	Firm	Firmness	5	7	6,837	,0106	0,3713	,138
7	Col	Color	5	8	6,406	,0170	0,5948	,354
8	Cal	Calyx	5	8	6,285	,0137	0,4814	,232
9	Kg	Kinking	1	9	8,802	,0314	1,113	1,239
10	Crk	Cracking	6	7	6,966	,0052	0,1817	,033
11	Drp	Dropping	6	8	6,97	,0050	0,1756	,031
12	Size	Size	150	360	258,35	,8171	28,6579	821,277
13	Uniovl	Uniformity	4	7	6,361	,0142	0,4971	,247
14	Set	Setting	4	9	6,4	,0147	0,5144	,265
15	Cvp	General Point	4	8	6,11	,0112	0,3934	,155

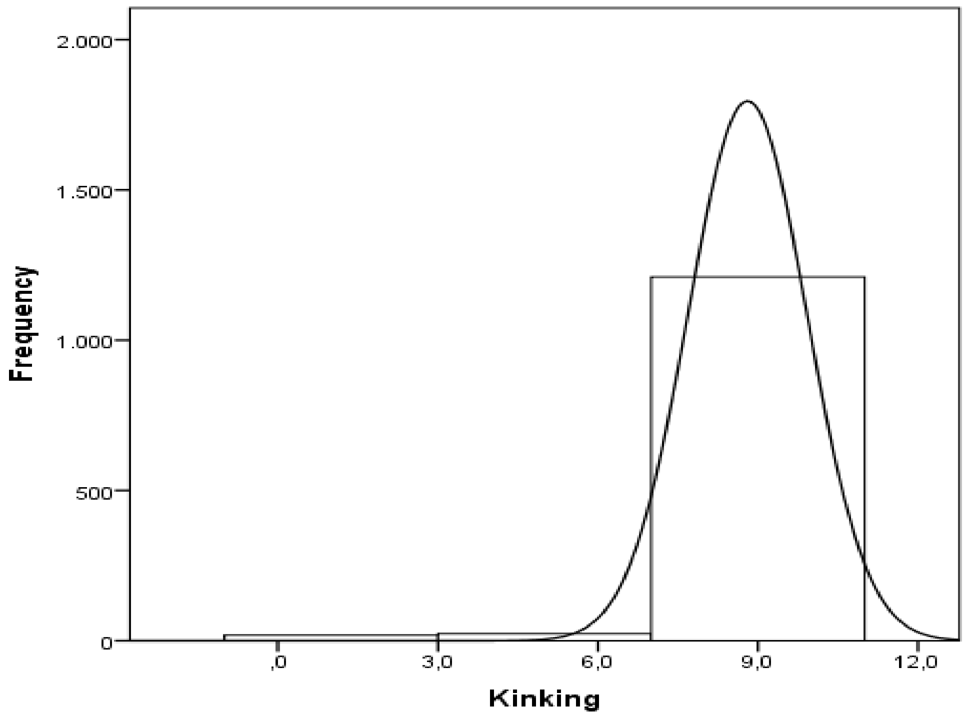

Figure 4.2. Frequency of kinking trait in the hybrids investigated spring season on 2019

4.3. Autumn season experiments with lines 2019

Descriptive statistics including the minimum, average and maximum values of plant growth parameters from the observations of 164 lines growth in the greenhouse in the 2019 autumn season are given in Table 4.3. In this experiment, general plant growth traits especially kinking, was investigated (Figure 4.3). The mean kinking ranged between absent (1), medium (5) and present (9) and mean present (8.07) (Table 4.3). The problem of kinking problem of 164 lines was investigated (Figure 4.3). 15 lines had no kinking problem (Kg=1), 23 lines had medium kinking problem (Kg=5) and 126 lines had kinking problem (Kg=9) (Figure 4.3). Therefore, no kinking problem were observed in 10% of the lines. 14% of lines had medium kinking problem and 76% had kinking problems. Lines, field codes of those which did not have any kinking problems N19_018111, N19_018134, N19_018191, N19_018194, N19_018239, N19_018240 N19_018241, N19_018243, N19_018244, N19_018247, N19_018249, N19_018254 N19_018263, N19_018283, N19_018308. Correlations and seasonal effects of the kinking trait and other traits are discussed in section 4.7.

Table 4.3. Plant growth parameters and traits investigated of 164 lines in the autumn growth season in 2019

Row No	Trait Code	Trait Explanation	Min.	Max.	Mean	S.E	Std. Deviation	Variance
1	Vig	Vigour	4	8	6,35	,059	0,756	,572
2	Cov	Cover	4	7	6,08	,050	0,646	,417
3	PHlt	Plant Health	3	7	5,82	,065	0,836	,699
4	Erl	Earliness	2	7	4,9	,085	1,083	1,173
5	ltn_nr	Number of Clusters	4	8	6,31	,063	0,803	,645
6	HeaSet	Heat setting	0	5	2,91	,108	1,378	1,900
7	Shp	Fruit shape	1	4	2,81	,061	0,78	,608
8	Size	Fruit Size	140	300	179,33	2,585	33,104	1095,866
9	Uni	Uniformity	4	7	5,77	,037	0,478	,228
10	Firm	Firmness	0	8	6,62	,066	0,846	,715
11	Col	Color	4	7	6,21	,053	0,681	,463
12	Clx	Calyx	5	8	6,1	,070	0,89	,793
13	TL	Lenght of Truss Stem	3	7	5,65	,064	0,826	,682
14	HrvDif	Harvest Difficulty	1	9	3,68	,173	2,22	4,930
15	Kinking	Kinking	5	9	8,07	,132	1,693	2,866
16	StmScar	Stem end scar	0	6	0,58	,130	1,661	2,761
17	Crk	Cracking	0	6	1,82	,200	2,558	6,543
18	Drp	Fruit Dropping	0	5	0,06	,043	0,55	,303
19	Lcol	Leaf Color	0	8	6,41	,100	1,281	1,642
20	Lrol	Leaf Rolling	0	7	6,44	,090	1,158	1,340
21	Yvis	Visual Yield	3	6	4,98	,048	0,611	,374
22	Cvp	General Point	3	6	4,68	,041	0,519	,269

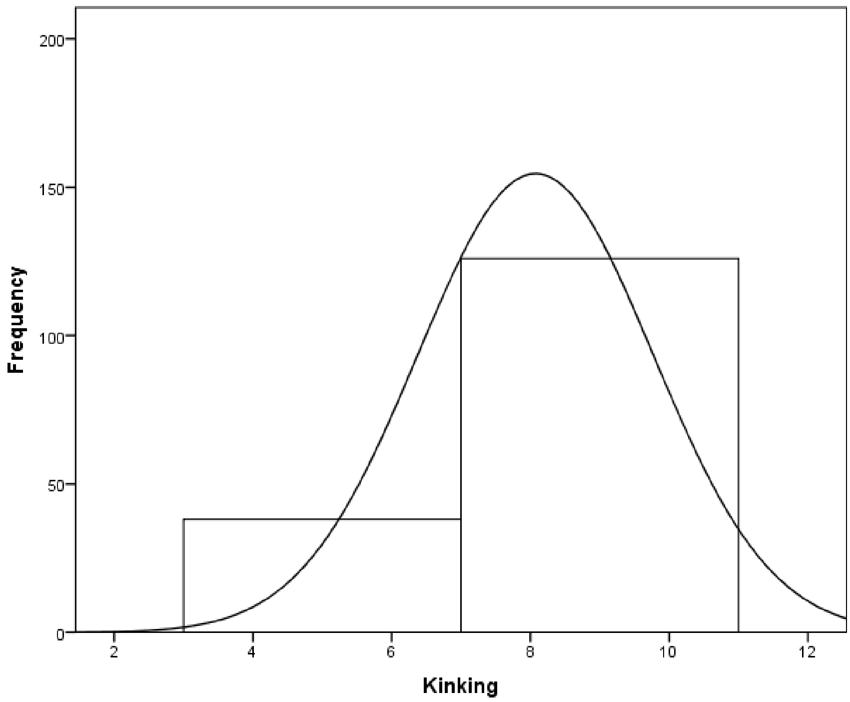

Figure 4.3. Frequency of kinking trait in the lines investigated autumn season on 2019

4.4. Autumn season experiments with hybrids 2019

Descriptive statistics including minimum, average and maximum values of plant growth parameters from observations of 1057 hybrids growth in greenhouse in autumn 2019 are given in Table 4.4. In this experiment, general plant growth, especially the kinking trait, was investigated (Fig. 4.4). The mean bending ranged between absent (1), medium (5) and present (9) and mean present (8.58)(Table 4.4). The kinking problem was investigated in 1057 hybrids (Fig. 4.4). No kinking problem was observed in 8 hybrids (Kg=1). Medium level kinking problem was observed in 55 crossbreeds (Kg=5) and kinking problem was observed in 994 crossbreeds (Kg=9). (Fig. 4.4). Therefore, 1% of hybrids do not have bending problems. 5% had medium level kinking problems and 94% had kinking problems. The field codes of hybrids without kinking problems are N19_017015, N19_016620, N19_017121, N19_017180, N19_017205, N19_017892, N19_017916, N19_017933. The relationship of the kinking problem with other traits and the effects of seasons are discussed in section 4.7.

Table 4.4. Plant growth parameters and traits investigated of 1057 hybrids in the autumn growth season in 2019

Row no	Trait Code	Trait Explanation	Min.	Max.	Mean	S.E	Std. Deviation	Variance
1	Vig	Vigour	4	8	6,75	,017	,561	,315
2	PHlt	Plant Health	4	7	6,27	,019	,630	,397
3	Cov	Cover	4	8	6,38	,017	,551	,304
4	Ltn	Number of Clusters	3	8	6,08	,014	,469	,220
5	Shp	Fruit shape	1	3	2,25	,014	,464	,215
6	Erl	Earliness	5	8	6,43	,021	,680	,463
7	Firm	Firmness	6	7	6,88	,010	,323	,104
8	HrvDif	Harvest Difficulty	1	9	4,69	,049	1,603	2,570
9	Col	Color	5	8	6,31	,017	,557	,310
10	Clx	Calyx	5	8	6,11	,010	,334	,112
11	Crk	Cracking	5	7	6,34	,015	,501	,251
12	Size	Size	140	280	194,42	,674	21,911	480,112
13	Kg	Kinking	1	9	8,58	,041	1,322	1,748
14	Gsh	Green Shoulder	0	6	,33	,042	1,378	1,899
15	Bss	Blossom Scar	0	6	,08	,021	,686	,471
16	StmSca	Stem End Scar	0	6	,45	,049	1,588	2,521
17	Drp	Fruit dropping	0	6	,13	,027	,876	,767
18	Uni	Uniformity	5	7	6,31	,015	,478	,229
19	Yvis	Visual Yield	5	8	6,38	,017	,544	,296
20	Cvp	General Point	4	7	5,93	,014	,455	,207

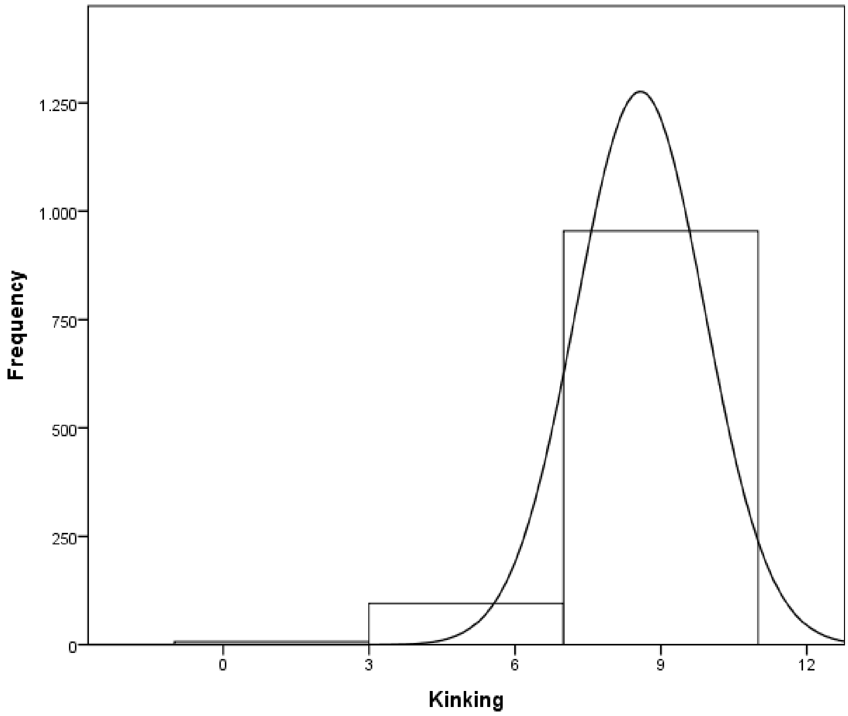

Figure 4.4. Frequency of kinking trait in the hybrids investigated autumn season on 2019

4.5. Winter season experiments with lines 2019/2020

Descriptive statistics including minimum, average and maximum values of plant growth parameters from observations of 182 lines growth in greenhouse in winter 2019 are given in Table 4.5.1. In this experiment, general plant growth, especially the kinking trait, was investigated (Fig. 4.5). The mean bending ranged between absent (1), medium (5) and present (9) and present (7,24) (Table 4.5). The kinking problem was investigated in 182 lines (Figure 4.5). No kinking problem was observed in 16 lines (Kg=1). Medium level kinking problem was observed in 48 lines (Kg=5) and kinking problem was observed in 118 lines (Kg=9). (Fig. 4.5). Therefore, 9% of hybrids do not have bending problems. 26% had medium level kinking problems and 65% had kinking problems. The field codes of hybrids without kinking problems are ; N19_025606, N19_025657, N19_025683, N19_025698, N19_025733, N19_025778, N19_025875, N19_025877, N19_025886, N19_025926, N19_025938, N19_025964, N19_025969, N19_026001, N19_026006, N19_026009. The relationship of the kinking problem with other traits and the effects of seasons are discussed in section 4.7.

Table 4.5. Plant growth parameters and traits investigated of 182 lines in the winter growth season in 2019

Row no	Trait Code	Trait Explanation	Min.	Max.	Mean	S.E	Std. Deviation	Variance
1	Vig	Vigor	5	8	6,73	,053	,712	,507
2	Cov	Cover	5	7	6,18	,051	,685	,470
3	PHlt	Plant Health	3	7	5,35	,062	,838	,703
4	Erl	Earliness	3	7	5,53	,067	,902	,814
5	Ltn	Number of Clusters	4	8	6,17	,062	,833	,695
6	ColSet	Cold Setting	3	6	4,05	,056	,756	,572
7	Shp	Fruit shape	1	4	2,43	,058	,782	,612
8	Size	Fruit Size	140	250	178,19	1,793	24,189	585,092
9	Uni	Uniformity	4	6	5,48	,042	,573	,328
10	Firm	Firmness	5	8	6,79	,040	,539	,291
11	Col	Color	4	8	6,22	,058	,784	,614
12	Clx	Calyx	4	8	5,66	,072	,965	,931
13	TL	Lenght of Truss Stem	3	7	6,02	,059	,797	,635
14	Kinking	Kinking	1	9	7,24	,193	2,606	6,792
15	HrvDif	Harvest Difficulty	1	9	4,98	,091	1,226	1,502
16	Bss	Blossom Scar	0	6	1,45	,179	2,414	5,828
17	StmSca	Stem End Scar	0	6	1,20	,167	2,251	5,066
18	Crk	Cracking	0	7	1,32	,175	2,364	5,588
19	Skn	Skin	0	6	,15	,059	,793	,628
20	Drp	Fruit Dropping	0	6	,14	,063	,855	,731
21	Lcol	Leaf Color	4	8	6,24	,073	,979	,958
22	Lrol	Leaf Rolling	0	7	5,77	,055	,742	,551
23	Yvis	Visual Yield	3	7	4,80	,057	,768	,590
24	Cvp	General Point	3	6	4,62	,047	,634	,402

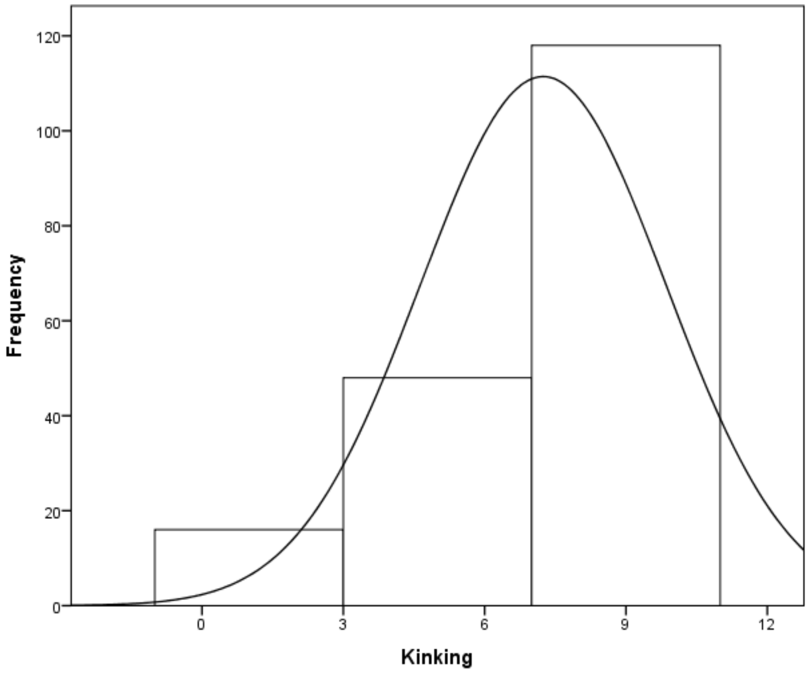

Figure 4.5. Frequency of kinking trait in the lines investigated winter season on 2019/2020

4.6. Winter season experiments hybrids 2019/2020

Descriptive statistics including the minimum, average and maximum values of plant growth parameters from the observations of 1229 hybrids growth in the greenhouse in the winter of 2019 are given in Table 4.6. In this experiment, general plant growth, especially the kinking trait, was investigated (Fig. 4.6). The mean bending ranged from absent (1), medium (5) and present (9) to mean present (8.59) (Table 4.6). Kinking problem was investigated in 1229 hybrids (Figure 4.6.1) and no kinking problem was observed in 16 hybrids (Kg=1). Medium level kinking problem was observed in 43 crosses (Kg=5) and kinking problem was observed in 1156 crossbreeds (Kg=9). (Fig. 4.6). Therefore, 1% of hybrids do not have bending problems. 3% had medium level kinking problems and 96% had kinking problems. Kinking problem of non-hybrid field codes are N19_026211, N19_026240, N19_026246, N19_026250, N19_026271, N19_026363, N19_026379, N19_026387, N19_026423, N19_026424, N19_026435, N19_026436, N19_026495, N19_026517, N19_026838, N19_026868. The relationship of the kinking problem with other traits and the effects of seasons are discussed in section 4.7.

Table 4.6. Plant growth parameters and traits investigated of 1229 hybrids in the winter growth season in 2019

Row no	Trait Code	Trait Explanation	Min.	Max.	Mean	S.E	Std. Deviation	Variance
1	Vig	Vigour	4	8	6,69	,017	,603	,364
2	Cov	Cover	4	9	6,39	,016	,547	,299
3	PHlt	Plant Health	3	8	5,95	,017	,586	,344
4	Erl	Earliness	5	8	6,49	,018	,615	,379
5	Ltn	Number of Clusters	5	8	6,20	,013	,467	,218
6	HrvDif	Harvest Difficulty	1	9	4,90	,033	1,160	1,346
7	Shp	Fruit shape	1	3	1,96	,010	,367	,135
8	Size	Size	120	400	222,63	,778	27,290	744,756
9	Uni	Uniformity	5	7	6,18	,012	,423	,179
10	Firm	Firmness	6	7	6,91	,008	,287	,082
11	Col	Color	4	7	6,21	,018	,614	,377
12	Gsh	Green Shoulder	0	6	,23	,033	1,151	1,325
13	Kinking	Kinking	1	9	8,59	,043	1,496	2,239
14	Clx	Calyx	5	8	6,04	,006	,218	,048
15	Bss	Blossom Scar	0	6	,02	,010	,342	,117
16	StmSca	Stem End Scar	0	6	,33	,039	1,363	1,857
17	Blo	Blotchy	0	6	,25	,034	1,208	1,460
18	Crk	Cracking	5	7	6,75	,012	,438	,192
19	Yvis	Visual Yield	4	7	6,31	,014	,508	,258
20	Cvp	General Point	3	7	5,98	,012	,419	,176

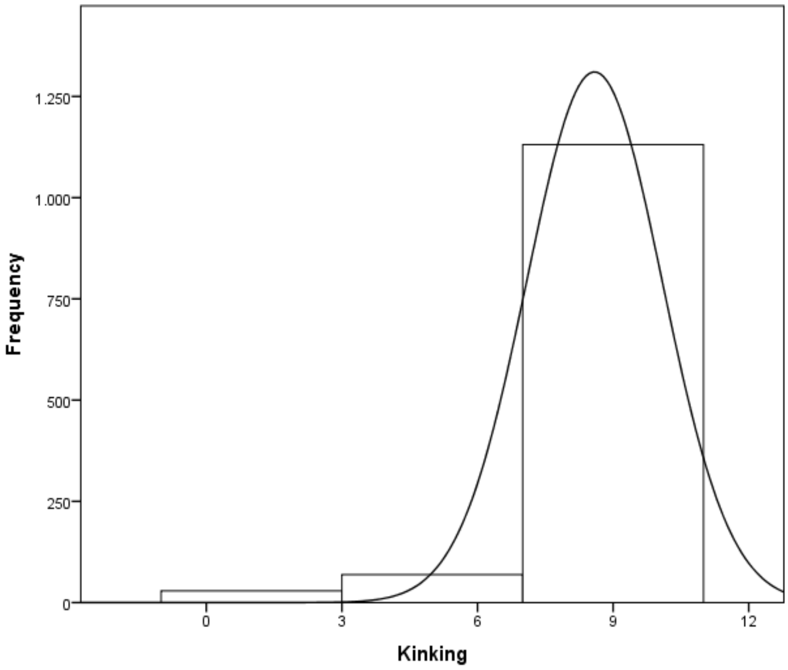

Figure 4.6. Frequency of kinking trait in the hybrids investigated winter season on 2019

4.7. Seasonal Effects

Data were analyzed from the six experiments in order to investigate seasonal effect on kinking trait (Table 4.7). Analysis of variance showed that line/hybrid effects (P<0.001), seasonal effects (P<0.001) and interaction effects (P<0.001) were statistically significant (Table 4.7).

Table 4.7. Analysis of Variance (Anova) table for kinking trait

Source	Sum of Squares	df	Mean Square	F	Sig.
Line/Hybrid	366,191	1	366,191	217,137	,000
Season	106,385	2	53,193	31,541	,000
Line/Hybrid * Season	17,157	1	17,157	10,173	,001
Error	6504,627	3857	1,686		
Total	297038,000	3862			

*Statistically significant at probability level P<0.05. ** Statistically significant at probability level P<0.001.

When all lines and hybrids were investigated, kinking trait in 3862 lines and hybrids ranged between 1 and 9 with a mean value of 8,67 (SE=0,022) (Table 4.7.2).

Table 4.8. Descriptive statistics for all lines and hybrids

	Descriptive Statistics								
Trait Code	Trait Explanation	N	Range	Min.	Max.	Mean	Std. Error	Std. Deviation	Variance
Vig	Vigour	3957	4	4	8	6,63	,010	,647	,419
Cov	Cover	3957	5	4	9	6,38	,009	,589	,347
Phlt	Plant Health	3957	5	3	8	6,19	,011	,690	,475
Erl	Earliness	3957	6	2	8	6,39	,013	,797	,635
Ltn	Number of Clusters	3957	5	3	8	6,25	,009	,561	,314
Heatset	Heat Settings	164	5	0	5	2,91	,108	1,378	1,900
Colset	Cold Settings	182	3	3	6	4,05	,056	,756	,572
Shp	Shape	3957	3	1	4	2,46	,010	,629	,395
Size	Size	3957	280	120	400	221,61	,623	39,191	1535,944
Uni	Uniformity	3957	3	4	7	6,26	,009	,541	,292
Firm	Firmness	3957	8	0	8	6,85	,006	,400	,160
Col	Color	3956	4	4	8	6,30	,010	,614	,377
Clx	Calyx	3957	4	4	8	6,13	,008	,476	,227
Hrvdif	Harvest Difficulty	2632	8	1	9	4,75	,029	1,468	2,155
Kinking	Blossom Scar	3862	8	1	9	8,67	,022	1,350	1,823
Crk	Stem End Scar	3957	7	0	7	6,11	,030	1,912	3,655
Stm	Stem End Scar	1498	7	0	7	,70	,049	1,878	3,527
Yvis	Cracking	3957	6	3	9	6,11	,011	,680	,462
Cvp	Visual Yield	3957	6	2	8	5,87	,010	,612	,375
Bss	Blossom Scar	1334	7	0	7	,61	,050	1,837	3,376
Blo	Blotchy	2459	3	5	8	6,57	,010	,512	,262
Gsh	Green Shoulder	1057	6	0	6	,33	,042	1,378	1,899
Tl	Truss Lenght	441	4	3	7	5,68	,045	,942	,888
Lcol	Leaf color	441	8	0	8	6,32	,053	1,122	1,260
Lrol	Leaf Rolling	441	7	0	7	6,15	,046	,957	,916

The variation in the presence of kinking trait in different seasons within the lines and hybrids was given Table 4.8. The percentage of the non-kinking plants was significantly higher in lines than in F1 Hybrids (Table 4.9). In 2019 Autumn period, 10 % of lines had kinking score of 1 compared with 1 % of F1 hybrids while in 2019 winter period 9 % of lines had kinking score of 1 as opposed to 1 % of F1 hybrids (Table 4.9). When high kinking (kinking score=9) plants are compared, lines had lower percentages of kinking plants compared with F1 hybrids both in Autumn and winter seasons (Table 4.9). When the average of seasons are compared, lines had similar percentages of non-kinking plants both in Autumn (5 %) and winter (9 %). There was however no statistically significant difference within F1 Hybrids in the seasons of spring (1,4 %), autumn (1 %) and winter (1 %) periods (Table 4.9).

Table 4.9. Frequency table of kinking trait in all lines and hybrids

	Kinking Score	**1**	**5**	**9**	**Total**
2019 Spring	**Hybrids**	17	10	1195	**1222**
	%	1,4	0,8	97,8	**100**
2019 Autumn	**Lines**	15	23	126	**164**
	%	10	14	76	**100**
	Hybrids	8	55	994	**1057**
	%	1	5	94	**100**
2019 Winter	**Lines**	16	48	118	**182**
	%	9	26	65	**100**
	Hybrids	16	43	1170	**1229**
	%	1	3	96	**100**
Total	**Lines**	31	71	244	**346**
Total	**Hybrids**	41	108	3359	**3508**
Total		72	179	3603	**3854**

In the 2019 Season, the field codes of the plots that did not show the Kinking character in all trials on all lines and hybrids are shown in Table 4.9.

Table 4.10. Field Codes of lines and hybrids showing non-kinking trait in spring, autumn and winter seasons of 2019

Non-Kinking Field Codes				
Lines 2019		Hybrids 2019		
Autumn	Winter	Spring	Autumn	Winter
N19_018111	N19_025606	N18_014824	N19_017015	N19_026211
N19_018134	N19_025657	N18_014952	N19_016620	N19_026240
N19_018191	N19_025683	N18_015105	N19_017121	N19_026246
N19_018194	N19_025698	N18_015139	N19_017180	N19_026250
N19_018239	N19_025733	N18_015215	N19_017205	N19_026271
N19_018240	N19_025778	N18_015315	N19_017892	N19_026363
N19_018243	N19_025875	N18_015451	N19_017916	N19_026379
N19_018244	N19_025877	N18_015556	N19_017933	N19_026387
N19_018247	N19_025886	N18_015626		N19_026423
N19_018249	N19_025926	N18_015710		N19_026424
N19_018254	N19_025938	N18_015768		N19_026435
N19_018283	N19_025964	N18_015842		N19_026436
N19_018308	N19_025969	N18_015854		N19_026495
N19_018241	N19_026001	N18_015938		N19_026517
N19_018263	N19_026006	N18_015997		N19_026838
	N19_026009	N18_016043		N19_026868
		N18_016223		
15	16	17	8	16
Total	31			41

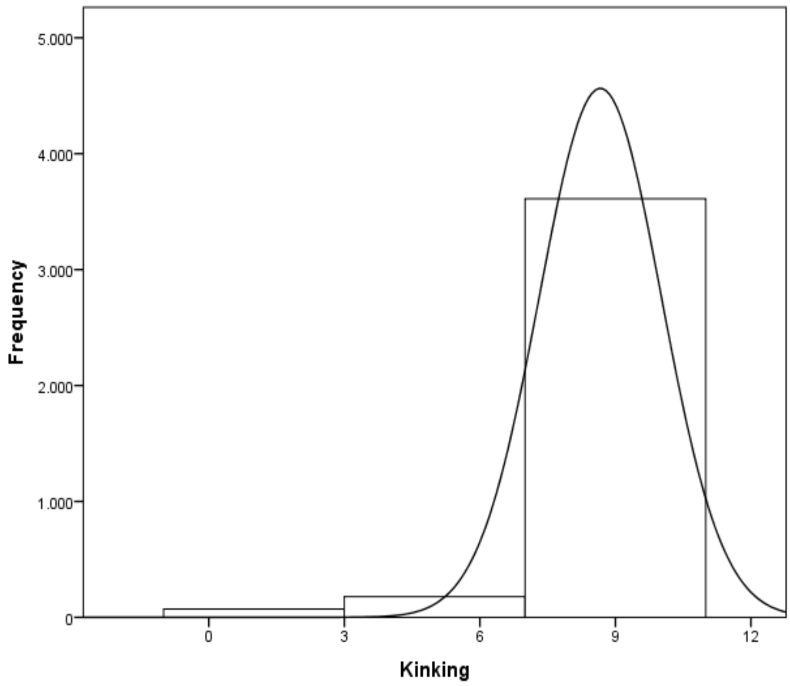

Figure 4.7. Frequency of kinking trait for all lines and hybrids

The distribution of the kinking character in all trials in all lines and hybrids in the 2019 season is shown in Figure 4.7.

4.8. Correlations

Correlation analyzes were performed to evaluate the relationship of the kinking character with other traits. In the analyzes using lines and hybrids, 3854 materials were analyzed. As a result of the analysis, there was no statistically significant correlation between the kinking character and other traits. The analysis presented in the appendix (Appendix 1).

4.9. Principle Component Analysis (PCA)

In the analysis, there are 7 components with high Eigenvalues ranging from 1,050 to 2,900. These make up 60 percent of the total variance. There are 3 most important components that affect the total variance; The 1st component is 14.5 percent, the 2nd component is 11.56 percent, and the 3rd component is 8,979 percent.

Table 4.11. Principle component analysis for total of lines and hybrids

Total Variance Explained						
	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2,900	14,500	14,500	2,900	14,500	14,500
2	2,312	11,560	26,060	2,312	11,560	26,060
3	1,796	8,979	35,039	1,796	8,979	35,039
4	1,548	7,740	42,779	1,548	7,740	42,779
5	1,293	6,465	49,244	1,293	6,465	49,244
6	1,154	5,772	55,016	1,154	5,772	55,016
7	1,050	5,252	60,268	1,050	5,252	60,268
8	,963	4,813	65,081			
9	,927	4,636	69,717			
10	,866	4,331	74,048			
11	,749	3,743	77,790			
12	,648	3,242	81,032			
13	,631	3,157	84,189			
14	,574	2,870	87,060			
15	,538	2,688	89,747			
16	,501	2,505	92,253			
17	,468	2,338	94,591			
18	,409	2,046	96,637			
19	,365	1,826	98,463			
20	,307	1,537	100,000			
Extraction Method: Principal Component Analysis.						

Table 4.12. Component matrix for total of lines and hybrids

		Component Matrix[a]						
		Component						
Trait Codes	**Trait Explanation**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Vig	Vigour	,002	,486	,576	,302	,140	-,195	-,001
Cov	Cover	,156	,275	,605	,186	,182	-,408	-,044
PHlt	Plant Health	,483	,161	,512	-,273	-,015	,149	,004
Erl	Earliness	,440	-,166	-,123	,582	,177	,115	,155
Ltn	Number of Clusters	,662	-,203	-,180	,098	-,017	-,133	,148
Shp	Fruit Shape	,082	,387	-,314	-,361	,238	-,463	,065
Size	Fruit Size	-,003	-,634	,233	,116	,084	,038	,045
Uni	Uniformity	,517	,291	-,206	-,048	,035	,117	-,222
Firm	Firmness	-,031	,413	-,131	,157	-,387	-,090	,080
Col	Color	,233	,475	-,014	,267	,034	,526	,172
Clx	Calyx	,060	,545	-,143	-,349	,140	,168	,313
Hrvdif	Harvest Difficulty	,013	,226	,290	,289	-,493	,259	-,029
Kinking	Kinking	,185	-,017	-,060	-,113	,418	,376	-,648
Crk	Cracking	,094	-,273	,078	,106	,588	,133	,516
Stm	Stem End Scar	-,173	-,462	,150	,160	-,002	-,090	-,199
Yvis	Visual Yield	,763	-,064	-,245	,098	-,022	-,272	-,132
Cvp	General Point	,739	,077	-,162	,225	-,051	-,101	-,112
TL	Truss Lenght	-,298	,383	,150	,085	,425	,012	-,209
Lcol	Leaf Color	,494	-,204	,525	-,340	-,119	-,029	,012
Lrol	Leaf Rolling	,380	-,198	,232	-,564	-,108	,188	,114
		Extraction Method: Principal Component Analysis.						
		a. 7 components extracted.						

Component matrix analysis is given in Table 4.12. When the 7 components are evaluated separately, the traits that affect the 1st component are; Visual yield (0.763) and General point (0.739). The traits that effects 2.component are ; Size (-0,645) and Calyx (0,545). The traits that effects 3. components are ; Cover (0,605) and Vigour (0,576).

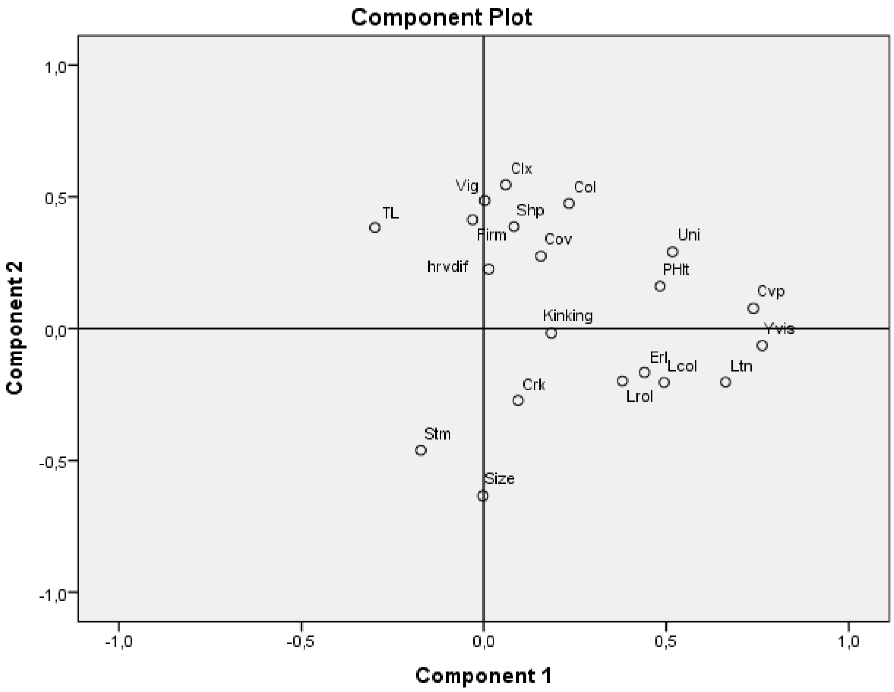

Figure 4.8. Component plot for total of lines and hybrids

4.10. Regressions and Path Analysis

Path analysis, including hybrid and lines, was performed in the observations made in 2019 (Table 4.14). In the analysis, a significant relationship was found between kinking and truss length (Table 4.14).

Table 4.13. Anova analysis for total of lines and hybrids

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	167,201	19	8,800	1,806	,021[b]
	Residual	1588,914	326	4,874		
	Total	1756,116	345			
a. Dependent Variable: Kinking						
b. Predictors: (Constant), Lrol, Stm, hrvdif, Erl, Cov, Firm, TL, Uni, Shp, Crk, Col, PHlt, Clx, Size, Cvp, Ltn, Vig, Lcol, Yvis						

*Statistically significant at probability level $P<0.05$. ** Statistically significant at probability level $P<0.001$.

Table 4.14. Path analysis for total of lines and hybrids

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	6,480	3,161		2,050	,041
	Vig	-,216	,196	-,072	-1,098	,273
	Cov	-,160	,211	-,047	-,754	,451
	PHlt	,283	,165	,109	1,710	,088
	Erl	-,079	,139	-,037	-,571	,568
	Ltn	,072	,185	,026	,388	,698
	Shp	-,261	,168	-,093	-1,552	,122
	Size	-,005	,005	-,065	-1,029	,304
	Uni	,434	,252	,106	1,727	,085
	Firm	-,429	,183	-,134	-2,350	,019
	Col	,111	,187	,036	,594	,553
	Clx	-,100	,142	-,042	-,702	,483
	Hrvdif	-,146	,068	-,121	-2,157	,032
	Crk	,006	,052	,006	,109	,913
	Stm	,002	,064	,002	,036	,971
	Yvis	-,031	,246	-,010	-,127	,899
	Cvp	,452	,287	,117	1,578	,116
	TL	,452	,160	,166	2,825	,005
	Lcol	-,018	,134	-,009	-,131	,896
	Lrol	,001	,138	,001	,009	,993
a. Dependent Variable: Kinking						

*Statistically significant at probability level $P<0.05$. ** Statistically significant at probability level $P<0.001$.

4.11. Hybridization Experiment 2020/2021

This experiment involving hybridization between the lines with or without kinking problem was set up in the growing season of 2020 and 2021 in greenhouse. In the spring of 2020, a total 4 F7 lines were selected from the autumn of 2019, 2 with a severe kinking problem and 2 without a kinking problem. Trials consisting of lines and hybrids were carried out in different periods between 2019 and 2020. The planted tomato plants were grown under cultural practices similar to previous experiments in the green house.

Phenotypic observations taken from in the trials in the spring, autumn and winter seasons of 2019 and the frequency of the kinking character was measured. A total of 3854 materials were analyzed, including 3508 hybrids and 346 lines. Frequency analyzes showed that the frequency of the kinking character was very high (Table 4.9). In these analyzes, it was observed that the frequency of the kinking character of the 2019 winter lines was lower than in other seasons (Table 4.9).

In the spring of 2020, 2 lines (F7) with high-kinking and 2 lines (F7) with low-kinking were selected phenotypically (Table 3.3). The field numbers of these lines were N20_002667, N20_002668, N20_002688, N20_002691 and detailed observations were taken from them (Table 4.16). The aim for detailed observations was the examination of the kinking character in these lines by taking more detailed data. When the detailed observations analyzed; as can be seen in Table 4.17; no correlation was found between kinking and other characters. And the lines crossed with each other. The crosses made are given in Table 3.4. Three crosses were harvested at spring and these hybrids were planted in plots in the autumn of 2020. Correlation analyzes were performed by taking detailed observations on these 3 hybrids. The analyzes performed are given in Table 4.21 and no correlation was found between kinking and other characters between these 3 hybrids.

Correlation analysis of the observations made in 2019 was carried out in separate seasons and together (Table 7.1). Correlation analyzes were performed to investigate the relationship of the kinking character with other traits. In the analyzes, totally (lines and hybrids) 3854 materials were analyzed. As a result of the correlation analysis, there was low but significant correlation between kinking and half truss length and there was a higher correlation between the kinking character and kinking length (Table 7.1).

In total, regression analysis was performed with all observations taken in 2019 (Table 4.14). In the regression analysis, there was a positive relationship between kinking and truss length (0.166), and a negative but significant relationship between kinking and harvest difficulty (-0.121)(Table 4.14). The reason for the negative correlation with harvest difficulty may be that the fruit stem tissues are stronger in the lines with greater harvest difficulty.

Principal Component analysis was performed with all observations taken in total in 2019 (Table 4.11). When the table is evaluated; uniformity and plant health had a positive effect on cracking and negative effect on kinking.

4.11.1. Observations on the parental lines

Table 4.15. Analysis of Variance (Anova) table on the parental lines used in hybridisation study in 2020 spring

Trait	Trait Explanation	Source	Line	Truss.no	Line * Truss.no
		df	3	2	6
Mainthcknss	Main stem thickness	**F**	7,535	0,000	0,000
Kinking	Total Kinking Truss out of 5 plants (20 truss)	**F**	4,000	,250	1,917
Thickness	Truss Stem Thickness	**F**	2,322	1,219	,642
Trusslenght	Whole Truss Length (Length of truss stem starting from main stem to the peduncle of the last fruit)	**F**	25,326	2,203	,419
Truss Stem Lenght	Half Truss Length from main stem to the peduncle of the first fruit (length of the	**F**	20,164	3,138	1,480
TLFL	Truss Length from peduncle of First Fruit to the Peduncle of the Last fruit	**F**	16,741	1,662	,552
Trussweight	Total Fruit Weight/truss	**F**	1,109	1,120	,815
Fruitpiece	Fruit Number Per Truss	**F**	5,324	1,626	,399
AbcisKinking	Total of plants truss with Abscission Zone on Truss Stem of 5 plants (20 truss)	**F**	,667	1,750	,417
AbcisFruitstem	Total of plants truss with Abscission zone on Fruit Peduncle of 5 plants (20 truss)	**F**	2,127	,857	1,365

*Statistically significant at probability level $P<0.05$. ** Statistically significant at probability level $P<0.001$.

Table 4.16. Observations on the parental lines

Trait Code	Traits		Line			
			2667	**2668**	**2688**	**2691**
MST	Main stem thickness	(mm)	1,62	1,64	1,44	1,78
Kg	Total Kinking Truss out of 5 plants (20 truss)	1 = Absent 9 = Present	6	6	12	12
TST	Truss Stem Thickness	mm	0,52	0,68	0,6	5,7
WTL	Whole Truss Length (Length of truss stem starting from main stem to the peduncle of the last fruit)	cm	11,74	11,6	27,8	13,9
HTL	Half Truss Length from main stem to the peduncle of the first fruit (length of the	cm	3,347	3,82	8,07	3,63
TLFL	Truss Length from peduncle of First Fruit to the Peduncle of the Last fruit	cm	8,39	7,75	19,8	10,3
TFW	Total Fruit Weight/truss	g	660,7	564	650,4	693
FNPT	Fruit Number Per Truss		3,85	3,4	4,94	5,74
AZOTS	Total of plants truss with Abscission Zone on Truss Stem of 5 plants (20 truss)	0 = Absent 1 = Present	1	1	2	0
AZOFP	Total of plants truss with Abscission zone on Fruit Peduncle of 5 plants (20 truss)	0 = Absent 1 = Present	2	4	7	2

*Statistically significant at probability level P<0.05. ** Statistically significant at probability level P<0.001.

Table 4.17. Pearson's correlations coefficients between kinking and other traits in lines used in hybridisation study in 2020 spring

	Kg	**TST**	**WTL**	**HTL**	**TLFL**	**TFW**	**FNPT**	**AZOTS**	**AZOFP**
Mainthcknss	,013	,008	-,300*	-,269*	-,266*	,151	,161	,163	,108
Kinking		,008	,215	,291*	,151	-,010	,136	-,055	,236
Thickness			,113	,068	,107	,105	,025	,241	,221
Trusslength				,769**	,963**	,225	,368**	,178	,445**
Truss Stem Lenght					,571**	,191	,248	,160	,475**
TLFL						,211	,371**	,165	,378**
Trussweight							,791**	,208	,157
Fruitpiece								,108	,076
AbcisKinking									,309*
AbcisFruitstem									

*Statistically significant at probability level $P<0.05$. ** Statistically significant at probability level $P<0.001$. N=60

Table 4.18. Principal component analyses between kinking and other traits in lines

Total Variance Explained						
	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3,399	33,995	33,995	3,399	33,995	33,995
2	1,718	17,180	51,174	1,718	17,180	51,174
3	1,334	13,345	64,519			
4	1,078	10,781	75,301			
5	,826	8,255	83,556			
6	,608	6,084	89,640			
7	,530	5,302	94,941			
8	,359	3,587	98,528			
9	,147	1,466	99,994			
10	,001	,006	100,000			
Extraction Method: Principal Component Analysis.						

Table 4.19. Contribution of the components to variance in lines

Component Matrix				
	Component			
	1	2	3	4
Mainthcknss	-,182	,667	,277	,402
Kinking	,314	-,145	,009	,806
Thickness	,219	,143	,572	-,292
Trusslength	,925	-,268	-,089	-,098
Truss Stem Length	,800	-,279	,001	,096
TLFL	,855	-,224	-,115	-,163
Trussweight	,472	,726	-,304	-,110
Fruitpiece	,554	,627	-,458	,021
AbcisKinking	,326	,334	,582	-,236
AbcisFruitstem	,598	-,003	,518	,260
Extraction Method: Principal Component Analysis.				

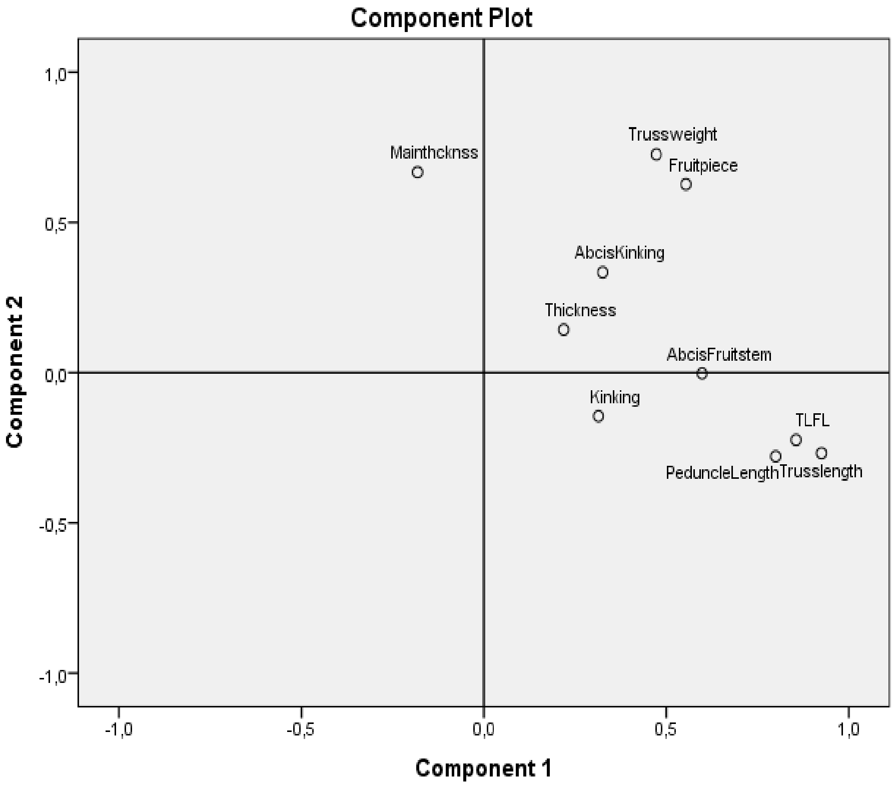

Figure 4.9. Component plot between kinking and other traits

4.11.2. Observations F1 Hybrids at autumn season 2020

Table 4.20. Analysis of Variance (Anova) table for the traits investigated

Trait	Trait Explanation	Source	Line	Truss.no	Line * Truss.no
		df	2	2	4
Mainthcknss	Main stem thickness	**F**	3,269	0,000	0,000
Kinking	Total Kinking Truss out of 5 plants (15 truss)	**F**	3,294	5,765	0,471
Thickness	Truss Stem Thickness	**F**	3,644	0,767	,603
Truss Lenght	Whole Truss Length (Length of truss stem starting from main stem to the peduncle of the last fruit)	**F**	17,687	1,033	1,198
Truss Stem Lenght	Half Truss Length from main stem to the peduncle of the first fruit (length of the	**F**	60,550	3,692	2,494
TLFL	Truss Length from peduncle of First Fruit to the Peduncle of the Last fruit	**F**	1,619	0,110	,770
Truss Weight	Total Fruit Weight/truss	**F**	2,811	2,201	,735
Fruitpiece	Fruit Number Per Truss	**F**	1,383	1,241	,174
AbcisKinking	Total of plants truss with Abscission Zone on Truss Stem of 5 plants (15 truss)	**F**	,222	0,222	1,889
AbcisFruitstem	Total of plants truss with Abscission zone on Fruit Peduncle of 5 plants (15 truss)	**F**	3,000	,000	0,000
Kinking Lenght	From main stem to kinking region	**F**	8,80645	5,51613	0,91935

Table 4.21. Detailed phenotypic measurements on the hybrids used in hybridisation study in 2020 autumn

Trait Code	Traits		Hybrids		
			2667 x 2668	**2668 x 2691**	**2688 x 2691**
			Non-kinking x Non-kinking	**Non-kinking x Kinking**	**Kinking x Kinking**
MST	Main stem thickness	(mm)	1,38	1,48	1,26
Kg	Total Kinking Truss out of 5 plants (15 truss)	1 = Absent 9 = Present	10	12	6
TST	Truss Stem Thickness	mm	0,48	0,51	0,42
WTL	Whole Truss Length (Length of truss stem starting from main stem to the peduncle of the last fruit)	cm	12,8	20,4	10,8
HTL	Half Truss Length from main stem to the peduncle of the first fruit (length of the	cm	4,13	9,93	2,53
TLFL	Truss Length from peduncle of First Fruit to the Peduncle of the Last fruit	cm	8,67	10,4	8,26
TFW	Total Fruit Weight/truss	g	658	610	502
FNPT	Fruit Number Per Truss		3,93	4,6	3,6
AZOTS	Total of plants truss with Abscission Zone on Truss Stem of 5 plants (15 truss)	0 = Absent 1 = Present	1	2	2
AZOFP	Total of plants truss with Abscission zone on Fruit Peduncle of 5 plants (15 truss)	0 = Absent 1 = Present	2	4	7

Table 4.22. Pearson's correlations coefficients between kinking and other traits in hybrids in 2020 autumn

	Kg	TST	WTL	HTL	TLFL	TFW	FNPT	AZOTS	AZOFP	Kinking Lenght
Mainthcknss	,289	,022	,265	,255	,189	,130	,135	-,051	,202	,211
Kinking		,241	,353*	,421**	,162	-,028	-,035	,130	-,024	,792**
Thickness			,597**	,491**	,517**	,428**	,275	,094	-,071	,473**
Trusslength				,860**	,827**	,418**	,533**	-,107	,000	,610**
Truss stem Length					,425**	,293	,345*	-,012	,061	,657**
TLFL						,420**	,565**	-,177	-,067	,359*
Truss Weight							,774**	,001	-,106	,064
Fruitpiece								-,141	-,048	,042
AbcisKinking									,094	,000
AbcisFruitstem										-,030

*Statistically significant at probability level P<0.05. ** Statistically significant at probability level P<0.001. N=45

Table 4.23. Principal component analysis between kinking and other traits in hybrids 2020

Total Variance Explained						
	Initial Eigenvalues			**Extraction Sums of Squared Loadings**		
Component	**Total**	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	4,193	38,122	38,122	4,193	38,122	38,122
2	1,905	17,321	55,443	1,905	17,321	55,443
3	1,198	10,892	66,335			
4	1,087	9,885	76,220			
5	,833	7,571	83,790			
6	,561	5,100	88,891			
7	,492	4,474	93,365			
8	,462	4,199	97,564			
9	,154	1,402	98,966			
10	,114	1,034	100,000			
11	1,491E-16	1,355E-15	100,000			
Extraction Method: Principal Component Analysis.						

Table 4.24. Contribution of the components to variance in lines

Component Matrix				
	Component			
	1	2	3	4
Mainthcknss	,333	,199	,684	-,101
Kinking	,495	,701	-,077	-,033
Thickness	,698	-,023	-,309	,253
Trusslength	,945	-,023	,028	-,076
Truss Stem Length	,818	,217	,045	,009
TLFL	,776	-,278	,001	-,145
Trussweight	,565	-,607	,013	,276
Fruitpiece	,602	-,650	,140	,074
AbcisKinking	-,070	,259	-,134	,891
AbcisFruitstem	-,035	,175	,750	,313
Kinkinglenght	,704	,600	-,160	-,108
Extraction Method: Principal Component Analysis.				
a. 4 components extracted.				

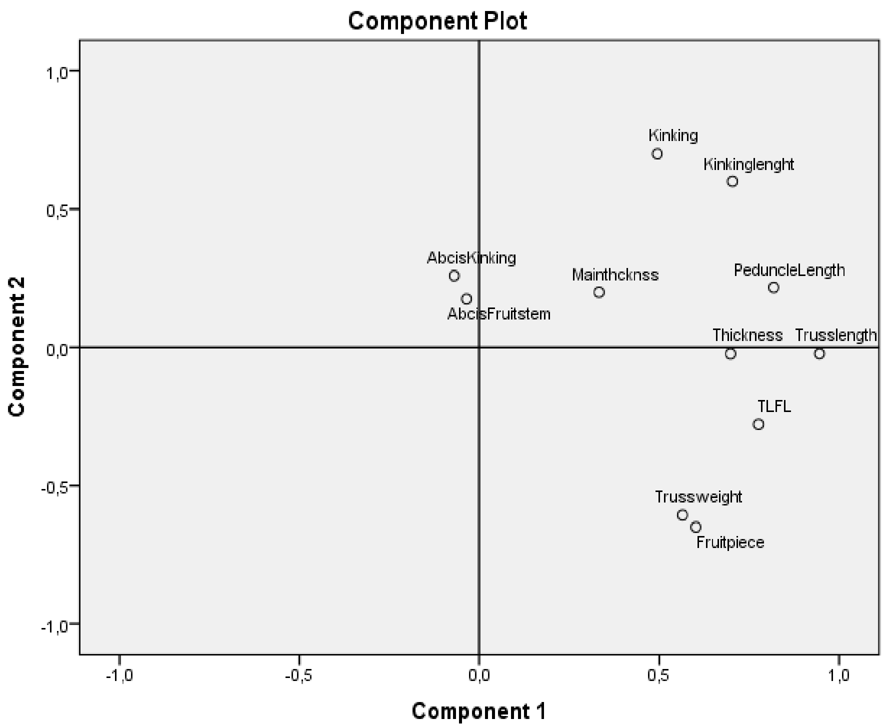

Figure 4.10. Component plot between kinking and other traits

4.11.3. Observations on F1 hybrids at spring season 2021

Table 4.25. Analysis of Variance (ANOVA) table for the traits investigated

Trait	Trait Explanation	Source	Line	Truss.no	Line * Truss.no
		df	2	2	4
Mainthcknss	Main stem thickness	**F**	0,577	0,407	0,546
Kinking	Total Kinking Truss out of 5 plants (20 truss)	**F**	0,87	0,87	1,261
Thickness	Truss Stem Thickness	**F**	0,328	2,297	1,078
Trusslenght	Whole Truss Length (Length of truss stem starting from main stem to the peduncle of the last fruit)	**F**	11,35**	2,02	1,051
Truss Stem Lenght	Half Truss Length from main stem to the peduncle of the first fruit (length of the	**F**	76,28**	1,309	1,124
Trussweight	Total Fruit Weight/truss	**F**	0,795	1,907	1,302
Fruitpiece	Fruit Number Per Truss	**F**	2,297	1,172	0,656
AbcisKinking	Total of plants truss with Abscission Zone on Truss Stem of 5 plants (20 truss)	**F**	0,74	0,74	0,296
AbcisFruitstem	Total of plants truss with Abscission zone on Fruit Peduncle of 5 plants (20 truss)	**F**	6,5**	1,625	0,5

*Statistically significant at probability level P<0.05. ** Statistically significant at probability level P<0.001.

Table 4.26. Detailed phenotypic measurements on the hybrids 2021

Trait Code	Traits		Hybrids		
			2667 x 2668	2668 x 2691	2688 x 2691
			Non-kinking x Non-kinking	Non-kinking x Kinking	Kinking x Kinking
MST	Main stem thickness	(mm)	1,28	1,4	1,48
Kg	Total Kinking Truss out of 5 plants (15 truss)	1 = Absent 9 = Present	10	9	9
TST	Truss Stem Thickness	mm	0,42	0,52	0,51
WTL	Whole Truss Length (Length of truss stem starting from main stem to the peduncle of the last fruit)	cm	10,8	17,6	11,2
HTL	Half Truss Length from main stem to the peduncle of the first fruit (length of the	cm	3,8	8,87	2,4
TFW	Total Fruit Weight/truss	g	495	525	513
FNPT	Fruit Number Per Truss		4,2	5,07	4,2
AZOTS	Total of plants truss with Abscission Zone on Truss Stem of 5 plants (15 truss)	0 = Absent 1 = Present	7	8	8
AZOFP	Total of plants truss with Abscission zone on Fruit Peduncle of 5 plants (15 truss)	0 = Absent 1 = Present	9	7	11

Table 4.27. Pearson's correlations coefficients between kinking and other traits in hybrids in spring 2021

Correlations									
	Kg	**TST**	**WTL**	**HTL**	**TFW**	**FNPT**	**AZOTS**	**AZOFP**	**Kinking Lenght**
Mainthcknss	-,080	-,088	-,197	-,268	,257	,060	-,096	-,019	-,122
Kinking		,043	-,101	,042	-,081	,056	-,120	,070	,055
Thickness			,295*	,141	,024	,090	-,168	,037	,027
Trusslength				,681**	,024	,335*	,001	-,143	,474**
Truss Stem Length					-,027	,167	-,045	-,312*	,504**
Trussweight						,439**	-,146	-,168	-,159
Fruitpiece							-,143	-,309*	,355*
AbcisKinking								-,177	,052
AbcisFruitstem									-,266

*Statistically significant at probability level P<0.05. ** Statistically significant at probability level P<0.001.

Table 4.28. Principal component analyses between kinking and other traits in hybrids

Total Variance Explained						
Component	**Initial Eigenvalues**			**Extraction Sums of Squared Loadings**		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	2,569	25,690	25,690	2,569	25,690	25,690
2	1,653	16,533	42,223	1,653	16,533	42,223
3	1,344	13,439	55,661	1,344	13,439	55,661
4	1,051	10,509	66,170	1,051	10,509	66,170
5	,832	8,321	74,491			
6	,751	7,512	82,003			
7	,670	6,702	88,705			
8	,598	5,978	94,684			
9	,338	3,379	98,063			
10	,194	1,937	100,000			
Extraction Method: Principal Component Analysis.						

Table 4.29. Contribution of the components to variance in hybrids

Component Matrix				
	Component			
	1	2	3	4
Mainthcknss	-,274	,594	-,108	-,023
Kinking	,012	-,105	,403	,820
Thickness	,280	-,007	,593	-,405
Trusslength	,824	-,103	,119	-,281
Truss Stem Length	,816	-,212	,030	-,024
Trussweight	,090	,828	,011	-,095
Fruitpiece	,554	,602	,021	,198
AbcisKinking	-,019	-,311	-,710	-,069
AbcisFruitstem	-,467	-,257	,527	-,145
Kinkinglenght	,732	-,152	-,141	,244
Extraction Method: Principal Component Analysis.				
a. 4 components extracted.				

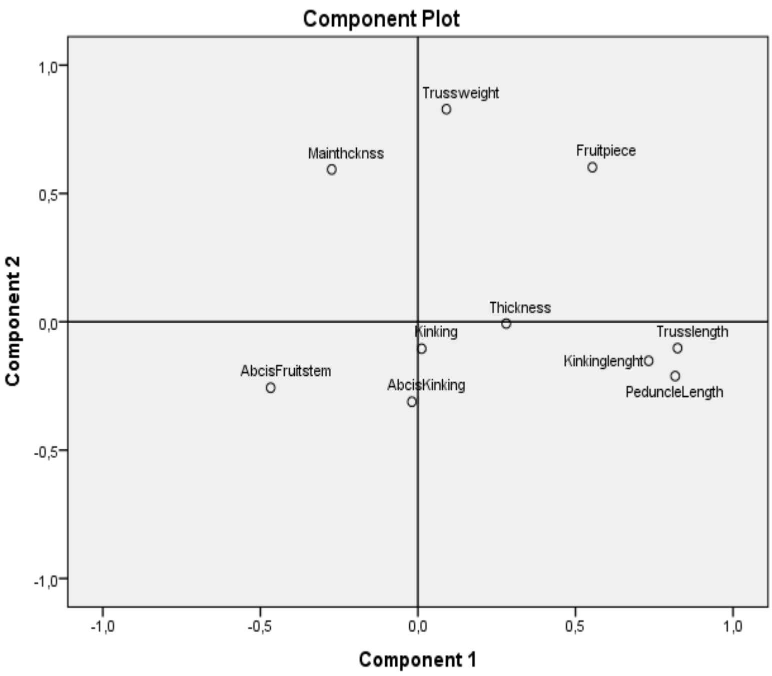

Figure 4.11. Component plot between kinking and other traits on hybrids

4.11.4. Observations on F2 Segregations in spring season 2021

Table 4.30. Analysis of Variance (ANOVA) table for the traits in F2 plants

Trait	Trait Explanation	Source	Line	Truss
		df	2	2
Mainthcknss	Main stem thickness	**F**	2,671	0,23
Kinking	Total Kinking Truss out of 5 plants (20 truss)	**F**	1,32	0,711
Thickness	Truss Stem Thickness	**F**	0,556	0,285
Truss lenght	Whole Truss Length (Length of truss stem starting from main stem to the peduncle of the last fruit)	**F**	21,727	0,974
Truss Stem Lenght	Half Truss Length from main stem to the peduncle of the first fruit (length of the	**F**	47,042	2,274
Truss Weight	Total Fruit Weight/truss	**F**	2,712	0,15
Fruitpiece	Fruit Number Per Truss	**F**	0,395	0,64
AbcisKinking	Total of plants truss with Abscission Zone on Truss Stem of 5 plants (20 truss)	**F**	6,129	0,968
AbcisFruitstem	Total of plants truss with Abscission zone on Fruit Peduncle of 5 plants (20 truss)	**F**	2,414	3,234

*Statistically significant at probability level P<0.05. ** Statistically significant at probability level P<0.001.

Table 4.31. Detailed phenotypic average measurements on the F2 selfings

Trait Code	Traits		Selfings (F2)		
			2667 x 2668	2668 x 2691	2688 x 2691
			Non-kinking x Non-kinking	Non-kinking x Kinking	Kinking x Kinking
MST	Main stem thickness	(mm)	1,43	1,34	1,26
Kg	Total Kinking Truss out of 5 plants (15 truss)	1 = Absent 9 = Present	11	12	8
TST	Truss Stem Thickness	mm	0,49	0,51	0,46
WTL	Whole Truss Length (Length of truss stem starting from main stem to the peduncle of the last fruit)	cm	13,6	20,4	9,8
HTL	Half Truss Length from main stem to the peduncle of the first fruit (length of the	cm	4,6	9,93	2,6
TFW	Total Fruit Weight/truss	g	630	610,3	481,3
FNPT	Fruit Number Per Truss		4,53	4,6	4,13
AZOTS	Total of plants truss with Abscission Zone on Truss Stem of 5 plants (15 truss)	0 = Absent 1 = Present	10	3	9
AZOFP	Total of plants truss with Abscission zone on Fruit Peduncle of 5 plants (15 truss)	0 = Absent 1 = Present	11	10	12

Table 4.32. Pearson's correlations coefficients between kinking and other traits in F2 selfings in spring 2020

Correlations									
	Kg	**TST**	**WTL**	**HTL**	**TFW**	**FNPT**	**AZOTS**	**AZOFP**	**Kinking Lenght**
Mainthcknss	,078	,046	,021	,101	,003	,178	-,052	,070	-,039
Kinking		-,051	,037	,191	-,269	-,132	-,141	,127	,691**
Thickness			,227	,282	-,036	,086	-,233	,110	,127
Trusslength				,876**	,423**	,342*	-,356*	-,032	,402**
Truss Stem Length					,284	,201	-,426**	,080	,465**
Trussweight						,617**	-,187	-,002	-,133
Fruitpiece							-,236	-,016	-,081
AbcisKinking								-,334*	-,137
AbcisFruitstem									,131

*Statistically significant at probability level $P<0.05$. ** Statistically significant at probability level $P<0.001$.

Table 4.33. Principal component analyses between kinking and other traits in F2 selfings

Total Variance Explained						
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2,890	28,904	28,904	2,890	28,904	28,904
2	2,012	20,120	49,024	2,012	20,120	49,024
3	1,223	12,228	61,252	1,223	12,228	61,252
4	1,063	10,633	71,885	1,063	10,633	71,885
5	,970	9,700	81,585			
6	,669	6,687	88,272			
7	,584	5,837	94,109			
8	,302	3,022	97,131			
9	,202	2,015	99,146			
10	,085	,854	100,000			
Extraction Method: Principal Component Analysis.						

Table 4.34. Contribution of the components to variance in lines in F2 selfings

Component Matrix				
	Component			
	1	2	3	4
Mainthcknss	,135	-,053	,352	,647
Kinking	,255	,776	-,077	,381
Thickness	,369	,043	,313	-,561
Trusslength	,873	-,110	-,306	-,118
Truss Stem Length	,887	,085	-,174	-,108
Trussweight	,461	-,692	-,113	,162
Fruitpiece	,467	-,608	,039	,333
AbcisKinking	-,611	-,008	-,469	,106
AbcisFruitstem	,206	,213	,758	,004
Kinkinglenght	,525	,701	-,249	,104
Extraction Method: Principal Component Analysis.				

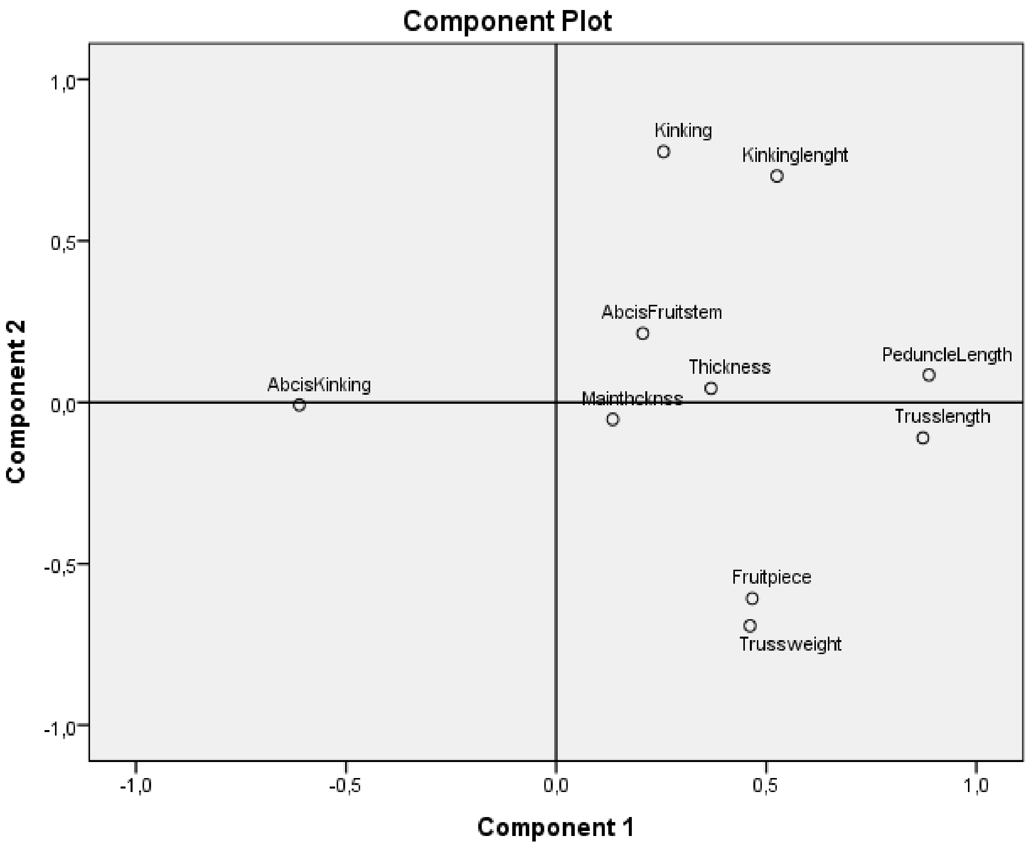

Figure 4.12. Component plot between kinking and other traits in F2 plants

5. CONCLUCIONS

This study was conducted between 2019-2020. Kinking is a very common character in indeterminate tomatoes. This character causes fruits to remain small and yield loss. This study investigated genotypic and environment effects on kinking character of indeterminate tomato.

When the analyzes of all trials were evaluated statistically. It was found that the interaction between kinking and season (environment) x genotype (hybrids and lines) was significant and the variation was high. As a result, a significant positive relationship was found between kinking character and stem length, and a negative relationship was found between harvest difficulty. If the stem of clusters are long, kinking problem may occur more common. Because generally stems can't support the weight of cluster. On the other hand, there is negative correlation with harvest difficulty. Which means if the fruit stem very strong kinking problem occur less. To reduce this problem, plants should be very strong at every growth stage. By fertilization, climate, cultivation are main factors.

In breeding studies, to reduce the kinking problem; materials that do not have kinking (non-kinking) problem with shorter stem can be used as a breeding material. Selections can be made from their progenies. Selected materials should be tested in different growing seasons and environments. Genome Wide association (GWAS) and QTL studies are suggested in order to elucidate the kinking problem in tomato.

Genomic prediction studies may be beneficial for the investigation of kinking trait in tomato. Exploratory experiments in genomic prediction using available GWAS data are recommended. Linkage and association mapping can be made on GWAS results by crossing parents that segregate for only one (putative) QTL. This may lead to the conclusion that linkage mapping and association mapping are complementary and their joint usage is recommended for future mapping studies. Advice can be given for optimal parent lines to generate the link mapping populations necessary to validate QTLs. The best use of QTLs will be in phenotypic prediction models.

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7. APPENDICES

Appendix 1. Pearson's Correlation table from whole lines and hybrids at 2019

Spring Hybrids 2019

	Vig	Phlt	Cov	Ltn	Erl	Firm	Col	Calyx	Crck	FDrp	Size	Uni	Set	Cvp
Kinking	-,033	-,033	-,015	-,007	-,033	-,016	-,038	,016	-,034	,019	,019	-,033	-,063*	-,001

Autumn Lines 2019

	Vig	Cov	PHlt	Erl	Ltn	HeaSet	Shp	Size	Uni	Firm	Col	Clx	TL	HrvDif	StmScar	Crk	Drp	Lcol	Lrol	Yvis	Cvp
Kinking	-0,13	-0,022	0,022	,161*	0,033	-0,047	-0,041	0,098	0,006	-0,041	0,066	0,097	0,102	-0,144	-0,087	0,051	-,202**	-0,051	-0,016	0,078	,188*

Autumn Hybrids 2019

	Vig	PHlt	Cov	Ltn	Shp	Erl	Firm	HrvDif	Col	Clx	Crk	Size	Gsh	Bss	StmSca	Drp	Uni	Yvis	Cvp
Kinking	0,038	0,02	0,001	-0,008	0	-0,042	0,002	-0,044	-0,029	0,028	0,038	-0,017	0,021	-,085**	-0,016	-,062*	-0,034	-0,04	-0,037

Winter Lines 2019

	Vig	Cov	PHlt	Erl	Ltn	ColSet	Shp	Size	Uni	Firm	Col	Clx	TL	HrvDif	Bss	StmSca	Crk	Skn	Drp	Lcol	Lrol	Yvis	Cvp
Kinking	,053	-,018	,088	,062	,057	-,029	-,101	-,135	,137	-,159*	,050	-,130	,174*	,043	,129	,048	-,013	-,275**	-,085	,090	,000	,057	,062

Winter Hybrids 2019

	Vig	Cov	PHlt	Erl	Ltn	HrvDif	Shp	Size	Uni	Firm	Col	Gsh	Clx	Bss	StmSca	Blo	Crk	Yvis	Cvp
Kinking	-,019	,008	-,015	,007	,001	,032	,030	,003	-,002	,030	,008	-,003	-,007	-,009	,010	-,033	,004	,021	,007

Total of Lines 2019

	Season	Vig	Cov	PHlt	Erl	Ltn	Heatset	Colset	Shp	Size	Uni	Firm	Col	Clx	TL	hrvdif	Stm	Crk	Lcol	Lrol	Yvis	Cvp
Season	1	,397**	,153**	-,524**	-,075	-,129**	.^{b}	.^{b}	-,125**	-,136**	-,299**	,141**	,029	-,249**	,377**	,344**	-,179**	,082	-,040	-,279**	-,321**	-,203**
Kinking	-,184**	-,062	-,033	,110*	,036	,062	-,047	-,029	-,030	-,025	,137*	-,113*	,053	-,005	,097	-,107*	-,021	,030	,040	,053	,085	,109*

Total of Hybrids 2019

	Season	Vig	PHlt	Cov	Ltn	Shp	Erl	Firm	HrvDif	Col	Clx	Crk	Size	Gsh	Bss	StmSca	Blo	Uni	Yvis	Cvp
Season	1	,095**	-,351**	-,061**	-,168**	-,760**	-,081**	,091**	,076**	-,137**	-,267**	-,196**	-,405**	-,007	-,004	-,009	-,775**	-,044**	-,330**	-,126**
Kinking	-,075**	-,004	,012	-,011	-,012	,024	-,047**	-,019	-,054**	-,022	,024	-,041*	-,030	,021	-,085**	-,016	,051*	-,044**	,005	-,020

Total of Lines and Hybrids 2019

	Season	Vig	Cov	PHlt	Erl	Ltn	heatset	Colset	Shp	Size	Uni	Firm	Col	Clx	hrvdif	Crk	Stm	Yvis	Cvp	Bss	Blo	Gsh	TL	Lcol	Lrol
Season	1	,123**	-,047**	-,377**	-,104**	-,157**	.^{b}	.^{b}	-,665**	-,380**	-,094**	,082**	-,119**	-,249**	,122**	-,098**	-,076**	-,309**	-,150**	-,236**	-,775**	.^{b}	,377**	-,040	-,279**
Kinking	-,121**	-,002	,019	,095**	,087**	,005	-,047	-,029	-,006	,059**	,079**	-,014	,003	,054**	-,039*	,204**	-,061*	,155**	,163**	-,128**	,051*	,021	,097	,040	,053

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