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Research Article

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Comparison of Fiber Quality Properties of Different Cotton (*G. hirsutum* L.) Varieties for Normal and Late Harvest Periods

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Abstract:

Cotton fibers are the most important raw material of the textile industry. Clean collection of cotton fibers increases the quality of textile products and the market prices. This study was conducted to investigate the effects of normal and late harvest period of different cotton varieties on cotton fiber and yarn properties. The quality properties of the fibers were determined with the HVI device, and the quality properties of the yarns obtained from the fibers were determined with the USTER TESTER device. The fiber quality properties such as fiber **fineness** (micronaire), fiber maturity, fiber length (UHML, mm), strength (g/tex), brightness/whiteness (Rd), and yarn quality properties such as yarn evenness (%), thin places, neps+200 (%) and hairiness were investigated in the study. The exposure of fibers to rain during the harvest period of 2018 caused a decrease in the quality properties. Inability of the plants to receive sufficient sunlight during the last physiological development period caused a decrease in photosynthesis rate. This negative situation negatively affected the physical quality properties of fiber and yarn. The results indicated that the physical quality properties of fibers and yarns obtained in 2019 were higher than those in 2018. The aim of this study was to determine the effect of late harvest period on fiber and yarn quality properties and thus on quality of textile products. In addition, the study was carried out to guide researchers who will conduct researchers on similar topics.

Keywords: *Cotton, harvest periods, fiber quality, yarn quality.*

Introduction:

Cotton fiber is the most important raw material of the textile industry, and harvest time and processing of fibers in the industry are important for fiber, yarn and fabric qualities and quality of final textile products. Several limiting factors may cause delay in the harvest time of cotton fibers. The factors for the late harvest maturity are genetic characteristics of the cotton variety used, environmental factors, disruptions caused by agricultural activities and climatic factors.

Ecology of a few countries is suitable for cotton agriculture in the world; therefore, almost 80% of the world production is carried out in these countries including Turkey. The International Cotton Advisory Committee (ICAC) reported that cotton cultivation area in 2018-2019 growing season was 32.986 million ha and total fiber cotton production was 25.69 million tons (Anonymous, 2020).

36 The reports of ICAC for 2018-2019 indicated that Turkey ranked the ninth country in the world
37 cotton cultivation, fifth in cotton yield per unit area, eighth in cotton production; fourth in cotton
38 consumption and fourth in cotton import (Anonymous, 2020).

39 Harvest time is one of the most important issues in cotton agriculture. The harvest time has a
40 significant effect on the amount of fiber per unit area and on the fiber quality properties. Delay in
41 harvest due to ecological and environmental factors or planning causes in quality losses. The
42 ripening of bolls is one of the important factors that determine the harvest time.

43 The parameters related to the yield and quality characteristics of cotton vary depending on the
44 genetic structure of the variety used, the maintenance carried out by the producers and the
45 environmental conditions of the growing environment.

46 The quality properties of cotton fiber can be affected by environmental factors, in addition to the
47 genetic characteristics of the variety used. Harvest and ginning methods and harvest time may affect
48 the quality properties of cotton fiber (Meredith, 1984).

49 Micronaire (fiber fineness), which is a measure of fiber fineness and maturity, is the major fiber
50 quality property of cotton. Micronaire is an important feature of cotton fiber quality that affects
51 spinning and dyeing processes.

52 The increase in the monthly average rainfall, and the length of the average rainfall period in autumn
53 negatively affect the fiber quality. Especially in the early autumn months, rainfalls coincide with the
54 harvest period are a serious risk on fiber quality properties (Luo et al., 2016).

55 Quality cotton fiber is vital to produce quality yarn and therefore higher quality fabrics. HVI and
56 AFIS fiber testing equipment, which are the state of the art of Uster are the devices used in testing
57 cotton fiber properties. Understanding the properties of cotton fibers and their relationship to yarn
58 and fabric quality are essential to produce quality textiles products. Cotton fiber quality is
59 determined by various parameters such as maturity, fineness, length, strength and uniformity. Better
60 yarns are produced by using higher quality fibers (Siddiqui et al., 2020).

61 Harvest time can have a significant impact on fiber yield. Late harvest negatively affects the fiber
62 properties of cotton. Cotton producers have understood that timely harvesting can have a significant
63 impact on cotton yield and quality. The results highlighted the importance of harvest time in cotton
64 for higher yield and better quality fiber production (Kelly et al., 2011).

65 Harvest time directly or indirectly affects fiber yield, physical fiber quality properties, and chemical
66 structure of fiber and textile product quality. Cotton harvest is carried out manually or using
67 machine. Although the harvesting methods are different, the delay in the harvest time causes some
68 problems in quality and yield. Exposure of unharvested cotton to rain and wind, due to late harvest,
69 is an undesirable situation for cotton quality. In addition, the fiber formation and the thickness of
70 the cell wall in the secondary wall are affected by the mitosis of the epidermis layer on cotton seeds
71 and immature fibers on rainy days. Because, photosynthesis process required for the production of
72 glucose which is the raw material of cellulose, slows down at low temperature and cloudy days.

73 The chemical structure of cotton fibers consists of approximately 94% cellulose, 2% hemicellulose,
74 2% pectin and 2% extracts (Saçak, 2002). Cellulose, the structural component of both primary and
75 secondary cell walls, is a polysaccharide composed of linear β -1,4-glucan chains synthesized by the
76 cellulose synthase complex (Bashline et al., 2014, McFarlane et al., 2014, Takenaka et al., 2018).
77 Cotton fibers, the natural material widely used in the textile industry, are single cell trichomes that
78 undergo mitosis of cells in the epidermis layer of seeds and sequentially undergo rapid elongation
79 and secondary cell wall biosynthesis. Mature cotton fibers consist almost entirely (>95%) of
80 cellulose (Applequist et al., 2001, Kim and Triplett, 2001, Lee et al., 2007, Mansoor and Paterson,
81 2012). Cellulose formation is associated with plant cell growth, dynamic processes of cell wall

82 biosynthesis, loosening and expansion (Cosgrove, 2005, Kang et al., 2019). Cell walls define the
83 shape of plant cells, controlling the extent and direction of cell elongation and thus the growth of
84 organs. The main carrier component of plant cell walls is cellulose, which is collected in the Golgi
85 apparatus and then synthesized by cellulose synthase complexes (Polko, 2019). The fiber cells of
86 cotton seeds on the epidermis layer are the most important agricultural textile product in the world.
87 Four different stages of fiber development, consisting of initiation, elongation, secondary cell wall
88 biosynthesis and maturation, which last approximately 2 months, are required to produce fully
89 mature fibers (Kim, 2015).

90 Plant cell growth involves a complex interaction between cell wall expansion, biosynthesis, and
91 specifically cell wall expansion. The tissues are developed with the secondary cell wall
92 accumulation, however, the coordination of these processes remains unclear. Cotton fiber cells
93 develop simultaneously, fairly elongated, and contain completely pure cellulose when mature (Cao
94 et al., 2020).

95 The aim of this study was to determine the effects of the normal harvest (2019) and late harvest
96 (2018) times on fiber and yarn quality properties of cotton varieties (Candia, Lima, ST-468 and
97 Candia + ST-468) produced in the Southeastern Anatolia region of Turkey, and to determine the
98 effects of harvest time on textile product quality.

99 **Material and Method:**

100 **Material**

101 In this study, the fiber and yarn quality characteristics of the fibers obtained from Candia, Lima, ST-
102 468 and Blended cotton (Candia + ST-468) varieties, which are widely cultivated standard cotton
103 varieties in Harran plain, located in the South Eastern region of Turkey, were determined in 2018
104 and 2019 cotton growing seasons. Climate and environmental factors differed in 2018 and 2019
105 cotton growing seasons. Climate data for 2018 and 2019 growing seasons were given in Table 1.

106 **Table 1.** Monthly climate data for 2018 and 2019 cotton growing seasons (Anonymous, 2019)

Climate Parameters	Years	Months								
		March	April	May	June	July	August	September	October	November
Min. Temperature (°C)	2018	0.3	6.7	11.9	14.7	17.6	17.4	11.9	3.6	2.9
	2019	0.1	5.5	8.4	16.7	17.8	17.3	8.6	7.7	-1.1
Max. Temperature (°C)	2018	25.4	31.8	36.4	41.3	41.0	39.7	39.9	33.3	28.8
	2019	21.9	26.5	39.4	43.3	40.1	43.3	37.3	36.1	27.8
Average Temperature (°C)	2018	12.7	19.0	23.2	27.8	29.3	28.5	25.3	19.8	12.3
	2019	10.7	14.5	24.2	29.4	29.3	29.6	24.8	21.0	13.1
Total Precipitation (mm= kg m ⁻²)	2018	20.4	59.3	10.9	0.0	0.0	0.6	20.2	133.2	20.4
	2019	67.0	3.9	1.1	0.0	0.0	0.0	12.3	5.4	67.0
Average Relative Humidity (%)	2018	78.9	44.6	54.4	44.0	50.9	59.2	56.7	62.7	83.9
	2019	82.3	80.1	45.8	39.4	46.5	55.0	57.8	62.6	56.9

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Monthly average temperature (°C) and average relative humidity (%) between March and November 2018, when cotton cultivation takes place, were similar to long term averages. However, the amount of rainfall was regular in late March and early April, when cotton was planted, and summer months, harvest could not be carried out in October and November due to excessive rainfall. Cotton harvest in 2018 was only completed in March 2019, due to heavy rainfall. Delay in harvest caused yield and quality losses, and the quality properties of cotton fibers were negatively affected.

The harvest in the second year (2019) was carried out on time as the weather conditions followed a normal course and there was no adverse impact. The reasons for the changes in cotton harvest times were summarized in Table 2.

Table 2. Seasonal changes in 2018 and 2019 cotton production periods

2018 (Late Harvest Period)	2019 (Normal Harvest Period)
<ul style="list-style-type: none"> • Prolonged rainfall occurred during the harvest season. • October and November, which are the cotton harvest months, were rainy. • The harvest was carried out in March 2019. 	<ul style="list-style-type: none"> • The cotton harvest was carried out at the beginning of October, which is the usual harvest time, as the weather conditions during the harvest period was as expected in that season.

All necessary agricultural practices from sowing to the harvest were fully implemented. Conventional practices which have been used in the Harran plain were used in cotton cultivation. The cotton harvest was carried out by machine, and the cotton obtained at the harvest was processed with a 30 Ne (yarn number) combed tricot ring spinning machine.

Method:

The quality characteristics of 4 different fibers obtained from 4 different cotton varieties produced in 2018 (late harvest period) and 2019 (normal harvest period) were determined using the HVI device. Fiber physical quality properties determined by using the HVI device were fiber fineness (micronaire), fiber maturity, fiber length (UHML, mm), strength (g/tex), and brightness/whiteness degree (Rd). The unevenness, fine places, nep and hairiness properties of 30 Ne 100% cotton yarns obtained from four different cotton fibers were determined using the Uster Tester.

The data obtained were subjected to analysis of variance (ANOVA) according to the splitted plots in randomized blocks experimental design using JUMP 13.1 statistical package program. Tukey multiple range test at 95 % probability was used as post-hoc where ANOVA indicated significant differences.

RESULTS AND DISCUSSION:

Fiber Properties

Fiber Fineness (micronaire):

Fiber fineness (micronaire) was statistically different ($p < 0.01$) between cotton varieties and harvest times. Similarly, the effects of variety x harvest time were significantly ($p < 0.01$) important on fiber fineness (micronaire) (Table 3). The lowest fiber fineness (micronaire) value was recorded for Mixture cotton (3.76), while the highest fiber fineness value was for Candia variety (4.38). The fiber

141 fineness, which is one of the important fiber quality characteristics in the textile industry, is preferred
142 to be low, therefore, the fibers obtained from the mixture of Candia + ST-468 varieties with the
143 lowest fineness value are preferred.

144 The findings on fiber fineness are partially in agreement with the findings of Meredith (1986), who
145 reported that 59% of the variation in fiber fineness caused by environmental factors. The relationship
146 between fiber breaking elongation, fiber fineness and fiber breaking strength of the cotton varieties
147 examined was positive. Our findings are in line with the findings of Dever (1988), who stated that
148 fiber breaking elongation is associated with both fiber fineness and fiber breaking strength. Our
149 findings are also agreement with the findings of Silvertooth (1997), who indicated that fiber fineness
150 is a genotype-dependent character, yet maturity, environmental conditions and cultural processes
151 have significant impact on fiber fineness, and cultural processes that lead to earliness and uniform
152 boll survival are very important for fiber fineness. The results are also in line with the findings of
153 Davidonis et al. (2004), who reported that the fineness values of fibers obtained in early cotton
154 planting and early harvest were at optimum value.

155 The results showed that the fiber maturity was not fully realized in the early harvest, whereas the
156 seed cotton was affected by the adverse weather conditions such as rain and wind in the late harvest.
157 The findings that environmental factors are important in determining the fiber quality are in
158 accordance with the findings of Kechagia (1998), who stated that the effect of genotype and
159 environmental factors should not be ignored in determining fiber quality criteria. The findings of
160 Krieg (2017), who stated that genotypic and environmental factors affect cotton fiber quality and
161 that the genotypic effect on fiber fineness is more important, are partially consistent with our
162 findings. Marani and Amirav (1971) and Ramey (1986) obtained higher fiber fineness values from
163 the 1st and 2nd sub branches of cotton plants exposed to rainwater. Ayele (2017) reported that the use
164 of fine fibers in the yarn enables more fiber to be placed in the cross-section of a given yarn and
165 improves spinning efficiency and yarn evenness, however, yarns made of thicker fibers are less
166 uniform and weaker than yarn spun from a large number of fine fibers. The findings that fibers
167 exposed to rain and obtained in late harvest have more thick fibers and reduce textile product quality
168 are similar to the findings of Ayele (2017).

169 Pettigrew (2001) reported that the fiber value of cotton (*Gossypium hirsutum* L.) grown in low light
170 conditions is lower than cotton plants grown in sufficient sunlight. This response to low light
171 conditions has been associated with poor photosynthetic assimilation and decreased fiber quality.
172 Pettigrew (2001) stated that the starch rate in cotton fiber grown under the shade for 14 days
173 decreased by 29% and the sucrose level in the fiber obtained in the shade for 21 days decreased by
174 31%. The researcher noted that the carbohydrate reductions in the shade were parallel to 3%
175 reduction in fiber strength under low light. In addition, the researcher stated that sucrose levels
176 decrease during secondary cell wall deposition of fibers and shade affects the fineness of the fibers
177 produced, and these data provide convincing evidence that adequate carbon assimilation is required
178 to produce quality fiber. In this study, exposure of cotton fibers to excessive rain and decrease in the
179 photosynthesis rate due prolonged shadow conditions or insufficient light between October and
180 December 2018 resulted caused decrease in starch ratio which negatively affected the fiber fineness
181 values.

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Table 3. Fiber Fineness (Micronaire) Obtained for Normal and Late Harvest of Different Cotton Varieties and the Coefficients of Variability (CV %) for the Groups Created by the Tukey Test

Parameters	Harvest Periods	Cotton Varieties				Mean
		1. Candia	2. Lima	3.St-468	4.Mixture (Candia-St 468)	
Fineness	2019 (Normal Harvest period)	4.03bc	3.81bc	3.97bc	3.93bc	3.93
	2018 (Late Harvest Period)	4.73a	4.16b	3.69c	3.60c	4.04
	Mean	4.38a	3.98b	3.86b	3.76b	3.99
	CV(%), tukey	CV (%):3.50 tukey(variety):0.20** tukey (harvest period): ns. tukey (variety*harvest):0.43**				

The difference between the mean in the same letter group are not statistically significant. ns: not significant. *: Important at 5% level of significance; **: Important at 1% level of significance.

Fiber Maturity (%):

Fiber maturity (%) values of cotton varieties were significantly different ($p < 0.01$). The effects of harvest time on fiber maturity (%) was not statistically significant, while the effect of variety x harvest time interaction on fiber maturity (%) was statistically significant ($p < 0.05$) (Table 4). The lowest fiber maturity value (0.840%) was recorded in ST-468 variety, while the highest fiber maturity (0.860%) was obtained in Candia variety. The lowest fiber maturity value in variety x harvest time interaction (0.836%) was obtained in ST-468 x late harvest period interaction, and the highest fiber maturity value was (0.864%) was in Candia x late harvest period interaction.

The findings regarding the positive effect of harvest time x cultivar interaction on fiber maturity are consistent with the findings of Davidonis et al. (2004), who reported that harvesting at normal harvest time period increases fiber maturity. Similarly, our results are in agreement with the findings of Silvertooth et al. (1998), who stated that the highest yield potentials were usually achieved at early and optimum harvest time. Marani and Amirav (1971) and Ramey (1986) reported that the immature fiber fractions in cotton bolls were affected by rain and did not reach the expected maturity during prolonged rain. The rain and adverse weather conditions slow down the photosynthesis rate and decrease the glucose production of plants, therefore, maturation of fibers and cellulose accumulation are negatively affected. In addition, the fibers inside the cotton bolls that develop with the fertilization of the flowers that bloom especially in the upper parts of the plant during the rainy period cannot reach enough physiological maturity. The researchers reported that celluloses accumulate in the secondary wall during fiber maturation and thicken significantly as a polymerized photosynthesis product, therefore, due to the physiological maturation of the fiber, cellulose synthesis is also modulated and cotton fiber wall is thickened (Bradow et al 1996); Murray 1996); Murray and Brown 1996, 1997). Fibers that mature with various physiological activities are affected by environmental factors. In our study, although the effects of harvest time on fiber maturity was not statistically significant, the maturity level of the fibers obtained in the normal harvest period was higher. The high level of maturity can be associated with the fibers reaching a higher photosynthesis rate in this long period of time, producing more glucose and thus, the thickening the cell walls of fibers in the primary and secondary layers and filling with cellulose. Therefore, the light on which the photosynthesis rate depends is important in the cellulose formation of fibers. The aforementioned findings of the researchers were similar to our findings on fiber maturity.

Table 4. Fiber Maturity (%) Obtained for Normal and Late Harvests of Different Cotton Varieties and the Coefficients of Variability (CV %) for the Groups Created by the Tukey Test

Parameters	Harvest Periods	Cotton Variety				Mean
		1. Candia	2. Lima	3.St-468	4.Mixture (Candia-St-468)	
Maturity (%)	2019 (Normal Harvest period)	0.856ab	0.840cd	0.843bcd	0.846bcd	0.846
	2018 (Late Harvest Period)	0.864a	0.853abc	0.836d	0.836d	0.847
	Mean	0.860a	0.846b	0.840b	0.841b	0.846
	CV(%), tukey	CV(%):0.59 tukey (Variety):0.10** tukey(Harvest period):n.s. tukey (Variety x Harvest):0.01*.				

The difference between the mean in the same letter group are not statistically significant. ns: not significant. *: Important at 5% level of significance; **: Important at 1% level of significance.

Fiber Length (UHML, mm):

Cotton variety and cultivar x harvest time interaction had a statistically significant effect on fiber length (UHML, mm). However, the fiber lengths (UHML, mm) obtained at different harvest times (Table 5) were not statistically different. The lowest fiber length (28.56 mm) was obtained in Candia+ST- 468 mixture, while the highest fiber length 29.39 was measured in Candia variety. The lowest fiber length in variety x harvest time interaction was recorded in Candia x late harvest period (28.37 mm) and the highest fiber length was obtained in Candia x normal harvest period (30.41 mm) treatment. The results showed that normal harvest period when the fibers achieve their maximum development is the ideal period for the harvest. The delay of harvest and the exposure of fibers in cotton bolls to rain causes a decrease in the fiber length. Our results are consistent with the findings of Davidonis et al. (2004), who reported that early sowing initiates the vegetation period earlier, and the fiber lengths of cotton increases.

Table 5. Fiber Length (UHML) Obtained for Normal and Late Harvests of Different Cotton Varieties and the Coefficients of Variability (CV %) for the Groups Created by the Tukey Test

Parameters	Harvest Periods	Cotton Variety				Mean
		1. Candia	2. Lima	3.St-468	4.Mixture (Candia-St-468)	
Length	2019 (Normal Harvest period)	30.41a	28.57b	28.50b	28.52b	29.00
	2018 (Late Harvest Period)	28.37b	29.05b	28.88b	28.60b	28.72
	Mean	29.39a	28.81ab	28.69b	28.56b	28.86
	CV(%), tukey	CV (%):1.38 tukey(variety):0.55* tukey (harvest period): ns. Tukey (variety*harvest): 1.26**				

The difference between the mean in the same letter group are not statistically significant. ns: not significant. *: Important at 5% level of significance; **: Important at 1% level of significance.

Fiber Strength (g/tex):

The effects of cotton variety and harvest time on fiber strength were not statistically significant. However, fiber strength values in the interaction of variety x harvest time treatment were significantly different ($p < 0.01$) (Table 6). The lowest fiber strength was in variety x harvest time interaction was obtained in Candia x late harvest (27.90 g/tex), while the highest fiber strength was recorded in Candia x normal harvest time (33.13 g/tex) interaction. The delay in cotton harvest caused a decrease in fiber strength. Our findings are not compatible with the findings of Meredith (1986) that more than 80% of the variation in fiber breaking strength is due to the difference is genotype. However, the findings of Silvertooth (1998), who stated that long-term excessive rainfall

decreases the yield, fiber and seed quality and may cause a decrease in fiber strength values, are in agreement with our findings.

Table 6. Fiber Strength (g/tex) Obtained for Normal and Late Harvest of Different Cotton Varieties and the Coefficients of Variability (CV %) for the Groups Created by the Tukey Test

Parameters	Harvest Periods	Cotton Variety				Mean
		1. Candia	2. Lima	3.St-468	4.Mixture (Candia-St-468)	
Strength	2019 (Normal Harvest period)	33.13a	29.70ab	27.96a	28.23b	29.75
	2018 (Late Harvest Period)	27.90b	30.46ab	29.76ab	30.06ab	29.55
	Mean	30.51	30.08	28.86	29.15	29.65
	CV(%), tukey	CV (%):3.97 tukey (variety): n.s. tukey(harvest period):n.s. tukey (variety x harvest):3.79**				

The difference between the mean in the same letter group are not statistically significant. ns: not significant. *: Important at 5% level of significance; **: Important at 1% level of significance.

Degree of Brightness/Whiteness (Rd):

The effects of variety ($p < 0.01$), harvest time ($p < 0.05$) and cultivar x harvest time interaction ($p < 0.01$) on brightness (Rd) values were statistically significant (Table 7). The lowest brightness values were measured in Candia variety (70.59), while the highest brightness value was recorded in Lima variety (74.70). The lowest brightness value of fibers between harvest times was in late harvest (72.57), and the brightness in normal harvest time was higher (73.73). The fiber brightness value is high, when the fibers reach harvest maturity and are harvested without exposure to rain. The findings of Riley (1961) who reported that late harvest will cause staining on cotton, are similar to our findings. The findings of Silvertooth (1998) that the fiber will become spotted due to contact with the leaves at late harvest, is also consistent with our findings. Our findings are in agreement with the findings of Silvertooth (2001) who stated that fibers fall to the ground in long-term excessive rain and wind, and if the open bolls are exposed to long-term or heavy rain, the cotton will be spotted and the graying and yellowness values will increase. Krieg (2002) reported that weather conditions during harvest have a direct impact on color and foreign matter content. The delay in cotton harvest causes exposing of blooming bolls to adverse weather conditions such as rain and storm, and weather conditions may have a detrimental effect primarily on the fiber foreign matter content and color. Shurley et al. (2004) also reported that the harvest time will affect the fiber color degree, in addition, high relative humidity during harvest will directly affect the moisture content of seed cotton, and high humidity will decrease the harvest efficiency and fiber brightness. Similar to our results, Özbek (2011) determined a direct relationship between fiber brightness and harvest time, and reported that fiber brightness decreases due to rainfall and other environmental factors as the harvest time is delayed. Our results also in agreement with the findings of Dadgar (2020), who reported that the most important parameters determining the cotton quality, such as the yellowness density and fiber color are harvest time, harvest method and storage conditions. Our findings on cotton color change are consistent with the findings of Meredith (1986), who stated that 79% of the variation in fiber color change is caused by environmental factors. The findings of Ayele (2017) stating that cotton is stained with soil contact due to rain or that the leaves of cotton plant will affect the color of cotton fibers are similar to our findings.

Table 7. Degree of Brightness/Whiteness (Rd%) Obtained for Normal and Late Harvest of Different Cotton Varieties and the Coefficients of Variability (CV %) for the Groups Created by the Tukey Test

Parameters	Harvest Periods	Cotton Varieties				Mean
		1. Candia	2. Lima	3.St-468	4.Mixture (Candia-St-468)	
Degree of Brightness/Whiteness	2019 (Normal Harvest period)	71.50bc	73.10b	76.13a	74.10ab	73.73a
	2018 (Late Harvest Period)	69.69c	76.26a	72.50bc	71.80bc	72.57b
	Mean	70.59b	74.70a	74.33a	72.98ab	73.15
	CV(%), tukey	CV(%):1.23 tukey (variety): 2.62** tukey (harvest period): 0.83* tukey (variety*harvest): 2.88**S				

The difference between the mean in the same letter group are not statistically significant. ns: not significant. *: Important at 5% level of significance; **: Important at 1% level of significance.

Yarn Properties

Yarn Unevenness (%):

The effects of cotton variety and the interaction of variety x harvest time on yarn evenness were not statistically significant. However, the evenness of yarns obtained from different cotton varieties at different harvest times was significantly different ($p < 0.01$) (Table 8). The lowest yarn evenness value was recorded in normal harvest time (9.06%), while the highest yarn evenness value was measured in late harvest time (9.24%). Ayele (2017) stated that fiber fineness affects yarn irregularity. Similarly, Kelly et al. (2015) reported that longer, stronger and thinner fibers provide higher spinning. The researchers indicated that the spinning will be excellent when the smoothness of the yarns is high as the speeds in the drafting section will be well controlled, however, the yarn irregularity increases when the short fiber content is high. Higher smoothness of yarns with the transformation of long fibers into yarn confirms our results. The results of this study showed that delay of harvest and exposure of fibers to rain for a long time negatively affected fiber length, strength and fineness properties and increased hairiness.

Table 8. Yarn Unevenness (%) Obtained by Conversion of Fibers to Yarn for Normal and Late Harvest of Different Cotton Varieties, and the Coefficients of Variability (CV %) for the Groups Created by the Tukey Test

Parameters	Harvest Periods	Cotton Varieties				Mean
		1. Candia	2. Lima	3.St-468	4.Mixture (Candia-St-468)	
Yarn Unevenness	2019 (Normal Harvest period)	9.10	9.09	9.05	9.02	9.06b
	2018 (Late Harvest Period)	9.32	9.22	9.19	9.22	9.24a
	Mean	9.21	9.16	9.12	9.12	9.15
	CV(%), tukey	CV(%):0.65 tukey(variety):n.s. tukey(harvest period): 0.04** tukey(variety*harvest):ns				

The difference between the mean in the same letter group are not statistically significant. ns: not significant. *: Important at 5% level of significance; **: Important at 1% level of significance.

Thin Places (-40%):

The thin places (-40%) in different cotton varieties were not significantly different from each other. Similarly, the effect of variety x harvest time on thin places was also not significant. However, the

thin places determined in different harvest time were significantly ($p<0.01$) different from each other (Table 9). The lowest thin places (-40%) value was recorded in normal harvest period (14.51). The highest thin place value was recorded in late harvest period (17.51). The fibers are exposed to rain when harvest time is delayed; thus, irregularities and fluctuations are observed in yarns obtained from the late harvested fibers. Thin and thick places occur in some parts of the thread strip. This is an undesirable situation in the production of yarn and fabric, which is a textile raw material, and negatively affects the quality of final textile products. Thin places in a yarn significantly affect the appearance of woven and knitted fabric. More twisting occurs in thin places. Because, the less fiber in the cross-section causes a decrease in the resistance to spinning. Öktem et al. (1999 and 2001) reported that fiber walls of immature fibers are thinner and more flexible since their secondary cell walls have not yet been completed. The researchers stated that immature cotton has a softer touch and shiny appearance, yet they contain more neps, their strength is low and other yarn quality properties are negatively affected. The findings of Öktem et al. (1999 and 2001) are in accordance with our findings. The findings of Bar (2018) who indicated that thick and thin places affect yarn strength, also support our findings. Kelly et al. (2019) reported that thin and thick places significantly differed between genotypes. Although there was no significant difference between genotypes used in this study, the difference in thin places between harvest times was statistically significant. In contrast to our findings, Uyanık (2019) reported no relationship between thin places and yarn quality characteristics. However, the findings of Mathangadeera et al. (2020) that yarns obtained from low-elongation samples have thin places, which are a type of yarn defect, are similar to our findings. Similar to our results, Long et al. (2021) obtained stronger and more uniform yarns with the finer fibers produced in the first season, whereas weaker and less evenly spun fibers were produced in the second season due to the adverse environmental conditions. Özkan et al. (2021) showed that cotton yarn and other yarns were significantly differed in terms of thin places and reported that the blending ratio had a statistically significant ($p<0.05$) effect on both irregularity and thin place data. The findings of Özkan et al. (2021) on the differences between years were similar to our results.

Table 9. Thin Places (-40%) Obtained by Conversion of Fibers to Yarn for Normal and Late Harvests of Different Cotton Varieties, and the Coefficients of Variability (CV %) for the Groups Created by the Tukey Test

Parameters	Harvest Periods	Cotton Varieties				Mean
		1. Candia	2. Lima	3.St-468	4.Mixture (Candia-St-468)	
Thin Places (-40 %)	2019 (Normal Harvest period)	16.53	14.40	11.93	15.20	14.51b
	2018 (Late Harvest Period)	16.86	20.26	14.93	18.00	17.51a
	Mean	16.70	17.33	13.43	16.60	16.01
	CV(%), tukey	CV(%):10.86 tukey(variety):n.s. tukey(harvest period): 1.63** tukey(variety*harvest): ns				

The difference between the mean in the same letter group are not statistically significant. ns: not significant. *: Important at 5% level of significance; **: Important at 1% level of significance.

Neps+200(%):

The Neps+200 (%) value of yarns obtained from different cotton varieties in different harvest times was significantly different ($p<0.01$) (Table 10). The lowest neps+200 value was obtained in normal harvest period (34.83%), while the highest neps+200 value was recorded in late harvest period (42.40%). High neps+200 value of yarn is not desired for yarn quality. The delay in harvest time causes matured cotton exposing to various environmental factors such as rain, dust, wind and so on. These factors lead to a decrease in the fiber quality properties of cotton and an increase in the neps+200 ratio. The increase in neps ratio of cotton and yarn causes a decrease in many quality parameters. Full maturation does not occur, when cotton fibers are exposed to rain in late harvest. Therefore, the uniformity index and length decrease in immature fibers and the neps ratio increases.

Mangialardi et al. (1987) reported that less defective yarn and fabric in terms of neps will be produced from cotton obtained at the beginning of the harvest season compared to cotton obtained at the end of the harvest season in the same field. The neps not only affect the appearance of cotton yarns and fabric, but also often lead to lower yarn strength, spinning ends down and low uniform yarn production (Van der Sluij and Hunter 2016).

Table 10. Neps+200(%) Obtained by Conversion of Fibers to Yarn for Normal and Late Harvest of Different Cotton Varieties, and the Coefficients of Variability (CV %) for the Groups Created by the Tukey Test

Parameters	Harvest Periods	Cotton varieties				Mean
		1. Candia	2. Lima	3.St-468	4.Mixture (Candia-St-468)	
Neps+200 (%)	2019 (Normal Harvest period)	36.33	36.93	32.86	33.20	34.83b
	2018 (Late Harvest Period)	45.13	42.86	41.60	40.00	42.40a
	Mean	40.73	39.90	37.23	36.60	38.61
	CV(%), tukey	CV (%):7.01 tukey(variety):n.s. tukey (harvest period): 2.53**. Tukey (variety*harvest) :ns				

The difference between the mean in the same letter group are not statistically significant. ns: not significant. *: Important at 5% level of significance; **: Important at 1% level of significance.

Hairiness (Uster H):

The effects of variety and harvest time on yarn hairiness (%) were significantly important ($p < 0.05$). The lowest yarn hairiness value was obtained in normal harvest period (1.50%), while the highest yarn hairiness value was determined in late harvest period (1.62%) (Table 11). The delay in harvest time caused an increase in yarn hairiness. The delay in harvest of the cotton that reaches harvest maturity negatively affects the fiber quality properties. This situation causes various quality problems in yarn, fabric woven from yarn and final textile products. Backe (1996) reported that the fiber length of three cotton blends representing low, medium and high elongation of cotton fiber affects yarn hairiness. Our findings that the fibers lengths obtained in the late harvest are low and the hairiness is high are similar to the findings of Backe (1996). The findings of El Mogahzy and Chewing (2001) that fiber length can affect CV% and hairiness of yarn are similar to our findings that late harvest will affect fiber length and hence hairiness.

Table 11. Yarn Hairiness (%) Obtained by Conversion of Fibers to Yarn for Normal and Late Harvest of Different Cotton Varieties, and the Coefficients of Variability (CV %) for the Groups Created by the Tukey Test

Parameters	Harvest Periods	Cotton Varieties				Mean
		1. Candia	2. Lima	3.St-468	4.Mixture (Candia-St-468)	
Hairiness (%)	2019 (Normal Harvest period)	1.55	1.44	1.57	1.66	1.50b
	2018 (Late Harvest Period)	1.42	1.58	1.83	1.43	1.62a
	Mean	1.48b	1.51b	1.70a	1.55ab	1.56
	CV(%), tukey	CV (%):6.6 tukey(variety):0.17* tukey (harvest period): 0.09*. tukey(variety*harvest):ns				

The difference between the mean in the same letter group are not statistically significant. ns: not significant. *: Important at 5% level of significance; **: Important at 1% level of significance.

386 **Conclusion:**

387 In this study, the fiber and yarn properties of different cotton varieties harvested in normal and late
388 harvest periods were determined. The results revealed that the best fiber fineness for all cotton
389 varieties was recorded in the normal harvest period. The results showed that harvest period has a
390 statistically significant effect on fiber properties.

391 The most important issue in the textile industry is the quality properties of fibers. Because the quality
392 of the final textile products depends on the raw material having the desired qualities. The desired
393 fiber quality properties depend on environmental factors as well as genetic factors. In this study,
394 fiber fineness (3.93), fiber length (29.0 mm), fiber strength (29.75 g/tex) and the brightness (73.73)
395 values were lower in fibers obtained in normal harvest period, while fiber maturity was higher in
396 fibers obtained in late harvest period (0.847). Yarn evenness (9.06%), thin places (14.51%) and
397 hairiness (1.50%) values were lower in fibers obtained in normal harvest period, while the neps
398 value was lower in fibers obtained in normal period (34.83). The results revealed that the quality
399 values of fibers and yarns obtained in the normal harvest period were higher, in contrast the quality
400 properties of fibers obtained in the late harvest period were lower due to adverse weather conditions.

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406 **Conflicts of interest/Competing interests** The author declares no conflict of interest.

407 **Availability of data and material** Data are transparent.

408 **Code availability** Not applicable.

409 **Ethics approval** Not applicable.

410 **Consent to participate** Not applicable.

411 **Consent for publication** Not applicable.

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