棉花种仁含油量与主要经济性状相关分析

郭宝生[1],刘素恩[1],王凯辉[1],耿香利[2],张香云[1],耿军义[1*],赵存鹏[1]

(1. 农业部黄淮海半干旱区棉花生物学与遗传育种重点实验室/河北省农林科学院棉花研究所,河北 石家庄 050051;2. 河北省农林科学院粮油作物研究所,河北 石家庄 050031)

摘要:高油分棉花品种选育成为棉花育种一个新的研究方向,明确陆地棉棉子油分含量与其他主要经济性状的关系对高油品种选育具有重要指导意义。本研究利用 DPS V3.01 数据处理软件分析了 108 份不同种质的种仁油分含量与粗蛋白含量、皮棉产量、衣分、铃重、单株结铃数、纤维长度、比强度及马克隆值和枯萎病病情指数、黄萎病病情指数等主要农艺性状的相关性。研究发现棉花种仁油分含量与棉花的皮棉产量、单株成铃、铃重和衣分主要产量构成性状不存在显著相关;棉花种仁油分与纤维整齐度指数、伸长率呈显著正相关;与纤维上半部平均长度有一定的正相关,但是没有达到统计学意义上的显著水平;与纤维比强度和纤维细度间无相关性;棉花种仁油分与枯萎病抗性有微弱的负相关,与黄萎病抗性不存在相关性。但是棉花种仁蛋白含量与油分含量存在显著负相关。本研究表明育种中提高陆地棉油分含量不会影响其皮棉产量,对抗病性的影响也很微弱,并且对纤维品质的提高有一定的促进作用。因此,在保证棉花枯萎病和黄萎病抗性、皮棉产量和纤维品质的基础上,选育高油分含量的棉花新品种是切实可行的,但选育种仁油分和蛋白质含量均高的品种难度较大。

关键词:相关分析;油分含量;主要经济性状;棉花

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Correlation Analysis of Seed Kernel Oil Content and Major Economic Traits in Cotton (*Gossypium hirsutum* L.)

GUO Bao-sheng[1], LIU Su-en[1], WANG Kai-hui[1], GENG Xiang-li[2], ZHANG Xiang-yun[1], GENG Jun-yi[1*], ZHAO Cun-peng[1]

(1. *Key Laboratory of Cotton Biology and Genetic Breeding in Huanghuaihai Semiarid Area of Ministry of Agriculture, Cotton Research Institute, Hebei Academy of Agriculture and Forestry Sciences, Shijiazhuang* 050051, *China*; 2. *Institute of Cereal and Crops, Hebei Academy of Agriculture and Forestry Sciences, Shijiazhuang* 050031, *China*)

Abstract: One of the new directions in cotton breeding is to develop varieties with high oil content. In this study, we analyzed the relationships between the oil content of cottonseed kernels and other selected major economic traits of cotton. We used the DPS V3.01 data processing system to calculate linear correlation coefficients using experimental data for cottonseed oil content and other agronomic characteristics obtained from 108 cotton lines. There were no significant correlations between oil content and lint yield, boll numbers per plant, boll weight, and lint percentage. There were significant positive correlations between oil content and fiber uniformity, and oil content and elongation. The positive correlation between oil content and the fiber upper half mean length was not statistically significant. There were no significant correlations between oil content and fiber strength or fiber fineness. Oil content was weakly negatively correlated with Fusarium wilt resistance, but showed no correlation with Verticillium wilt resistance. The results of this study indicated that improvement of the oil content of cottonseed kernels will not affect lint production, and only weakly affect disease resistance. The results further indicated that such improvement may improve the fiber quality to some extent. Cottonseed kernel protein content and oil content were significantly negatively correlated. The findings indicated that it will be feasible to produce new varieties with high oil contents combined with good disease resistance, high

Date received: 2013-01-17　**Author:** Guo Bao-sheng (1971-), male, doctoral student, associate research fellow, guobaosheng111@126.com; *Corresponding author, Geng Jun-yi, male, research fellow, gengjunyi66@126.com;

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lint yield, and better fiber quality. However, it will be very difficult to breed new varieties with both high oil and high protein content.

Key words: correlation analysis; oil content; major economic traits; cotton
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Cotton plays a major role in the world economy. Although cotton is grown mainly for fiber, the seeds are also important sources of vegetable oil and protein[1], and the plant can supply biomass resources for energy production. In China, 10 million tons of cottonseed are produced each year. Recently, several research institutions have studied the production of biodiesel from cottonseed oil[2-4]. The cultivation of new high-oil cotton varieties in which lint yield and fiber quality are not sacrificed for oil yield can resolve the land-use conflicts caused by the need to produce both cotton and oil crops.

Beginning in the 1970s, Turner et al[5] analyzed the relationships among yield, seed quality, and fiber properties in upland cotton. Some researchers[6-8] conducted surveys of the *Gossypium hirsutum* L. germplasm collections to analyze seed oil and protein percentage, and seed characteristics. There have been some genetic analyses of seed quality characteristics in upland cotton[9-10], and the effects of environmental conditions on cottonseed composition have been evaluated[5, 11]. With the development of molecular biology, some researchers have used new techniques to improve the nutritional quality of cottonseed[12-14].

Most research performed to date has shown that the quality characteristics of cottonseed are inherited as quantitative traits, and that these traits are controlled by quantitative genes. However, these previous studies have used different experimental methods and materials. Some studies[10, 15-16] demonstrated that cottonseed protein and oil content are mainly controlled by dominant gene effects. Others[9,17] reported that there were significant additive genetic effects and dominance effects for cottonseed oil content. However, Boghara[6] found that cottonseed oil content was controlled by non-additive genetic effects. Danir and Ye[18-19] reported maternal and epistatic effects for cottonseed oil content. These diverse results highlight the complexity of the inheritance of cottonseed quality characteristics. Pleiotropy and linkage cause genetic correlations among two or more traits. If genetic correlations are high, selection for one trait will simultaneously change other traits. Therefore, for any attempt to improve cottonseed quality the correlations among cottonseed quality factors(e.g., between oil and protein content) and the correlations among these qualities and other characteristics must be taken into account. Based on a diverse range of experimental materials, it has been established that there is a significant negative correlation between cottonseed oil content and protein content. The studies that established this correlation examined various species and cultivars: *G. hirsutum* and *Gossypium barbadense*[13], gossypol and glandless[16-17], and native varieties[20].

Because the experimental materials, the research methods, and environmental factors have not been consistent in previous studies, the conclusions of these studies about the correlations between cottonseed oil and various agronomic traits have not been completely unanimous. Wang et al[21] found no significant covariances among cotton yield per plant, kernel quality, and seed physical traits. This finding is consistent with other results[5, 22], all of which showed that there is no simple correlation between seed cotton yield and oil or protein content. Wang et al. also reported a correlation between oil content and boll number per plant. The same study demonstrated positive cytoplasmic and maternal relationships between lint percentage and protein content. However, there was no correlation between lint percentage and oil content. Some studies[5, 23-24] have reported a significant negative correlation between fiber properties and cottonseed protein content, but only a small positive correlation between fiber properties and cottonseed oil content.

The past 40 years have seen the emergence of new breeding technologies and methods, and the improvement of cotton germplasm resources. The use of interspecific introgression to introduce desirable genes through distant hybridization has produced many new varieties and lines. Improved yield parameters, fiber properties, and stress resistance have been bred into these plants[25]. To further improve cotton varieties, it will be necessary to conduct systematic research on the correlations between the oil content of cottonseed kernels and major economic traits (yield parameters, fiber properties, and stress resistance). The objectives of this study were to determine the correlations between the oil content of cottonseed kernels and these traits. We investigated lint yield, fiber properties, boll weight, lint percentage, and disease resistance for 108 new, distant-genetic-background, bollworm-resistant cotton lines. This information will be useful in breeding programs that aim to improve the cottonseed oil content without affecting yield or fiber quality.

1 Materials and Methods

In total, 108 cotton lines were planted in a field at the Xiaoanshe Experiment Station of the Cotton Research Institute, Hebei Academy of Agriculture and Forestry Sciences, Shijiazhuang, during the 2009 and 2010 growing seasons. The lines used in this study were upland cotton varieties improved by our institute. The lines included interspecifically introgressed lines[25-26] selected for more than eight generations from different cross-combinations (bollworm-resistant cotton lines × distant hybridization offspring from *G. hirsutum*, *G. barbadense*, and *G. thurberi*).

The crops were managed with conventional cultural practices (weed and insect control, fertilization, and supplemental irrigation) used in typical cotton performance tests at this field location. The 108 lines were planted with three replications in a randomized complete block design. Within each replication, the plots contained three rows (each 0.7 m × 7.15 m). The seeds were planted on 22 April 2009 and 28 April 2010. The investigations and statistical measurements to calculate the Fusarium wilt index were performed on 20 June. The Verticillium wilt index was measured on 20 August and the number of bolls per plant was counted on 10 September. At harvest, 50 bolls from each plot were sampled by hand to determine boll weight and lint percentage. The samples were ginned separately using a laboratory roller gin. The seed cotton weight of the plots was measured and recorded individually. The total seed cotton weight of each plot was calculated as the sum of the seed cotton weight of the sampled bolls and the remaining bolls in that plot. The lint yield per plot was calculated by multiplying the seed cotton weight per plot by the lint percentage. The 108 lint samples were submitted to the Cotton Quality Supervision, Testing and Inspection Centre of the Ministry of Agriculture in China for fiber quality analysis. Fiber properties were measured separately using Premier HFT9000 high-volume fiber tester made in India.

The protein content of the seed kernel samples was determined by an automated micro-Kjeldahl analysis using a 0.2000-g sample per analysis. The nitrogen values were multiplied by 6.25 to obtain the protein content value. Protein content was expressed as a percentage of the total weight of the seed kernel. Oil was analyzed by the Soxlet extraction method[27] with an 8-g seed kernel sample. All analyses were conducted using three replications.

The correlations between the oil percentage of the seed kernels and other major economic traits (protein percentage, lint yield, lint percentage, boll weight, bolls per plant, fiber properties, and disease index) were analyzed with a linear regression model using the DPS V3.01 data processing system[28].

2 Results and Discussion

The range, average, and coefficient of variation of all the major economic traits for the 108 lines are shown in Table 1. There was a wide range and considerable variation among the 108 test lines in the values of these parameters, especially in lint yield and bolls per plant, as well as in other parameters. The amount of variation often exceeded 10%. The genetic diversity of the test lines appeared to be ample; therefore, the experimental data represented a wide range of variation.

Table 1 Range, average, and coefficient of variation of all major economic traits for 108 cotton lines

Trait	Range	$\bar{X}\pm S$	Coefficient of variation
Seed fatty acid content /%	23.93~36.96	31.00±2.6	8.38
Seed total protein content /%	42.41~49.24	45.76±1.55	3.39
Lint yield /(kg·hm^{-2})	615.6~1169.7	873.3±135.5	15.51
Lint /%	22.46~47.57	39.9±3.34	8.37
Boll weight /g	4.96~7.84	6.28±0.65	10.35
No. of bolls per plant	6.55~15.35	11.04±1.50	13.59
Fiber upper half mean length /mm	25.14~35.26	29.43±2.09	7.10
Fiber strength /(cN·tex^{-1})	22.1~35.1	27.96±3.10	11.09
Micronaire	3.89~6.67	5.36±0.60	11.19
Uniformity /%	82.3~87.7	84.73±1.31	1.55
Elongation /%	6.0~6.6	6.34±0.14	2.2
Fusarium wilt index	1.86~18.36	7.34±3.56	48.5
Verticillium wilt index	18.62~34.11	26.34±4.30	16.32

The relationship between the oil content and protein content of the cottonseed kernels was described by the linear regression $y = -1.2025x + 79.537$. The correlation coefficient of oil content and protein content was $r = -0.814^{**}$. These results indicated that the amount of oil in cottonseed kernels was significantly negatively correlated with the amount of protein, consistent with most previous reports[8, 11, 13, 20, 29]. This relationship indicates that the metabolic conditions that favor an increase in oil content are at the expense of an increase in protein content; that is, the protein and oil biosynthetic pathways are competitive. Therefore, it will be difficult to breed simultaneously for high oil content and high protein content in cottonseed.

Next, we analyzed the relationships between oil content and yield parameters. This analysis revealed some linear correlation coefficients (Table 2). There were no significant correlations between the oil content of the cottonseed kernels and cotton lint yield, lint percentage, boll weight, or the number of bolls per plant. These results are consistent with previous findings[5, 21-22]. Therefore, there is no simple correlation between seed cotton yield and oil content. These findings differ from those reported by Zhou[24] and Guo[29]. Zhou[24] reported significant positive correlations between oil percentage and four traits: bolls per plant, boll weight, lint index, and lint yield per plant (the correlation coefficients were 0.2097, 0.2072, 0.1589, and 0.1742, respectively). These results suggested that an increase in oil content would favor increased yield. However, Guo[29] reported a significant negative correlation between oil percentage and lint percentage. The discrepancies among these results may be because of differences in the test materials used, population size, and/or the genetic diversity of the experimental materials. Overall, the correlation between seed cotton yield and oil content is positive but not significant. Therefore, it would be practical to breed for a high oil percentage and still maintain high yield.

Table 2　Correlations between oil content of cottonseed kernels and yield parameters

Trait	Regression equation	Correlation coefficient
Lint yield	y = 1.3185x + 828.59	r = 0.01
Lint percentage	y = 0.1417x + 38.753	r = 0.061
Boll weight	y = 0.0534x + 4.5388	r = 0.075
Boll numbers per plant	y = 0.0249x + 10.23	r =0.02

There was no significant correlation between kernel oil content and fiber strength or fiber fineness (Table 3). A positive but non-significant correlation was found between kernel oil content and the fiber upper half mean length. Kernel oil content was positively and significantly correlated with fiber uniformity and elongation. This finding is consistent with some previous results[5, 24], but differs slightly from the results reported by Wang et al[23] and Zhou et al[30], although the trend is consistent with their results. Zhou et al[30] reported correlation coefficients of 0.361, 0.302, 0.078, 0.542, and 0.743 between the oil content of cottonseed and the following fiber properties: 2.5% span length, uniformity, strength, elongation, and micronaire, respectively. Wang et al[23] analyzed the correlations among yield, fiber properties, and seed quality in glandless cotton, and found a significant negative correlation between the main fiber quality traits and protein content. A positive but non-significant correlation was found between the main fiber quality traits and oil content. It should be noted that the cottonseed can be viewed as a special organ of the plant. The developing cottonseed is also the location of cotton fiber development. This dual role makes the cottonseed a current focus of research on the links between seed kernel development and cotton fiber development. Qin et al[31] found that the long-chain saturated fatty acids in the kernel can increase ethylene production, and subsequently promote fiber elongation. In the present study, we also found some positive correlations between kernel oil content and the fiber upper half mean length, but these correlations were not statistically significant. Overall, there was a positive correlation between kernel oil content and fiber length, no correlation between kernel oil content and fiber strength or micronaire, and significant positive correlations between kernel oil content and fiber uniformity and elongation. It follows that increases in kernel oil content will not negatively affect fiber quality but will have a certain positive effect. However, different studies have reached different or even conflicting conclusions. Guo[29] found that seed oil content was significantly negatively correlated with fiber uniformity and fiber upper half mean length. These conflicting results may be because of differences in the number of materials analyzed, in their genetic diversity, in their population size, or because of different statistical analysis methods.

Table 3　Correlations between oil content of cottonseed kernels and some fiber properties

Trait	Regression equation	Correlation coefficient
Fiber upper half mean length	y = 0.2322x + 22.544	r = 0.188
Fiber strength	y = 0.1519x + 23.692	r = 0.079
Micronaire	y = -0.0366x + 6.2712	r = -0.061
Uniformity	y = 0.5257x + 67.208	r =0.524*
Elongation	y = 0.0613x + 4.3018	r =0.551*

We analyzed the correlation between kernel oil content and disease indices (Table 4) and found that there was weakly negative correlation between kernel oil content and Fusarium wilt index, and no correlation between kernel oil content and Verticillium wilt index.

Table 4 Correlations between oil content of cottonseed kernels and disease indices

Trait	Regression equation	Correlation coefficient
Fusarium wilt index	y = 0.6649x - 15.227	r =0.197
Verticillium wilt index	y = 0.0584x + 24.356	r =0.014

We selected three high-oil lines and one low-oil line (Table 5). These specially selected materials with single or double desirable traits could be used in further genetic research and modern breeding of new cotton varieties with improved characteristics.

Table 5 Characteristics of three high-oil and one low-oil cotton lines

Name	Combinations	Seed fatty acid content /%	Lint percentage /%	Boll weight /g	Fiber length /mm	Fiber strength /(cN·tex^{-1})	Micronaire
JiN 71	(Ji 9119 × 9658) × 95-538	36.96	36.6	5.9	33.42	33.3	5.27
Ji 7160	(8919 × 33) F_4 × 9658	36.42	39.8	6.4	30.50	33.7	5.45
Jiyou 3	02N59 × Ji298	36.10	37.74	5.6	31.70	29.3	4.94
Ji 2286	Han682 × new Bt cotton	23.93	40.5	5.4	27.95	25	5.40

3 Conclusions

The comprehensive analyses in this study and other studies indicate that there is no significant correlation between cottonseed kernel oil content and cotton lint yield, bolls per plant, boll weight, or lint percentage. Our results showed significant positive correlations between kernel oil content and fiber uniformity, and between kernel oil content and elongation. Positive but non-significant correlations were found between kernel oil content and fiber upper half mean length. Kernel oil content was not significantly correlated with fiber strength or fiber fineness. Kernel oil content was weakly correlated with Fusarium wilt resistance, but not correlated with Verticillium wilt resistance. These results indicated that improvement of the kernel oil content will not affect lint production and will only weakly affect disease resistance. Improvement of kernel oil content may tend to improve fiber quality. Cottonseed kernel protein content and oil content were significantly negatively correlated; therefore, if the oil content of cottonseed is increased, then the protein content will decrease. The findings related to Fusarium and Verticillium wilt resistance, lint yield, and fiber quality indicated that it will be feasible to breed new varieties with high oil content coupled with good disease resistance, high lint yield, and high-quality fiber. This represents a new direction in cotton breeding. However, it will be very difficult to breed new varieties that have both high oil and protein content in the kernels.

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