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Climatic Influence on Seed Oil Concentration in Soybean(*Glycine max*)

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기상요인이 대두의 지방함량에 미치는 영향

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ABSTRACT

This study was carried out to identify how soybean seed oil is influenced by climatic factors and to investigate how genotypes differ in their responses. Twelve lines selected were studied in 13 environments of North Carolina. Responses of oil concentration and total seed oil to climatic variables were investigated using a linear regression model. The best response models were determined. There were wide climatic effects in oil concentration and total seed oil. The lowest oil concentration environment was characterized by the most HTD and the smallest VADTRg and the lowest total oil environment was distinguished by the largest VADTRa and the smallest VMnDT. For oil concentration, most lines except for NC107 responded negatively to MxDT, HTD, ADT, and ADTRg, although they had different degrees of sensitivities, indicating that warmer temperature may result in decreased oil concentration. All lines responded positively to VMnDT, VADTRg, and ADRa, although they had different degrees of sensitivities, suggesting that larger variation in minimum daily temperature and average daily temperature range and more average daily rain may result in increased oil concentration. Eleven lines had best response models with 1 to 3 variables. However, although NC109 did not show a significant sensitivity to any variable, it had the best response model with 2 significant variables, demonstrating that an interaction between 2 variables might be more critical in determining oil concentration than one variable.

Key word : soybean, seed oil concentration, climatic variables, linear response, best response model.

INTRODUCTION

Cropping environments are characterized by differences n soil and climatic conditions. These can vary considerably n Eastern North Carolina where most soybeans are grown. This variation in environment may stimulate physiological and biochemical processes which in turn affect growth and grain productivity or quality in soybean crops. Climatic factors are likely to be major influences on seed growth and development at maturity. The effects have been investigated in research programs on economically important traits in crop species.

Carls(1984) found that seven soybean varieties grown in warmer environments were characterized by having higher oil concentration. Weiss et al.(1952) showed a significant positive correlation between mean temperature and oil concentration in 5 soybean varieties at maturity. Howell and Cartter(1966) indicated that temperatures for periods 20 to 30 and 30 to 40 days before maturity may have a greater effect on oil concentration than those at other periods. However Viljoen(1937)' s study, where there were wide variations in rainfall at the different locations ranging from 1.88 to 25.67 inch, indicated that there was no correlation between maximum temperature and oil concentration and a highly significant correlation between minimum temperature and oil concentration and between mean temperature and oil concentration in soybean at maturity. In four varieties of flax, Dillan and Hoffer(1943) found correlations between oil concentration and July temperatures at nonirrigated and irrigated stations. For the nonirrigated stations, the correlation coefficients of oil concentration with average maximum, average minimum, and average mean temperatures were significantly negative at .01 probability level for all four varieties. For the irrigated stations, the correlation coefficients between oil concentration and average minimum temperature and between oil concentration and average mean temperatures were negative for only two varieties.

Although soybean is a major source of edible oil, there have been a few studies on environmental influence on seed oil concentration. It is important to know how environment affects seed oil, because predictable oil concentration in soybean seeds produced in different environments might be an essential characteristic of new cultivars, should seed oil concentration become a factor in determining the price of a soybean crop. This study was conducted to investigate how seed oil concentration and total seed oil in soybean are influenced by temperature and rainfall, and to determine if genotypes differ in their sensitivities.

MATERIALS & METHODS

Materials and Procedures

Twelve lines of soybean (NC101 to NC112) derived from a recurrent selection program were developed by the USDA-ARS in cooperation with the North Carolina Agricultural Research Service. These lines were used for this study because they are similar in maturity(Group 6 and 7) and different in genetic background.

The lines were planted at three locations in North Carolina in 1988 and at five locations in North Carolina in 1989 and 1990. A randomized complete block design was used with two replications in 1988 and three replications in 1989 and 1990. Each 10' plot consisted of 3 rows and all plants in the middle row of each 3-row plot were harvested in bulk. A 30 gram random sample from each plot were analyzed for seed oil concentration using an infrared grain quality analyzer at the Northern Regional Research Center, Peoria, Illinois. Total seed oil(Kg/ha) were calculated as oil concentration multiplied by seed yield(Kg/ha) and divided by 100.

Several modified environmental variables were used in order to investigate the way temperature and rainfall affect seed oil concentration. Temperature and rainfall data of September and October in 1988, 1989, and 1990 were collected from the office of the North Carolina Climate Program for each environment where the tests were grown. The climatic variables derived from the temperature and rainfall data were based on daily recordings during the seed filling period from R5 to the harvest and modified as follows : average maximum daily temperature(MxDT), average minimum daily temperature(MnDT), and average daily temperature(ADT), variance of MxDT(VMxDT), variance of MnDT(VMnDT), average daily temperature range(ADTRg) which is the difference between MxDT and MnDT, variance of ADTRg(VADTRg), degree of high temperature(DHT) which is a sum of positive deviation from average maximum daily temperature, high temperature days(HTD) which is the number of days above average maximum daily temperature, average daily rainfall(ADRa), and variance of ADRa (VADRa).

Statistical Methods of Analysis

An analysis for seed oil concentration and total seed oil were performed using the SAS programs, Proc GLM and Proc REG(SAS Institute, 1987). A linear regression model, where each environmental mean of oil concentration and total seed oil was regressed on each climatic variable, was used to determine sensitivity of each line to each climatic variable.

Table 1. Mean climatic variables, mean oil concentration(%) and total seed oil(kg/ha) over 13 environments of North Carolina.

Variables*	E1+	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13
HTD (days)	24	23	20	31	30	29	36	33	39	41	35	46	41
MxDT (°C)	24.5	24.3	23.6	26.9	26.3	25.6	27.1	26.2	27.0	27.5	27.1	28.2	27.4
MnDT (°C)	13.5	11.8	10.3	15.6	15.0	12.4	14.3	13.4	14.1	13.9	13.2	14.4	13.2
ADTRg (°C)	11.0	12.4	13.2	11.3	11.3	13.2	12.8	12.7	12.9	13.6	13.9	13.9	14.3
VMxDT	29.8	20.5	25.4	25.8	18.0	24.4	15.9	21.6	20.5	20.3	25.8	16.1	22.6
VMnDT	37.5	38.8	47.2	35.4	31.9	29.7	37.2	41.4	28.7	29.4	28.4	32.1	34.2
VADTRg	13.7	15.3	23.6	11.6	15.2	12.6	17.9	16.3	10.4	15.9	11.3	10.2	12.2
ADRa(mm)	3.1	2.8	4.5	3.6	6.4	3.7	3.6	4.2	2.2	2.2	4.8	3.0	3.7
VADRa	55	43	177	91	259	110	113	117	72	57	302	148	158
Oil	17.8	17.2	18.7	18.2	18.5	17.7	18.8	18.3	16.0	16.9	15.9	15.7	17.2
Total Oil	727	669	215	654	601	422	284	791	544	731	132	300	372

+: E1 to E13 : Clayton(1988), Plymouth(1988), Sandhills(1988), Clayton(1989), Plymouth (1989), Sandhills(1989), Kinston(1989), Clinton(1989), Clayton(1990), Plymouth(1990), Sandhills(1990), Kinston(1990), and Clinton(1990).

* : Variables:HTD, number of days above average maximum daily temperature;MxDT, average maximum daily temperature;MnDT, average minimum daily temperature;ADTRg, average daily temperature range;VMxDT, variance of maximum daily temperature;VMnDT, variance of minimum daily temperature VADTRg, variance of average daily temperature range;ADRa, average daily rainfall;VADRa, variance of average daily rainfall.

Two stepwise selection methods, 'Maximum R-square' and 'Stepwise Selection' of the STEPWISE procedure(SAS Institute, 1987) were performed to determine the best response model, using a multiple regression method which includes all modified climatic variables on which each environmental mean of protein concentration was regressed. The stepwise selection methods have criteria for terminating the processes, which are called 'stopping rules'. The stopping rules are 'SLE' (significance level to enter) and 'SLS' (significance level to stay), where the significance levels are F-tests of partial sums of squares of variables in a model. The choice of the two criteria, SLE and SLS, have a great impact in determining the best response model. Bendel and Afini(1977) suggested that the optimum SLE varies between 0.15 and 0.25. Also, they recommended SLE of 0.25, and SLS of 0.125 for the stepwise selection. Therefore, several levels of SLE and SLS, which are based on Bendel' s suggestion, were applied with a multiple regression in order to find the best response models for seed oil concentration with independent climatic variables.

RESULTS & DISCUSSION

There were wide variations in temperature and rainfall over 13 environments of North Carolina(Table 1). The lowest oil concentration environment was characterized by the most HTD(46 days) and the smallest VADTRg(Table 1). Thus, more high temperature days and less variation in average daily temperature range appeared to decrease oil concentration during soybean seed maturity. The lowest total seed oil environment was distinguished by the smallest VMnDT and the largest VADRa(Table 1). Thus, smaller variation in minimum daily temperature and larger variation in average daily rain seemed to decrease oil synthesis during seed maturity.

Linear Response of Oil Concentration

Most lines responded negatively to variables associated

Table 2. Linear response of 12 lines when each of environmental oil concentration is regressed on each of climatic variables.

Lines	Climatic Variables#						
	MxDT	ADT	HTD	ADTRg	VMnDT	VADTRg	ADRa
NC101	-.36(.3)+	-.17(.3)	-.08(.1)	-.76*(.3)	.13(.1)	.22(.1)	.42(.4)
NC102	-.16(.2)	-.06(.2)	-.05(.0)	-.39(.3)	.10*(.1)	.15(.1)	.51(.2)
NC103	-.26(.2)	-.15(.3)	-.07(.0)	-.46(.3)	.06(.1)	.14(.1)	.72**(.2)
NC104	-.81**(.3)	--.73*(.3)	-.16**(.0)	-.68(.4)	.19*(.1)	.32**(.1)	.32(.4)
NC105	-.29(.2)	-.17(.2)	-.06(.0)	-.54(.3)	.08(.1)	.13(.1)	.20(.3)
NC106	-.24(.2)	-.10(.3)	-.06(.0)	-.57*(.3)	.04(.1)	.08(.1)	.22(.3)
NC107	.06(.2)	.11(.2)	-.01(.0)	-.11(.2)	.01(.0)	.03(.1)	.59**(.1)
NC108	-.23(.2)	-.13(.2)	-.05(.0)	-.42(.3)	.11*(.0)	.17*(.1)	.34(.2)
NC109	-.21(.3)	-.03(.3)	-.06(.1)	-.65(.3)	.12(.1)	.20(.1)	.59(.3)
NC110	-.38(.2)	-.30(.3)	-.08(.0)	-.47(.3)	.12*(.1)	.26**(.1)	.46(.3)
NC111	-.57*(.2)	-.50(.3)	-.11(.0)	-.50(.3)	.18**(.0)	.26*(.1)	.10(.4)
NC112	-1.01**(.2)	-1.00**(.3)	-.19**(.0)	-.60(.4)	-.25**(.0)	.36**(.1)	.45(.4)

: MxDT, average maximum daily temperature; ADT, average daily temperature; HTD, high temperature days which is the number of days above average maximum daily temperature ; ADTRg, average daily temperature range; VMnDT, variance of maximum daily temperature; VADTRg, variance of average daily temperature range; ADRa, average daily rainfall.

*, ** : Significantly different at the 0.05 and 0.01 probability levels, respectively.

+ : Standard errors of regression coefficients in a linear model.

with temperature(MxDT, HTD, ADT, and ADTRg)(Table 2). Among the lines, three(NC104, NC111, and NC112), two(NC104 and NC112), three(NC104, NC111, and NC112), and two(NC101 and NC106) showed significant sensitivities to MxDT, ADT, HTD, and ADTRg, respectively(Table 2). These suggest that warmer temperature may result in decreased oil concentration during seed maturity. However, NC107 responded just positively to MnDT and ADT(Table 2).

All lines responded positively to variables associated with variation in temperature(VMnDT and VADTRg)(Table 2). Among the lines, six(NC102, NC104, NC108, NC110, NC111, and NC112) and six (NC101, NC104, NC108, NC110, NC111, and NC112) showed significant sensitivities to VMnDT and VADTRg, respectively(Table 2). This suggests that larger variation in minimum daily temperature and average daily temperature range may produce increased oil concentration during seed maturity.

All lines responded positively to average daily rainfall(ADRa). Among the lines, two(NC103 and NC107) were significantly sensitive to ADRa(Table 2). This suggests that, with more daily rainfall during seed maturity, oil concentration tends to increase.

Using linear responses to each of HTD, ADTRg, VADTRg, VMnDT, and ADRa as a criterion, the twelve lines were classified into 2 groups, sensitive or not(Table 3). Based on HTD, the lines, NC104, NC111, and NC112 are sensitive and the others not. Based on ADTRg, the lines, NC101 and NC106 are sensitive and the others not. Based on VADTRg, the lines, NC101, NC104, NC108, NC110, NC111, and NC112 are sensitive and the others not. Based on VMnDT, the lines, NC102, NC104, NC108, NC110, NC111, and NC112 are sensitive and the others not. Based on ADRa, the lines, NC103 and NC107 are sensitive and the others not(Table 3). However, NC105 and NC109 was not significantly sensitive to all the climatic

Table 3. Linear sensitivity of soybean oil concentration to climatic variables.

Climatic Variables*	Oil Concentration Sensitivity	
	Sensitive[+]	No response
HTD	N4, N11, N12[$]	N1, N2, N3, N5, N6, N7, N8, N9, N10
ADTrg	N1, N6	N2, N3, N4, N5, N7, N8, N9, N10, N11, N12
VADTRg	N1, N4, N8, N10, N11, N12	N2, N3, N5, N6, N7, N9
VMnDT	N2, N4, N8, N10, N11, N12	N1, N3, N5, N6, N7, N9,
ADRa	N3, N7	N1, N2, N4, N5, N6, N8, N9, N10, N11, N12

* : HTD, high temperature days which is the number of days above average maximum daily temperature; ADTRg, average daily temperature range ; VADTRg, variance of average daily temperature range; VMnDT, variance of minimum daily temperature; ADRa, average daily rainfall.
$: N1- N12 ; NC101, NC102, NC103, NC104, NC105, NC106, NC107, NC108, NC109, NC110, NC111, NC112
+ : Significant in linear responses.

Table 4. Linear response of 12 lines when environmental total seed oil(g/ha) is regressed on each of climatic variables.

Lines	Total Seed Oil	
	VADRa#	ADTRg
NC101	-5.57*(1.90)[+]	-269(169)
NC102	-5.27*(1.77)	-298(150)
NC103	-4.11*(1.80)	-229(146)
NC104	-5.68**(1.80)	-287(161)
NC105	-5.54*(1.77)	-289(157)
NC106	-4.49*(2.01)	-311(151)
NC107	-3.33(1.53)	-185(122)
NC108	-4.55*(2.01)	-329*(149)
NC109	-4.25*(1.43)	-151(133)
NC110	-5.23**(1.60)	-257(146)
NC111	-5.54*(2.01)	-357*(160)
NC112	-5.13*(2.21)	-288(180)

: VADRa, variance of average daily rainfall ; ADTRg, average daily temperature range.
*, **:Significantly different at the 0.05 and 0.01 probability levels, respectively.
+: Standard errors of regression coefficients in a linear model.

/ariables(Table 2 and 3). By this standard, this line nay be considered phenotypically more stable in oil :oncentration over environments and the others less stable.

Linear Response of Total Seed Oil

All lines showed negative responses to both VADRa and ADTRg (Table 4). The extent to which they respond to each of the two variables appeared to differ. Eight lines(NC101, NC102, NC104, NC105, NC109, NC110, NC111, and NC112) and seven lines(NC102, NC104, NC105, NC106, NC108, NC111, and NC112) were significantly sensitive to VADRa and ADTRg, respectively. This suggests that oil synthesis may increase with smaller variation in average daily rainfall, i.e., continuous supply of water and with less average daily temperature range. However, NC103 and NC107 did not show significant sensitivities to any variables and thus seemed to be phenotypically more stable in total seed oil.

Best Response Models for Seed Oil concentration

Best response models of a multiple regression included the most significant variables in a linear model(Table 2 and 5). Determination coefficients ranged from 44 to 78, which explains how much protein concentration of a given line vary with changing climatic variables. Nine lines(NC101, NC102, NC103, NC104, NC105, NC109 NC110, NC111 and NC112) appeared to have 2 variables NC102 appeared to have three variables and NC106 seeme to have one variable(Table 5). However, although botl NC105 and NC109 did not show significant sensitivitie to any variable, NC109 had the best response mode with 2 variables, MnDT and VADTRg, but NC105 did not This suggests that NC105 may be considered phenotypicall more stable over environments, and that NC109 may b more affected by an interaction between the 2 climati variables than each of them.

Carls(1984) found that seven soybean varietie grown in warmer environments were characterized by having higher oil concentration. Weiss et al.(1952) showed a significant positive correlation between mean temperature and oil concentration in five soybean varieties at maturity. Howell and Cartter(1966) indicated that temperatures for periods 20 to 30 and 30 to 40 days before maturity may

Table 5. The best response models of twelve lines for oil concentration.

Lines	Climatic Variables#								R^{2+}
	MnDT	ADTRg	HTD	DHT	VMnDT	VADTRg	ADRa	VADRa	
NC101		-.71*				.21*			.61
NC102	.34				.14*		.40*		.68
NC103							1.38**	-.01**	.76
NC104			-.10*			.20			.69
NC105									
NC106		-.57*							.33
NC107				.01			.62*		.82
NC108	.39*					.25**			.61
NC109	.68*					.34**			.62
NC110	.39*					.34**			.80
NC111						.27**		-.01	.68
NC112			-.12**			.15**			.89

: MnDT, average minimum daily temperature ; ADTRg, average daily temperature range ; HTD, high temperature days which is the number of days above average maximum daily temperature ; DHT, degree of high temperature which is a sum of positive deviation from average maximum daily temperature ; VMnDT, variance of minimum daily temperature ; VADTRg, variance of daily temperature range ; ADRa, average daily rainfall ; VADRa, variance of average daily rainfall.

*, ** : where partial sums of squares in the best response models are significantly different at the 0.05 and 0.01 probability levels, respecticely.

+ : Determination coefficients.

have a greater effect on oil concentration than those at other periods.

However, Viljoen(1937), whose study there were wide variations in rainfall at the different locations ranging from 1.88 to 25.67 inch, indicated that there was no correlation between maximum temperature and oil concentration and a highly significant correlation between minimum temperature and oil concentration and between mean temperature and oil concentration in soybean at maturity. In four varieties of flax, Dillan and Hoffer(1943) found correlations between oil concentration and July temperatures at nonirrigated and irrigated stations. For the nonirrigated stations, the correlation coefficients between oil concentration and average maximum, average minimum, and average mean temperatures were significantly negative at .01 probability level for all four varieties. This result is consistent with the result of our study. However, for the irrigated stations, the correlation coefficients between oil concentration and average minimum and average mean temperatures were negative for only two varieties. Therefore, the different results may implicate genotypic differences in responses to each climatic factor.

Soybean oil is known to be composed of three major fatty acids, oleic, linoleic, and linolenic acids. The complex composition of soybean seeds may make it more difficult to investigate how environments affect oil concentration at seed maturity. Therefore, more research work is still needed to get information about an environmental influence on seed oil concentration as well as each of the three fatty acids in soybean.

적 요

본 연구는 콩계통들의 지방함량이 서로 다른 기상요인에 어떻게 영향을 받는 지를 규명하기 위해 미국 노스캐롤라이나지방의 5개 지역에서 3년에 걸쳐 수행되었다. 각 계통의 지방함량 및 지방수량들의 기상요인에 대한 Linear response가 조사되었고, 또한 최적기상 반응모델을 결정하기 위해 Stepwise Selection Program이 사용되었다. 콩지방함량, 지방수량은 기상요인인 온도와 강우량에 의해 크게 영향을 받았으며 성숙시기에 온도가 가장 높고, 최고최저 온도범위가 가장 작은 환경에서 지방함량이 가장 낮게 나타났고, 최저온도 변이가 가장 작고 강우량변이가 가장 큰 환경에서 지방수량이 가장 높게 나타났다. 계통들의 대부분은 지방함량이 MxDT, HTD, ADT, ADTRg 에 반비례하는 경향을 나타내었으며 이는 성숙시기에 온도가 높아질수록 지방함량이 감소한다는 것을 의미한다. 그러나 NC107은 MxDT, ADT에 비례하는 경향을 보였다. 모든 계통들이 VMnDT, VADTRg, ADRa 에 비례하는 경향을 나타내었고 이는 최저온도와 최고최저 온도범위의 변이가 클수록, 평균강우량이 많을수록 지방함량은 증가한다는 것을 의미한다. 11계통이 1개 내지 3개의 기상변수를 가지는 최적기상모델을 형성하였다. 그러나 NC109와 NC105는 모든 기상변수에 유의한 Linear 반응을 나타내지는 않았으나 전자는 2개의 기상변수를 가지는 최적기상모델을 형성하였고 후자는 가지지 않았다. 이는 NC109는 지방함량이 아마도 기상변수 하나에 의한 영향보다도 2개 변수의 상호작용에 의한 영향이 큰 것으로 추측할 수 있고, NC105 는 지방함량이 기상환경에 상대적으로 더 안정하기 때문인 것으로 생각된다. 위와 같은 사실은 콩지방함량의 기상반응에 대한 품종적 차이가 상당히 크다는 것을 의미한다.

지방수량은 ADTRg 와 VADRa에 반비례하는 경향을 나타내었으며 이는 최고최저 온도차이와 평균강수량 변이가 클수록 지방수량은 감소한다는 것을 의미한다.

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