values as a result of sucrose feeding. Color readings were similar.

Differences in shear force values of the roast loin were slight and inconsistent. Quality scores by the panel of judges were also similar. In general, livers of high total carbohydrate content were preferred to the livers of low carbohydrate content on the basis of tenderness and flavor.

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GOSSYPOL IN COTTONSEED

Influence of Variety of Cottonseed and Environment

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Considerable variation was found in the gossypol content of the kernels from seed of 8 varieties of cotton grown at 13 locations during 3 years. Both variety of seed and environment significantly influenced the gossypol content. Gossypol in the kernels was found to be negatively correlated with temperature and positively correlated with rainfall. Individual varieties differed in response to environmental factors of temperature and rainfall.

THE GROWING USE OF SCREW PRESSING and solvent extraction for the processing of cottonseed and the increased interest in improving the nutritive value and utility of cottonseed meal have focused attention on the role of gossypol in contributing to oil color and to reduction of the protein value of the meal (*1, 7, 8, 11*). Knowledge of the variability in the gossypol content of cottonseed kernels and the agronomic factors which contribute to such variability is basic to the solution of these problems. Several investigators (*5, 9, 13, 16*) have reported considerable variations in the gossypol content of cottonseed kernels which were attributed to environmental factors. Schwartze and Alsberg (*13*), while reporting values ranging from 0.4 to 1.2% for seed grown at widely scattered locations, were unable to assess the effect of the varietal characteristics. Gallup (*5*) concluded that rainfall during the growing season influences the gossypol content of the seed. Other investigators (*6, 14*) attributed variability in gossypol content to genetical characteristics. As no systematic investigation of the influence of variety and environment on the gossypol content of cottonseed kernels has been reported, such an investigation was undertaken. The purpose of this report is to record the findings.

Samples and Methods of Analysis

The seed used in the investigation were from 8 commercial varieties of cotton grown at 13 locations during 1947, 1948, and 1949 by the Division of Cotton and Other Fiber Crops and Diseases of the Bureau of Plant Industry, Soils, and Agricultural Engineering. The varieties and locations are listed in Table I. The experimental plots were irrigated at State College, N. M., Sacaton, Ariz., and Shafter, Calif. The cottons were grown in replicated plots from which representative samples of seed cotton were picked from recently opened bolls. The samples of cottonseed containing less than 8.5% moisture were stored in sealed containers at 0° F., conditions which have been shown to produce no significant changes in the chemical composition of cottonseed (*12, 15*).

The kernels were separated from the hull and residual lint and ground to pass a 2-mm. screen to provide analytical samples.

The samples were analyzed for moisture, oil, and free gossypol by use of official methods of the American Oil Chemists' Society (*2*, Ba 2-38, Ba 3-38, and Ba 7-50, respectively). The analytical values for free gossypol are equivalent to total gossypol in fresh cottonseed samples, such as those analyzed, and include any gossypollike pigments such as gossypurpurin (*10*), if present in the samples. Hereafter in this report the combined content of gossypol and gossypollike pigments is termed gossypol.

Results and Discussion

The gossypol contents of the moisture-free kernels (Table I) varied considerably, ranging from 0.39 to 1.70%. The analysis of variance (Table II) discloses that both variety of cottonseed and the environment have a highly significant influence on the gossypol content of the kernels.

The variety means indicate that the gossypol content of the kernels may be a genetical characteristic. The values for Rowden 41B are consistently high and those for Acala 4-42 and Coker Wilds are consistently low. The 3-year mean values for Stoneville 2B, Deltapine 15, and Coker 100W are grouped together within a narrow range (1.20 to 1.22%), while those for Acala 1517W and Mebane are similarly paired (1.14 to 1.15%).

Standard deviations of the means (0.171 for variety and 0.205 for location), calculated from the mean values listed in Table I, indicate that variety and location of growth appear to be approximately equal in their influence on the gossypol content of the kernel.

The data were also calculated to a moisture- and oil-free basis to eliminate the effects of the variability of the oil content, and to express them in terms more nearly comparable to commercial cottonseed meals. On this basis the ordinal ranking of the varieties, with respect to gossypol content, remained the same. Analysis of variance again showed that both variety of cottonseed and environment have a highly significant influence on the gossypol content of the kernel.

Because analysis of variance shows that environments differ significantly in influencing the gossypol content (Table II), the over-all influence of temperature and rainfall during significant periods of growth of the cotton plant was estimated. The periods selected were:

Period 1. Squaring, 21 days prior to average blooming date.
Period 2. Fiber length and development, 17 days after average blooming date.
Period 3. Maturation, 35 days following period 2 to average boll-opening date.
Period 4. Combination of periods 1 and 2.
Period 5. Combination of periods 2 and 3.
Period 6. Combination of periods 1, 2, and 3.

Simple over-all regression and correlation coefficients (Table III) for the relation between gossypol, y, in the moisture-free kernels and temperature, x, indicate that high temperatures tend to produce low gossypol content, with mean temperature relations having larger coefficients than those for maximum or minimum temperatures. Significant correlations with mean temperature for all periods, other than period 1, suggest that the influence of temperature is exerted throughout the entire period of seed development and maturation. The relative effect of mean temperature during each of the individual periods, 1, 2, and 3, is shown by the standard partial regression coefficients listed in Table V. These coefficients, which allow an evaluation of the effect of temperature in each period apart from the other two periods, show that the influence of temperature is not limited to any given period.

In contrast to the temperature relations, high rainfall tends to increase gossypol content of the kernels (Table IV). The magnitude of the regression and correlation coefficients (Table IV) and the standard partial regression coefficients (Table V) demonstrates that rainfall exerts its greatest influence during period 3, the maturation period. This is reasonable, as it has been established that

Table I. Gossypol in Moisture-Free Cottonseed Kernels of 8 Varieties Grown at 13 Locations during 3 Years

Year and Location	Gossypol in Moisture-Free Cottonseed Kernels, %								
	Acala 4-42	Acala 1517W	Rowden 41B	Mebane	Stoneville 2B	Deltapine 15	Coker 100W	Coker Wilds	Mean
				1947					
Statesville, N. C.	0.80	1.05	1.24	1.13	1.03	1.07	1.09	1.07	1.06
Florence, S. C.	0.95	1.37	1.59	1.48	1.56	1.49	1.31	1.32	1.38
Tifton, Ga.	0.84	1.07	1.28	1.16	1.09	1.07	1.04	0.95	1.06
Auburn, Ala.	0.85	1.18	1.23	1.14	1.16	1.07	1.22	0.94	1.10
Jackson, Tenn.	0.73	1.11	1.21	1.12	1.07	0.95	1.08	0.91	1.02
Stoneville, Miss.	0.62	0.90	1.02	0.96	1.01	0.92	0.99	0.71	0.89
St. Joseph, La.	0.83	1.22	1.28	1.18	1.31	1.19	1.31	0.95	1.16
Chickasha, Okla.	0.55	0.70	0.97	0.79	0.80	0.73	0.86	0.45	0.73
Greenville, Tex.	0.39	0.62	0.92	0.76	0.88	0.76	0.76	0.41	0.69
College Station, Tex.	0.81	1.23	1.49	1.28	1.31	1.25	1.30	1.05	1.22
State College, N. M.	0.87	1.25	1.35	1.23	1.15	1.31	1.37	1.08	1.20
Sacaton, Ariz.	0.64	0.91	1.02	0.87	0.96	1.06	0.80	0.66	0.87
Shafter, Calif.	0.81	1.16	1.13	1.08	1.15	1.16	1.31	1.03	1.10
Mean	0.75	1.06	1.21	1.09	1.11	1.08	1.11	0.89	1.04
				1948					
Statesville, N. C.	0.83	1.10	1.18	0.99	1.05	1.04	1.11	1.08	1.05
Florence, S. C.	0.97	1.31	1.53	1.31	1.42	1.26	1.54	1.15	1.31
Tifton, Ga.	0.93	1.33	1.31	1.25	1.30	1.18	1.37	1.29	1.25
Auburn, Ala.	1.17	1.20	1.49	1.28	1.35	1.21	1.34	1.13	1.27
Jackson, Tenn.	0.73	0.95	1.21	1.00	0.98	1.08	0.94	0.86	0.97
Stoneville, Miss.	0.88	1.29	1.37	1.16	1.24	1.41	1.31	1.14	1.23
St. Joseph, La.	1.00	1.40	1.62	1.35	1.44	1.57	1.56	1.27	1.40
Chickasha, Okla.	0.63	0.83	1.10	0.86	1.01	0.89	0.98	0.76	0.88
Greenville, Tex.	0.50	0.67	0.96	0.81	0.91	0.89	0.87	0.60	0.78
College Station, Tex.	0.45	0.59	1.00	0.71	0.81	0.85	0.81	0.49	0.71
State College, N. M.	0.91	1.31	1.48	1.36	1.30	1.50	1.61	1.15	1.33
Sacaton, Ariz.	0.75	1.01	1.32	1.04	1.12	1.18	1.06	0.88	1.05
Shafter, Calif.	0.87	1.22	1.34	1.17	1.17	1.28	1.27	1.07	1.17
Mean	0.82	1.09	1.30	1.10	1.16	1.18	1.21	0.99	1.11
				1949					
Statesville, N. C.	1.06	1.37	1.48	1.34	1.42	1.20	1.38	1.21	1.31
Florence, S. C.	0.92	1.30	1.54	1.33	1.44	1.39	1.45	1.24	1.33
Tifton, Ga.	0.93	1.16	1.34	1.11	1.35	1.23	1.27	1.16	1.19
Auburn, Ala.	0.90	1.14	1.31	1.19	1.25	1.09	1.32	1.15	1.17
Jackson, Tenn.	1.13	1.44	1.61	1.38	1.55	1.49	1.51	1.31	1.43
Stoneville, Miss.	0.82	1.04	1.29	1.11	1.16	1.27	1.22	0.94	1.11
St. Joseph, La.	1.02	1.39	1.69	1.30	1.48	1.70	1.60	1.39	1.45
Chickasha, Okla.	1.08	1.43	1.47	1.39	1.40	1.49	1.41	1.29	1.37
Greenville, Tex.	0.85	1.21	1.35	1.18	1.28	1.38	1.31	1.06	1.20
College Station, Tex.	0.77	1.03	1.28	1.10	1.02	1.15	1.06	0.96	1.05
State College, N. M.	1.02	1.51	1.60	1.40	1.34	1.49	1.34	1.20	1.36
Sacaton, Ariz.	0.85	1.08	1.31	1.17	1.21	1.36	1.20	0.99	1.15
Shafter, Calif.	0.92	1.46	1.46	1.30	1.26	1.44	1.37	1.21	1.30
Mean	0.94	1.27	1.44	1.25	1.32	1.36	1.34	1.16	1.26
				3-year mean					
Statesville, N. C.	0.90	1.17	1.30	1.15	1.17	1.10	1.19	1.12	1.14
Florence, S. C.	0.95	1.33	1.55	1.37	1.47	1.38	1.43	1.24	1.34
Tifton, Ga.	0.90	1.19	1.31	1.17	1.25	1.16	1.23	1.13	1.17
Auburn, Ala.	0.97	1.17	1.34	1.20	1.25	1.12	1.29	1.07	1.18
Jackson, Tenn.	0.86	1.17	1.34	1.17	1.20	1.17	1.18	1.03	1.14
Stoneville, Miss.	0.77	1.08	1.23	1.08	1.14	1.20	1.17	0.93	1.07
St. Joseph, La.	0.95	1.34	1.53	1.28	1.41	1.49	1.49	1.20	1.34
Chickasha, Okla.	0.75	0.99	1.18	1.01	1.07	1.04	1.08	0.83	0.99
Greenville, Tex.	0.58	0.83	1.08	0.92	1.02	1.01	0.98	0.69	0.89
College Station, Tex.	0.68	0.95	1.26	1.03	1.05	1.08	1.06	0.83	0.99
State College, N. M.	0.93	1.36	1.48	1.33	1.26	1.43	1.44	1.14	1.30
Sacaton, Ariz.	0.75	1.00	1.22	1.03	1.10	1.20	1.02	0.84	1.02
Shafter, Calif.	0.87	1.28	1.31	1.18	1.19	1.29	1.32	1.10	1.19
Mean	0.84	1.14	1.32	1.15	1.20	1.21	1.22	1.01	1.14

Table II. Analysis of Variance of Gossypol Content of Mature Cottonseed Kernels

Source	D. F.	Mean Square	F Value
Variety	7	0.8619	159.61[a]
Station-years	38	0.3345	61.94[a]
Error[b]	265	0.0054	
Total[b]	310		

[a] Highly significant.
[b] One degree of freedom subtracted from "error" and one from "total" for missing plot.

Table III. Over-all Correlations between Gossypol Content of Moisture-Free Kernels and Average Temperatures

Period	Range in Average Temperatures, °F.			Regression Coefficients, b_{yx}			Correlation Coefficients, r		
	Maximum	Minimum	Mean	Max. temp.	Min. temp.	Mean temp.	Max. temp.	Min. temp.	Mean temp.
1	85.2– 99.8	60.0–71.9	75.4–84.4	−0.008	+0.002	−0.011	−0.15	+0.03	−0.11
2	85.3–107.2	62.2–80.0	75.2–91.6	−0.014	−0.014	−0.023	−0.36[a]	−0.27	−0.38[a]
3	83.6–107.6	60.2–75.4	71.9–91.4	−0.018	−0.016	−0.024	−0.46[b]	−0.33[a]	−0.46[b]
4	86.0–101.9	61.0–73.1	75.6–84.2	−0.015	−0.007	−0.029	−0.29	−0.12	−0.32[a]
5	86.1–106.0	61.6–76.8	74.6–89.1	−0.019	−0.018	−0.029	−0.45[b]	−0.33[a]	−0.49[b]
6	85.9–103.8	61.5–73.9	76.9–86.6	−0.019	−0.017	−0.036	−0.40[a]	−0.27	−0.47[b]

$N = 39$.
[a] Significant.
[b] Highly significant.

gossypol is synthesized in the seed during a time interval of approximately 30 to 20 days before opening of the bolls (*3, 4*).

The response of the individual varieties to changes in mean temperature and in total rainfall occurring during the maturation period is illustrated by the regressions and correlations recorded in Tables VI and VII. Those for temperature (Table VI) suggest that some varieties, particularly the low-gossypol varieties, respond differently to temperature. With regard to rainfall (Table VII) all varieties, with the possible exception of Acala 4–42, tend to respond in a similar manner.

The influence of temperature independent of the effects of rainfall, and of rainfall independent of temperature, is illustrated by the partial correlation and regression coefficients recorded in Table VIII. In all cases, the partial correlations are lower than the simple correlations shown in Tables VI and VII, demonstrating the interrelated effect of temperature and rainfall. With respect to temperature, significant differences in response are shown by the three lowest gossypol varieties, Acala 4-42, Acala 1517W, and Coker Wilds. With the possible exception of Acala 4-42, there is little difference in the varietal response to rainfall.

Table IV. Over-All Correlations between Gossypol Content of Moisture-Free Kernels and Total Rainfall (Rain-Grown Cotton)

Period	Total Rainfall, Inches		Regression Coefficients, b_{yx}	Correlation Coefficients, r
	Range	Average		
1	0.00– 8.81	2.19	+0.038	+0.31
2	0.00–11.12	2.86	+0.021	+0.25
3	0.00– 8.38	3.76	+0.056	+0.54[a]
4	0.33–13.58	5.04	+0.027	+0.38[b]
5	0.86–17.30	6.62	+0.030	+0.50[a]
6	1.63–19.76	8.81	+0.027	+0.53[a]

$N = 30$.
[a] Highly significant.
[b] Significant.

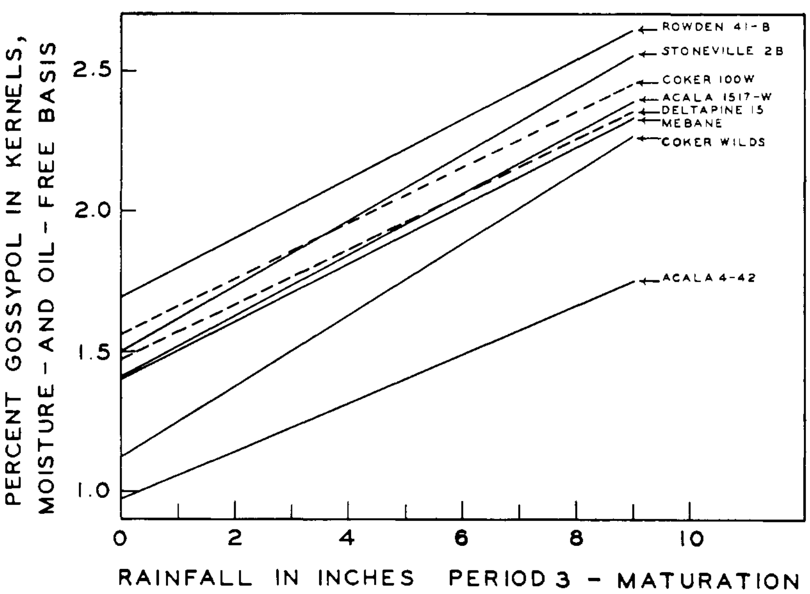
Table V. Multiple Correlations of Gossypol Content of Moisture-Free Kernels on Average Temperatures and Total Rainfall (Rain-Grown Cotton)

Relations	Multiple Correlation Coefficient, R	Standard Partial Regression Coefficients		
		Period 1, $\beta_{y1.23}$	Period 2, $\beta_{y2.13}$	Period 3, $\beta_{y3.12}$
Temperature relations	0.499	+0.035	−0.227	−0.356
Rainfall relations	0.572[a]	+0.111	+0.160	+0.468[a]

$N = 30$.
[a] Significant.

The simple and partial correlation and regression coefficients are larger for rainfall than for the temperature relations. This is further evidence that the influence of moisture is greater than that of temperature on the elaboration of gossypol in cottonseed.

Figure 1. Relations between rainfall during maturation of cottonseed and gossypol content of moisture- and oil-free kernels



The influence of both variety of cottonseed and of rainfall during the maturation period on the gossypol content of the kernels is illustrated in Figure 1. The regression equations shown are those for the moisture- and oil-free kernels given in Table VI. On this basis the gossypol contents approximate those of the meals obtainable on processing the seed for oil and meal.

The data suggest that varieties of cotton can be developed which have relatively low levels of gossypol in the kernels. They also suggest that the ratio of nitrogen or protein to gossypol should be considered in developing laboratory methods for evaluating the protein value of cottonseed meals and in developing improved methods of processing, to the end that the meal produced may have the highest protein value.

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Table VI. Correlations between Gossypol Content of Cottonseed Kernels and Mean Temperatures during Maturation Period for Rain-Grown Cotton

Variety	Mean Gossypol Content, %	r	Regression Equation, y = % Gossypol, x = Mean Temperature	S_{yx}
		Moisture-Free Kernels		
Acala 4-42	0.84	−0.60[a]	$y = 3.768 - 0.037x$	0.16
Acala 1517W	1.14	−0.49[a]	$y = 4.151 - 0.038x$	0.22
Rowden 41B	1.32	−0.38[b]	$y = 3.329 - 0.025x$	0.20
Mebane, Watson's	1.15	−0.47[a]	$y = 3.504 - 0.030x$	0.18
Stoneville 2B	1.20	−0.40[b]	$y = 3.392 - 0.027x$	0.21
Deltapine 15	1.21	−0.34	$y = 3.242 - 0.026x$	0.23
Coker 100W	1.22	−0.36	$y = 3.292 - 0.026x$	0.22
Coker Wilds	1.01	−0.52[a]	$y = 4.508 - 0.044x$	0.23
		Moisture- and Oil-Free Kernels		
Acala 4-42	1.30	−0.56[a]	$y = 6.110 - 0.060x$	0.29
Acala 1517W	1.85	−0.44[a]	$y = 6.816 - 0.063x$	0.41
Rowden 41B	2.09	−0.34	$y = 5.621 - 0.044x$	0.40
Mebane, Watson's	1.80	−0.43[b]	$y = 5.807 - 0.050x$	0.34
Stoneville 2B	1.93	−0.32	$y = 5.416 - 0.043x$	0.42
Deltapine 15	1.89	−0.28	$y = 5.047 - 0.040x$	0.45
Coker 100W	1.94	−0.28	$y = 5.174 - 0.041x$	0.45
Coker Wilds	1.60	−0.48[a]	$y = 7.393 - 0.072x$	0.43

$N = 30$ in all instances.
[a] Highly significamt.
[b] Significant.

Table VII. Correlations between Gossypol Content of Cottonseed Kernels and Rainfall in Inches during Maturation Period for Rain-Grown Cotton

Variety	r	Regression Equation, y = % Gossypol, x = Inches Rainfall	S_{yx}
	Moisture-Free Kernels		
Acala 4-42	+0.51[a]	$y = 0.656 + 0.047x$	0.17
Acala 1517W	+0.52[a]	$y = 0.894 + 0.060x$	0.21
Rowden 41B	+0.53[a]	$y = 1.112 + 0.053x$	0.18
Mebane, Watson's	+0.58[a]	$y = 0.931 + 0.055x$	0.17
Stoneville 2B	+0.58[a]	$y = 0.975 + 0.061x$	0.18
Deltapine 15	+0.46[b]	$y = 0.975 + 0.053x$	0.22
Coker 100W	+0.45[b]	$y = 1.024 + 0.050x$	0.21
Coker Wilds	+0.54[a]	$y = 0.750 + 0.066x$	0.23
	Moisture- and Oil-Free Kernels		
Acala 4-42	+0.54[a]	$y = 0.974 + 0.087x$	0.29
Acala 1517W	+0.51[a]	$y = 1.407 + 0.108x$	0.39
Rowden 41B	+0.54[a]	$y = 1.692 + 0.106x$	0.36
Mebane, Watson's	+0.58[a]	$y = 1.406 + 0.102x$	0.31
Stoneville 2B	+0.57[a]	$y = 1.500 + 0.117x$	0.36
Deltapine 15	+0.45[b]	$y = 1.469 + 0.098x$	0.41
Coker 100W	+0.45[b]	$y = 1.566 + 0.097x$	0.42
Coker Wilds	+0.56[a]	$y = 1.119 + 0.127x$	0.40

$N = 30$ in all instances.
[a] Highly significant.
[b] Significant.

Table VIII. Partial Correlations of Gossypol Content in Moisture-Free Kernels of Individual Varieties on Mean Temperature and Total Rainfall during Maturation Period (No. 3)

Variety	Mean Gossypol Content, %	Partial Correlation Coefficients: Temp., $r_{y1.2}$	Partial Correlation Coefficients: Rainfall, $r_{y2.1}$	Partial Regression Coefficients: Temp., $b_{y1.2}$	Partial Regression Coefficients: Rainfall, $b_{y2.1}$
Acala 4-42	0.84	−0.52[a]	+0.38[b]	−0.029 ± 0.009	+0.030 ± 0.013
Acala 1517W	1.14	−0.37[b]	+0.41[b]	−0.026 ± 0.012	+0.045 ± 0.018
Rowden 41B	1.32	−0.23	+0.45[b]	−0.014 ± 0.011	+0.045 ± 0.016
Mebane, Watson's	1.15	−0.33	+0.49[a]	−0.017 ± 0.009	+0.045 ± 0.015
Stoneville 2B	1.20	−0.23	+0.51[a]	−0.014 ± 0.011	+0.052 ± 0.016
Deltapine 15	1.21	−0.20	+0.38[b]	−0.014 ± 0.004	+0.045 ± 0.006
Coker 100W	1.22	−0.22	+0.37	−0.016 ± 0.013	+0.041 ± 0.019
Coker Wilds	1.01	−0.41[b]	+0.44[b]	−0.031 ± 0.013	+0.051 ± 0.019

$N = 30$.
[a] Highly significant.
[b] Significant.

of the Division of Cotton and Other Fiber Crops and Diseases of the Bureau of Plant Industry, Soils, and Agricultural Engineering. Barker assisted with the over-all plans and developed coordination among the field locations. G. T. Den Hartog developed the statistical procedure and assisted in interpreting the results. W. H. Tharp assisted in planning the influence of environment. Individuals responsible for growing the cotton varieties at the field locations included R. H. Tilly, P. M. Kime, W. H. Jenkins, S. A. Parham, H. B. Tisdale, J. M. Epps, N. I. Hancock, J. B. Dick, C. B. Haddon, I. M. Parrott, M. G. Keathley, D. R. Hooton, T. R. Richmond, A. R. Leding, R. H. Peebles, G. J. Harrison, and E. G. Smith.

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