

# 亚麻荠 *CsFAD* 基因家族鉴定及 $\alpha$ -亚麻酸合成关键基因 *CsFAD3.3* 的功能分析

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## Genome-wide Identification of the *CsFAD* Gene Family in *Camelina sativa* and Functional Characterization of the Key Gene *CsFAD3.3* Involved in $\alpha$ -linolenic Acid Biosynthesis

DOI: 10.13560/j.cnki.biotech.bull.1985.2025-1058

附表 1 实验所用引物表

Table S1 Primers used in the experiment

基因名称 Gene name	引物序列 Primer sequence
<i>CsFAD3.3</i> -F- <i>Xba</i> I-1303	AACCTGCAGGTCGAC <u>CTAGA</u> ATGGTTGTGCTATGGACAAAC 波浪线为酶切位点
<i>CsFAD3.3</i> -R- <i>Kpn</i> I-1303	GGTTTAAACGAGCTCGGTACCTTAATTGATTTAGACTTGTCAGAAGCG 波浪线为酶切位点
<i>CsFAD3.3</i> -F	GTCGATGCCACAAAAGCAGCTAAAC
<i>CsFAD3.3</i> -R	TGATTTTAGACTTGTCAGAAGCGTA
1303-F	CAGGAAACAGCTATGACC
1303-R	TGTAAAACGACGGCCAGT
<i>CsFAD3.3</i> -F- <i>Xba</i> I-1300	ATACACCAAATCGAC <u>CTAGA</u> ATGGTTGTGCTATGGACAAACG 波浪线为酶切位点
<i>CsFAD3.3</i> -R- <i>kpn</i> I-1300	GCCCTTGCTCACCATGGT <u>ACC</u> ATTGATTTAGACTTGTCAGAAGCGT 波浪线为酶切位点

附表 2 亚麻荠 *CsFAD* 基因编码蛋白的理化性质Table S2 Physicochemical properties of proteins encoded by *CsFAD* genes in *Camelina sativa*

序列号 Gene ID	重命名 Gene name	氨基酸数 (aa) Length (aa)	分子量 (kD) Molecular weight (kDa)	等电点 (pI) Isoelectric point (pI)	不稳定指数 Instability index	脂肪系数 Aliphatic index	亲水系数 Grand average of hydropathicity	跨膜区数 Number of transmembrane domains
Csa01g013220. 1	CsFAD2.1	384	44.046	8.39	40.46	85.10	-0.072	5
Csa15g016000. 1	CsFAD2.2	385	44.205	8.39	40.17	83.84	-0.082	6
Csa19g016350. 1	CsFAD2.3	502	57.866	8.51	35.42	85.48	-0.053	7
Csa16g014970. 1	CsFAD3.1	439	50.002	8.60	34.86	89.91	-0.086	3
Csa05g033930. 1	CsFAD3.2	387	44.045	8.42	28.19	90.16	-0.091	3
Csa07g013360. 1	CsFAD3.3	387	44.059	8.43	28.93	90.16	-0.093	3
Csa12g016160. 1	CsFAD6.1	496	56.702	8.89	42.86	88.87	-0.081	2
Csa10g011570. 1	CsFAD6.2	445	50.900	8.95	44.46	88.11	-0.074	2
Csa11g012410. 1	CsFAD6.3	558	63.356	9.40	48.63	89.66	-0.063	2
Csa01g012210. 1	CsFAD7.1	448	51.430	7.16	37.37	85.71	-0.266	3

序列号 Gene ID	重命名 Gene name	氨基酸数 (aa) Length (aa)	分子量 (kD) Molecular weight (kDa)	等电点 (pI) Isoelectric point (pI)	不稳定指数 Instability index	脂肪系数 Aliphatic index	亲水系数 Grand average of hydropathicity	跨膜区数 Number of transmembrane domains
Csa15g014910. 1	CsFAD7.2	448	51.347	8.10	37.10	84.84	-0.269	3
Csa19g015230. 1	CsFAD7.3	448	51.256	7.41	38.56	85.94	-0.253	3
Csa20g006850. 1	CsFAD8.1	433	49.986	8.42	35.71	78.13	-0.285	4
Csa13g007570. 1	CsFAD8.2	433	50.130	8.42	36.98	77.67	-0.307	4
Csa08g058890. 1	CsFAD8.3	433	50.019	8.42	38.14	77.90	-0.311	4
Csa08g048970. 1	CsDES1.1	337	39.200	8.53	43.20	87.03	-0.082	5
Csa13g052810. 1	CsDES1.2	266	30.595	7.25	49.98	97.78	0.192	5
Csa02g011080. 1	CsDES1.3	307	35.633	8.78	37.80	97.10	0.203	5
Csa02g014480. 1	CsDES1.4	194	22.188	9.10	43.90	110.52	0.410	4
Csa16g003620. 1	CsSLD1.1	766	87.973	8.60	39.09	91.53	0.132	9
Csa07g003100. 1	CsSLD1.2	449	51.570	8.85	40.88	88.62	0.027	5

序列号 Gene ID	重命名 Gene name	氨基酸数 (aa) Length (aa)	分子量 (kD) Molecular weight (kDa)	等电点 (pI) Isoelectric point (pI)	不稳定指数 Instability index	脂肪系数 Aliphatic index	亲水系数 Grand average of hydropathicity	跨膜区数 Number of transmembrane domains
Csa05g093640. 1	CsSLD1.3	450	51.689	8.85	40.61	88.42	0.019	5
Csa04g065230. 1	CsSLD2.1	449	51.574	8.89	31.70	90.31	-0.027	5
Csa05g003010. 1	CsSLD2.2	449	51.564	8.97	30.52	89.20	-0.029	5
Csa06g052640. 1	CsSLD2.3	508	58.130	8.95	30.25	91.71	-0.008	5
Csa03g008530. 1	CsADS1	923	108.550	9.40	38.90	80.31	-0.218	7
Csa17g009480. 1	CsADS2	305	36.076	9.37	39.91	82.79	-0.209	3
Csa16g012010. 1	CsADS3	307	36.354	9.41	56.65	84.43	-0.150	4
Csa07g011510. 1	CsADS4	307	36.354	9.41	56.65	84.43	-0.150	4
Csa05g029860. 1	CsADS5	305	36.080	9.59	53.75	84.98	-0.115	4
Csa19g022640. 1	CsADS6	537	61.034	9.39	29.92	86.69	-0.017	4
Csa01g018460. 1	CsADS7	373	42.659	9.20	30.25	82.68	-0.066	2

序列号 Gene ID	重命名 Gene name	氨基酸数 (aa) Length (aa)	分子量 (kD) Molecular weight (kDa)	等电点 (pI) Isoelectric point (pI)	不稳定指数 Instability index	脂肪系数 Aliphatic index	亲水系数 Grand average of hydropathicity	跨膜区数 Number of transmembrane domains
Csa15g020490. 1	CsADS8	372	42.692	9.04	30.05	82.10	-0.073	3
Csa19g022670. 1	CsADS9	584	68.598	9.56	34.85	79.04	-0.190	2
Csa15g020510. 1	CsADS10	363	42.356	9.51	34.41	83.99	-0.128	2
Csa01g018480. 1	CsADS11	361	42.204	9.62	32.47	82.55	-0.130	2
Csa15g020520. 1	CsADS12	146	17.252	6.23	35.84	74.11	-0.443	0
Csa03g009800. 1	CsADS13	299	35.467	9.31	39.87	84.45	-0.125	4
Csa17g009740. 1	CsADS14	422	49.829	9.34	39.49	84.10	-0.126	6
Csa14g007750. 1	CsADS15	299	35.367	9.26	39.71	85.42	-0.118	4
Csa14g007760. 1	CsADS16	177	21.189	9.19	45.00	83.16	-0.002	2
Csa17g009750. 1	CsADS17	114	13.360	9.64	35.58	88.16	0.013	2
Csa17g009490. 1	CsADS18	300	35.269	9.49	36.72	72.20	-0.243	4

序列号 Gene ID	重命名 Gene name	氨基酸数 (aa) Length (aa)	分子量 (kD) Molecular weight (kDa)	等电点 (pI) Isoelectric point (pI)	不稳定指数 Instability index	脂肪系数 Aliphatic index	亲水系数 Grand average of hydropathicity	跨膜区数 Number of transmembrane domains
Csa03g008510. 1	CsADS19	197	22.510	10.34	33.73	62.94	-0.680	0
Csa14g007470. 1	CsADS20	898	106.074	9.50	39.65	79.93	-0.196	10
Csa17g009510. 1	CsADS21	347	41.186	9.11	44.38	83.46	-0.133	4
Csa17g009500. 1	CsADS22	288	33.869	9.38	43.86	82.05	-0.128	4
Csa14g007490. 1	CsADS23	259	30.684	8.87	43.27	79.46	-0.148	3
Csa12g024850. 1	CsFAD4.1	323	36.263	8.95	45.27	89.91	-0.173	0
Csa11g017130. 1	CsFAD4.2	321	36.087	8.95	43.43	89.56	-0.152	0
Csa10g015800. 1	CsFAD4.3	555	62.115	9.56	41.23	86.09	-0.182	0
Csa09g096780. 1	CsFAD4.4	295	32.966	8.66	40.35	83.97	-0.141	0
Csa16g044640. 1	CsFAD4.5	291	32.897	7.24	47.44	93.09	-0.033	0
Csa09g087170. 1	CsFAD4.6	296	33.543	8.29	43.53	86.59	-0.101	2



附表 3 *CsFAD* 同源基因对的选择压力分析Table S3 Analysis of selective pressure on *CsFAD* homologous gene pairs

基因 ID	基因 ID	非同义替换率	同义替换率	Ka/Ks 比值	复制类型	选择压力
Gene ID	Gene ID	Ka	Ks	Ka_Ks	Duplication type	Selection pressure
<i>CsADS1</i>	<i>CsADS5</i>	0.148195307	1.206265536	0.122854631	Purifying selection	fragment duplication
<i>CsADS1</i>	<i>CsADS4</i>	0.141352201	1.229776178	0.114941405	Purifying selection	fragment duplication
<i>CsADS10</i>	<i>CsADS12</i>	0.066458546	0.28765154	0.231038382	Purifying selection	tandem duplication
<i>CsADS14</i>	<i>CsADS13</i>	0.026399238	0.062720459	0.420903137	Purifying selection	fragment duplication
<i>CsADS14</i>	<i>CsADS17</i>	0.003833874	0.026260888	0.145991792	Purifying selection	tandem duplication
<i>CsADS15</i>	<i>CsADS14</i>	0.013201397	0.051790093	0.254901974	Purifying selection	fragment duplication
<i>CsADS15</i>	<i>CsADS13</i>	0.021745906	0.041713617	0.521314327	Purifying selection	fragment duplication
<i>CsADS15</i>	<i>CsADS16</i>	0.069494123	0.10567909	0.657595774	Purifying selection	tandem duplication
<i>CsADS18</i>	<i>CsADS19</i>	0.246247822	0.569191521	0.432627354	Purifying selection	fragment duplication
<i>CsADS18</i>	<i>CsADS22</i>	0.117005596	0.437168021	0.267644452	Purifying selection	tandem duplication
<i>CsADS2</i>	<i>CsADS1</i>	0.006351485	0.053457735	0.118813202	Purifying selection	fragment duplication
<i>CsADS2</i>	<i>CsADS5</i>	0.146321703	1.145236143	0.127765531	Purifying selection	fragment duplication
<i>CsADS2</i>	<i>CsADS4</i>	0.139501777	1.166978914	0.119540957	Purifying selection	fragment duplication
<i>CsADS2</i>	<i>CsADS18</i>	0.284480095	1.397902948	0.203504897	Purifying selection	tandem duplication
<i>CsADS20</i>	<i>CsADS3</i>	0.142659966	1.224448938	0.116509526	Purifying selection	fragment duplication
<i>CsADS20</i>	<i>CsADS2</i>	0.007766603	0.058853712	0.131964535	Purifying selection	fragment duplication
<i>CsADS20</i>	<i>CsADS19</i>	0.218723039	0.378410682	0.578004399	Purifying selection	fragment duplication
<i>CsADS20</i>	<i>CsADS5</i>	0.147257479	1.198975722	0.1228194	Purifying selection	fragment duplication
<i>CsADS20</i>	<i>CsADS4</i>	0.142641478	1.251301769	0.113994467	Purifying selection	fragment duplication
<i>CsADS22</i>	<i>CsADS21</i>	0.048865964	0.051438594	0.949986387	Purifying selection	tandem duplication
<i>CsADS23</i>	<i>CsADS1</i>	0.042916521	0.061221735	0.701001395	Purifying selection	fragment duplication
<i>CsADS3</i>	<i>CsADS2</i>	0.139519833	1.143035385	0.122060817	Purifying selection	fragment duplication
<i>CsADS3</i>	<i>CsADS1</i>	0.141370538	1.203834748	0.117433509	Purifying selection	fragment duplication
<i>CsADS3</i>	<i>CsADS13</i>	0.326352686	1.996247036	0.163483116	Purifying selection	fragment duplication
<i>CsADS3</i>	<i>CsADS5</i>	0.001414261	0.060258241	0.023469999	Purifying selection	fragment duplication
<i>CsADS3</i>	<i>CsADS4</i>	0	0.034418165	0	Purifying selection	fragment duplication
<i>CsADS5</i>	<i>CsADS4</i>	0.001414094	0.055070601	0.025677842	Purifying selection	fragment duplication
<i>CsADS7</i>	<i>CsADS8</i>	0.008137249	0.053649541	0.151674164	Purifying selection	fragment duplication
<i>CsADS7</i>	<i>CsADS6</i>	0.009290741	0.061869483	0.150166782	Purifying selection	fragment duplication
<i>CsADS8</i>	<i>CsADS6</i>	0.008139615	0.057879949	0.140629267	Purifying selection	fragment duplication
<i>CsDESI.2</i>	<i>CsDESI.3</i>	0.066186351	0.134478217	0.492171539	Purifying selection	fragment duplication
<i>CsDESI.2</i>	<i>CsDESI.1</i>	0.027396397	0.074954306	0.365507983	Purifying selection	fragment duplication
<i>CsDESI.3</i>	<i>CsDESI.1</i>	0.028539687	0.080697011	0.353664734	Purifying selection	fragment duplication
<i>CsFAD2.1</i>	<i>CsFAD2.2</i>	0.00572358	0.109390785	0.052322325	Purifying selection	fragment duplication
<i>CsFAD2.1</i>	<i>CsFAD2.3</i>	0.002284411	0.056595036	0.040364153	Purifying selection	fragment duplication
<i>CsFAD2.2</i>	<i>CsFAD2.3</i>	0.003428251	0.096940157	0.035364611	Purifying selection	fragment duplication
<i>CsFAD3.1</i>	<i>CsFAD3.2</i>	0.004501139	0.018774447	0.23974814	Purifying selection	fragment duplication
<i>CsFAD3.1</i>	<i>CsFAD3.3</i>	0.002249299	0.037910786	0.059331367	Purifying selection	fragment duplication
<i>CsFAD3.2</i>	<i>CsFAD3.3</i>	0.002247193	0.018774447	0.119694214	Purifying selection	fragment duplication
<i>CsFAD4.2</i>	<i>CsFAD4.1</i>	0.010356896	0.088404101	0.117154027	Purifying selection	fragment duplication

基因 ID	基因 ID	非同义替换率	同义替换率	Ka/Ks 比值	复制类型	选择压力
Gene ID	Gene ID	Ka	Ks	Ka_Ks	Duplication type	Selection pressure
<i>CsFAD4.3</i>	<i>CsFAD4.2</i>	0.022002997	0.070559959	0.311834047	Purifying selection	fragment duplication
<i>CsFAD4.3</i>	<i>CsFAD4.1</i>	0.021293126	0.127364025	0.167183209	Purifying selection	fragment duplication
<i>CsFAD4.5</i>	<i>CsFAD4.6</i>	0.026186719	0.063842203	0.410178808	Purifying selection	fragment duplication
<i>CsFAD6.2</i>	<i>CsFAD6.3</i>	0.001937673	0.04089599	0.047380504	Purifying selection	fragment duplication
<i>CsFAD6.2</i>	<i>CsFAD6.1</i>	0.001937986	0.073058876	0.026526354	Purifying selection	fragment duplication
<i>CsFAD6.3</i>	<i>CsFAD6.1</i>	0.005640008	0.073269532	0.076976168	Purifying selection	fragment duplication
<i>CsFAD7.1</i>	<i>CsFAD8.2</i>	0.125013337	0.708254715	0.176509008	Purifying selection	fragment duplication
<i>CsFAD7.1</i>	<i>CsFAD7.2</i>	0.00582433	0.108517403	0.053671848	Purifying selection	fragment duplication
<i>CsFAD7.1</i>	<i>CsFAD7.3</i>	0.007777127	0.036714783	0.211825503	Purifying selection	fragment duplication
<i>CsFAD7.1</i>	<i>CsFAD8.1</i>	0.125065102	0.753633762	0.165949441	Purifying selection	fragment duplication
<i>CsFAD7.1</i>	<i>CsFAD8.3</i>	0.125164725	0.765665424	0.163471825	Purifying selection	fragment duplication
<i>CsFAD7.2</i>	<i>CsFAD7.3</i>	0.007782171	0.097020885	0.080211296	Purifying selection	fragment duplication
<i>CsFAD7.2</i>	<i>CsFAD8.1</i>	0.112856214	0.679717809	0.166033923	Purifying selection	fragment duplication
<i>CsFAD7.2</i>	<i>CsFAD8.3</i>	0.118215543	0.726168827	0.162793469	Purifying selection	fragment duplication
<i>CsFAD7.3</i>	<i>CsFAD8.1</i>	0.119312324	0.699986611	0.170449437	Purifying selection	fragment duplication
<i>CsFAD7.3</i>	<i>CsFAD8.3</i>	0.116313469	0.710588728	0.16368606	Purifying selection	fragment duplication
<i>CsFAD8.1</i>	<i>CsFAD8.3</i>	0.006993058	0.03132706	0.223227387	Purifying selection	fragment duplication
<i>CsFAD8.2</i>	<i>CsFAD7.2</i>	0.118622608	0.718452938	0.165108391	Purifying selection	fragment duplication
<i>CsFAD8.2</i>	<i>CsFAD7.3</i>	0.130149444	0.689380609	0.188791855	Purifying selection	fragment duplication
<i>CsFAD8.2</i>	<i>CsFAD8.1</i>	0.007992084	0.03497137	0.228532186	Purifying selection	fragment duplication
<i>CsFAD8.2</i>	<i>CsFAD8.3</i>	0.008997109	0.038559893	0.233328158	Purifying selection	fragment duplication
<i>CsSLD1.1</i>	<i>CsSLD2.1</i>	0.131823281	0.784305969	0.168076345	Purifying selection	fragment duplication
<i>CsSLD1.1</i>	<i>CsSLD1.3</i>	0.021770388	0.203963126	0.106736881	Purifying selection	fragment duplication
<i>CsSLD1.1</i>	<i>CsSLD2.2</i>	0.139601372	0.770996041	0.181066264	Purifying selection	fragment duplication
<i>CsSLD1.1</i>	<i>CsSLD2.3</i>	0.13816907	0.726898846	0.190080189	Purifying selection	fragment duplication
<i>CsSLD1.3</i>	<i>CsSLD2.3</i>	0.133976077	0.708057467	0.189216388	Purifying selection	fragment duplication
<i>CsSLD1.3</i>	<i>CsSLD1.1</i>	0.021770388	0.203963126	0.106736881	Purifying selection	fragment duplication
<i>CsSLD2.1</i>	<i>CsSLD1.3</i>	0.13114762	0.762716532	0.17194805	Purifying selection	fragment duplication
<i>CsSLD2.1</i>	<i>CsSLD2.2</i>	0.007753259	0.103672526	0.074786055	Purifying selection	fragment duplication
<i>CsSLD2.1</i>	<i>CsSLD2.3</i>	0.002896922	0.096435309	0.030040051	Purifying selection	fragment duplication
<i>CsSLD2.1</i>	<i>CsSLD1.1</i>	0.131823281	0.784305969	0.168076345	Purifying selection	fragment duplication
<i>CsSLD2.2</i>	<i>CsSLD1.3</i>	0.138622742	0.741391199	0.186976514	Purifying selection	fragment duplication
<i>CsSLD2.2</i>	<i>CsSLD2.3</i>	0.004833659	0.134198997	0.036018592	Purifying selection	fragment duplication
<i>CsSLD2.2</i>	<i>CsSLD1.1</i>	0.139601372	0.770996041	0.181066264	Purifying selection	fragment duplication
<i>CsSLD2.3</i>	<i>CsSLD1.1</i>	0.13816907	0.726898846	0.190080189	Purifying selection	fragment duplication

附表 4 亚麻荠 *CsFAD* 基因在 3 个异源亚基因组中的分布情况Table S4 Distribution of *CsFAD* genes among the three subgenomes of *Camelina sativa*

亚基因组 Subgenome	染色体 Chromosome	<i>FAD</i> 基因的数量 Number of <i>FAD</i> genes
Cs-G1	Chr4	1
	Chr11	2
	Chr13	2
	Chr15	5
	Chr16	4
	Chr17	6
	<b>总计 Total</b>	<b>20</b>
Cs-G2	Chr6	1
	Chr7	3
	Chr8	2
	Chr10	2
	Chr14	4
	Chr18	0
	Chr19	4
<b>总计 Total</b>	<b>16</b>	
Cs-G3	Chr1	4
	Chr2	2
	Chr3	3
	Chr5	4
	Chr9	2
	Chr12	2
	Chr20	1
<b>总计 Total</b>	<b>18</b>	