
Supplementary File

1 Content Description

This file contains multiple sets of tests with different dimensions based on the 30 functions mentioned in this paper and details of tests on CEC 2019 problems. In part 2, Table S1, Table S2 and Table S3 present the test results with dimensions equal to 10, 50 and 100 on 30 functions, respectively. Part 3 shows the details of testing on CEC 2019. Part 3.1 introduces the details of test functions of CEC 2019 in Table S4. Part 3.2 presents the results of accuracy analysis, where the detailed results are shown in Table S5, and the results are confirmed by the Wilcoxon rank-sum tests shown in Table S6. Besides, the Friedman test results with the Holm procedure is presented in Table S7. Part 3.3 depicts the convergence behavior, where the convergence curves of all functions are shown in Fig. S1.

2 Multi-dimensional test results

See Tables S1, S2 and S3.

Table S1: Results on unimodal/multimodal functions (10D).

		F1	F2	F3	F4	F5	F6
WOA	Mean	0.00E+00	8.18E-215	7.48E-02	4.44E-14	5.24E+00	3.93E-05
	Std	0.00E+00	0.00E+00	1.58E-01	1.26E-13	1.05E+00	3.41E-05
OWOA	Mean	9.29E-305	1.24E-164	1.41E-129	1.92E-120	4.76E+00	6.46E-04
	Std	0.00E+00	0.00E+00	5.42E-129	1.05E-119	3.34E-01	5.87E-04
IWOA	Mean	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.15E+00	5.80E-05
	Std	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.20E-01	6.18E-05
LWOA	Mean	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.95E+00	1.70E-05
	Std	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.75E-01	1.69E-05
RDWOA	Mean	7.29E-157	5.24E-13	3.05E-80	3.34E-46	2.79E+00	2.85E-04
	Std	3.99E-156	2.87E-12	1.67E-79	1.83E-45	1.50E+00	3.07E-04
TLBO	Mean	5.87E+02	5.69E+00	9.14E+02	1.19E+01	9.27E+04	3.23E-03
	Std	4.34E+02	2.33E+00	7.14E+02	3.73E+00	1.30E+05	1.68E-03
GWO	Mean	7.68E-240	3.19E-135	6.33E-109	1.57E-75	6.21E+00	1.76E-04
	Std	0.00E+00	8.86E-135	2.43E-108	5.09E-75	7.57E-01	1.36E-04
MFO	Mean	1.77E-63	9.56E-39	1.21E-17	1.91E-01	1.11E+01	4.21E-03
	Std	7.69E-63	2.64E-38	2.59E-17	4.92E-01	3.13E+01	3.99E-03
ETLBO	Mean	0.00E+00	6.82E-162	0.00E+00	4.22E-157	8.88E+00	2.91E-04
	Std	0.00E+00	2.26E-161	0.00E+00	1.07E-156	2.27E-01	1.79E-04
wPSO	Mean	4.49E-05	1.60E-02	2.10E-02	3.80E-01	1.44E+01	6.84E-01
	Std	1.04E-04	2.12E-02	4.18E-02	2.95E-01	2.56E+01	3.28E-01
OABC	Mean	1.13E-16	7.73E-17	1.28E-01	1.12E+01	1.66E+01	2.46E-03
	Std	1.03E-16	1.24E-16	4.31E-01	1.61E+01	5.27E+01	1.05E-03
EWOA	Mean	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.12E+00	1.68E-05
	Std	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.40E+00	1.35E-05
		1	1	1	1	3	1
		F7	F8	F9	F10	F11	
WOA	Mean	0.00E+00	8.88E-16	1.04E-02	6.15E-05	9.71E-04	
	Std	0.00E+00	0.00E+00	2.71E-02	3.23E-05	2.78E-03	
OWOA	Mean	0.00E+00	8.88E-16	0.00E+00	2.36E-07	8.46E-03	
	Std	0.00E+00	0.00E+00	0.00E+00	1.20E-07	2.51E-02	
IWOA	Mean	0.00E+00	8.88E-16	0.00E+00	1.97E-08	4.34E-03	
	Std	0.00E+00	0.00E+00	0.00E+00	2.16E-08	1.79E-02	
LWOA	Mean	0.00E+00	8.88E-16	0.00E+00	3.36E-03	2.53E-02	
	Std	0.00E+00	0.00E+00	0.00E+00	8.56E-03	4.37E-02	
RDWOA	Mean	0.00E+00	1.01E-15	6.25E-03	1.86E-06	6.43E-06	
	Std	0.00E+00	6.49E-16	2.89E-02	4.43E-06	1.72E-05	
TLBO	Mean	2.59E+01	8.17E+00	8.37E+00	2.69E+01	2.64E+04	
	Std	7.56E+00	2.96E+00	3.80E+00	7.75E+01	7.77E+04	
GWO	Mean	0.00E+00	4.44E-15	1.38E-02	2.65E-03	2.43E-02	
	Std	0.00E+00	0.00E+00	2.10E-02	6.87E-03	4.93E-02	
MFO	Mean	1.28E+01	4.32E-15	1.55E-01	1.45E-01	1.83E-03	
	Std	5.78E+00	6.49E-16	9.60E-02	2.27E-01	4.16E-03	
ETLBO	Mean	0.00E+00	2.78E-15	0.00E+00	2.25E-01	5.63E-01	
	Std	0.00E+00	1.80E-15	0.00E+00	1.73E-01	2.40E-01	
wPSO	Mean	7.83E+00	1.41E+00	2.57E-01	9.96E-02	9.94E-03	
	Std	3.16E+00	9.22E-01	1.42E-01	1.67E-01	1.21E-02	
OABC	Mean	6.63E-02	8.23E-15	2.12E-02	1.27E-16	3.66E-04	
	Std	2.52E-01	2.79E-15	1.46E-02	8.35E-17	2.01E-03	
EWOA	Mean	0.00E+00	8.88E-16	0.00E+00	2.18E-02	8.69E-02	
	Std	0.00E+00	0.00E+00	0.00E+00	1.53E-02	5.73E-02	
Rank		1	1	1	5	9	

Table S2: Results on unimodal/multimodal functions (50D).

		F1	F2	F3	F4	F5	F6
WOA	Mean	0.00E+00	1.06E-206	1.38E+04	1.88E-06	4.68E+01	2.84E-05
	Std	0.00E+00	0.00E+00	6.42E+03	7.55E-06	5.49E-01	3.21E-05
OWOA	Mean	4.57E-248	3.26E-141	3.57E-57	5.22E-93	4.58E+01	1.48E-03
	Std	0.00E+00	1.38E-140	1.41E-56	2.55E-92	6.75E-01	6.26E-04
IWOA	Mean	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.49E+01	5.44E-05
	Std	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.97E-01	5.46E-05
LWOA	Mean	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.74E+01	2.15E-05
	Std	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.84E-01	1.93E-05
RDWOA	Mean	2.25E-142	2.96E-48	1.01E-93	9.78E-53	3.41E+01	5.74E-04
	Std	1.12E-141	1.62E-47	5.37E-93	4.10E-52	1.91E+01	7.83E-04
TLBO	Mean	1.12E+04	5.46E+01	2.20E+04	2.98E+01	4.92E+06	3.53E-03
	Std	2.59E+03	5.87E+00	1.10E+04	3.78E+00	2.57E+06	1.53E-03
GWO	Mean	4.33E-91	7.69E-54	1.29E-17	4.02E-20	4.71E+01	6.23E-04
	Std	1.57E-90	1.44E-53	3.56E-17	4.45E-20	9.04E-01	4.66E-04
MFO	Mean	1.12E-02	3.79E-03	2.51E+03	5.86E+01	1.72E+02	5.29E-01
	Std	5.77E-02	1.33E-02	9.93E+02	5.10E+00	1.32E+02	6.80E-01
ETLBO	Mean	0.00E+00	4.66E-163	0.00E+00	1.88E-158	4.89E+01	2.55E-04
	Std	0.00E+00	2.22E-162	0.00E+00	7.21E-158	2.50E-02	1.39E-04
wPSO	Mean	8.06E+02	1.57E+01	8.03E+03	2.85E+01	1.12E+05	6.50E-01
	Std	2.71E+02	3.42E+00	2.27E+03	3.51E+00	7.50E+04	2.99E-01
OABC	Mean	1.12E+03	5.77E-04	2.35E+04	7.92E+01	5.51E+06	3.43E-01
	Std	4.44E+03	4.49E-04	5.26E+03	7.88E+00	2.25E+07	2.78E-01
EWOA	Mean	0.00E+00	0.00E+00	0.00E+00	2.77E-303	4.82E+01	1.49E-05
	Std	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.99E-01	1.41E-05
		1	1	1	3	7	1
		F7	F8	F9	F10	F11	
WOA	Mean	0.00E+00	8.88E-16	1.71E-03	1.96E-03	1.53E-01	
	Std	0.00E+00	0.00E+00	9.34E-03	1.28E-03	1.50E-01	
OWOA	Mean	0.00E+00	8.88E-16	0.00E+00	4.57E-03	3.87E-01	
	Std	0.00E+00	0.00E+00	0.00E+00	5.23E-03	2.28E-01	
IWOA	Mean	0.00E+00	8.88E-16	0.00E+00	3.91E-04	1.50E-01	
	Std	0.00E+00	0.00E+00	0.00E+00	1.49E-03	1.81E-01	
LWOA	Mean	0.00E+00	8.88E-16	0.00E+00	1.45E-02	3.53E-01	
	Std	0.00E+00	0.00E+00	0.00E+00	1.05E-02	2.74E-01	
RDWOA	Mean	0.00E+00	8.88E-16	4.31E-11	3.70E-05	3.79E-03	
	Std	0.00E+00	0.00E+00	2.36E-10	1.68E-04	9.08E-03	
TLBO	Mean	3.51E+02	1.36E+01	9.60E+01	3.73E+05	4.79E+06	
	Std	2.00E+01	6.59E-01	2.80E+01	4.94E+05	4.01E+06	
GWO	Mean	0.00E+00	1.52E-14	7.24E-04	9.66E-02	1.62E+00	
	Std	0.00E+00	1.98E-15	2.85E-03	6.21E-02	2.90E-01	
MFO	Mean	1.18E+02	3.19E+00	2.13E-01	7.68E-01	1.45E+00	
	Std	1.76E+01	1.20E+00	5.65E-01	1.06E+00	2.29E+00	
ETLBO	Mean	0.00E+00	2.66E-15	0.00E+00	9.33E-01	4.99E+00	
	Std	0.00E+00	1.81E-15	0.00E+00	1.64E-01	3.50E-02	
wPSO	Mean	1.55E+02	9.38E+00	8.13E+00	4.73E+01	1.58E+04	
	Std	2.36E+01	1.07E+00	2.29E+00	3.20E+01	2.40E+04	
OABC	Mean	5.43E+00	2.85E-01	1.52E+00	2.28E+06	9.30E+05	
	Std	1.42E+01	1.55E+00	8.21E+00	9.61E+06	2.18E+06	
EWOA	Mean	0.00E+00	8.88E-16	0.00E+00	4.14E-02	7.11E-01	
	Std	0.00E+00	0.00E+00	0.00E+00	2.62E-02	4.19E-01	
Rank		1	1	1	6	6	

Table S3: Results on unimodal/multimodal functions (100D).

		F1	F2	F3	F4	F5	F6
WOA	Mean	2.58E-302	1.26E-208	1.22E+05	1.33E-07	9.71E+01	3.47E-05
	Std	0.00E+00	0.00E+00	5.80E+04	5.08E-07	5.87E-01	3.70E-05
OWOA	Mean	7.54E-244	1.14E-135	1.77E-45	1.08E-88	9.59E+01	1.12E-03
	Std	0.00E+00	4.42E-135	8.64E-45	5.54E-88	7.72E-01	7.01E-04
IWOA	Mean	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.52E+01	6.68E-05
	Std	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.51E-01	6.59E-05
LWOA	Mean	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.77E+01	2.96E-05
	Std	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.55E-01	3.51E-05
RDWOA	Mean	2.36E-126	1.79E-67	5.90E-58	4.12E-42	7.09E+01	2.99E-04
	Std	1.29E-125	9.82E-67	3.23E-57	2.26E-41	4.10E+01	3.60E-04
TLBO	Mean	2.36E+04	1.28E+02	9.52E+04	3.31E+01	1.29E+07	3.40E-03
	Std	3.48E+03	8.93E+00	3.60E+04	2.92E+00	3.34E+06	2.01E-03
GWO	Mean	1.43E-63	9.48E-38	1.14E-04	5.32E-12	9.74E+01	1.09E-03
	Std	1.73E-63	7.41E-38	3.86E-04	7.02E-12	7.83E-01	5.62E-04
MFO	Mean	6.25E+02	4.40E+00	3.78E+04	7.38E+01	4.15E+05	8.37E+00
	Std	6.51E+02	3.22E+00	7.61E+03	3.48E+00	7.68E+05	7.09E+00
ETLBO	Mean	0.00E+00	1.65E-162	0.00E+00	5.66E-160	9.90E+01	3.06E-04
	Std	0.00E+00	4.97E-162	0.00E+00	1.25E-159	2.01E-02	1.72E-04
wPSO	Mean	8.08E+03	6.11E+01	4.32E+04	3.93E+01	2.97E+06	4.23E+00
	Std	1.23E+03	9.40E+00	7.63E+03	3.41E+00	9.07E+05	1.35E+00
OABC	Mean	7.15E+03	1.69E+00	1.12E+05	8.98E+01	3.44E+07	3.82E+01
	Std	1.46E+04	5.69E+00	2.77E+04	5.18E+00	4.67E+07	6.10E+01
EWOA	Mean	0.00E+00	0.00E+00	0.00E+00	7.83E-305	9.81E+01	2.01E-05
	Std	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.61E-01	1.67E-05
		1	1	1	3	7	1
		F7	F8	F9	F10	F11	
WOA	Mean	0.00E+00	8.88E-16	0.00E+00	5.91E-03	6.97E-01	
	Std	0.00E+00	0.00E+00	0.00E+00	1.93E-03	2.73E-01	
OWOA	Mean	0.00E+00	8.88E-16	0.00E+00	7.12E-03	1.48E+00	
	Std	0.00E+00	0.00E+00	0.00E+00	5.62E-03	5.53E-01	
IWOA	Mean	0.00E+00	8.88E-16	0.00E+00	3.57E-03	8.25E-01	
	Std	0.00E+00	0.00E+00	0.00E+00	3.41E-03	5.67E-01	
LWOA	Mean	0.00E+00	8.88E-16	0.00E+00	3.09E-02	1.34E+00	
	Std	0.00E+00	0.00E+00	0.00E+00	3.99E-02	1.24E+00	
RDWOA	Mean	0.00E+00	1.01E-15	0.00E+00	5.66E-04	5.40E-03	
	Std	0.00E+00	6.49E-16	0.00E+00	1.33E-03	2.44E-02	
TLBO	Mean	8.13E+02	1.43E+01	2.28E+02	1.76E+06	1.89E+07	
	Std	4.86E+01	5.90E-01	3.72E+01	1.20E+06	1.07E+07	
GWO	Mean	1.89E-14	2.92E-14	1.69E-03	2.48E-01	6.08E+00	
	Std	4.31E-14	2.38E-15	4.63E-03	6.87E-02	3.94E-01	
MFO	Mean	2.81E+02	1.07E+01	7.80E+00	5.19E+05	1.76E+06	
	Std	3.27E+01	2.58E+00	8.73E+00	1.51E+06	4.65E+06	
ETLBO	Mean	0.00E+00	3.02E-15	0.00E+00	1.08E+00	9.99E+00	
	Std	0.00E+00	1.77E-15	0.00E+00	9.18E-02	4.03E-03	
wPSO	Mean	5.18E+02	1.31E+01	7.00E+01	1.78E+05	3.26E+06	
	Std	4.86E+01	7.91E-01	1.46E+01	1.32E+05	1.81E+06	
OABC	Mean	3.23E+01	1.43E+00	7.49E+01	1.09E+08	2.01E+08	
	Std	1.22E+01	3.72E+00	1.93E+02	1.41E+08	2.67E+08	
EWOA	Mean	0.00E+00	8.88E-16	0.00E+00	4.10E-02	1.53E+00	
	Std	0.00E+00	0.00E+00	0.00E+00	3.03E-02	8.33E-01	
Rank		1	1	1	6	6	

3 Tests on CEC 2019 benchmarks

3.1 Function description of CEC 2019

See Table S4.

Table S4: CEC 2019 test problems.

No.	Functions	D	Search Range
1	Storn's Chebyshev Polynomial Fitting Problem	9	[-8192, 8192]
2	Inverse Hilbert Matrix Problem	16	[-16384, 16384]
3	Lennard-Jones Minimum Energy Cluster	18	[-4,4]
4	Rastrigin's Function	10	[-100,100]
5	Griewangk's Function	10	[-100,100]
6	Weierstrass Function	10	[-100,100]
7	Modified Schwefel's Function	10	[-100,100]
8	Expanded Schaffer's F6 Function	10	[-100,100]
9	Happy Cat Function	10	[-100,100]
10	Ackley Function	10	[-100,100]

3.2 Accuracy analysis

See Tables S5, S6 and S7.

3.3 Convergence behavior

See Fig. S1

Table S5: Results on CEC 2019 problems

		F1	F2	F3	F4	F5
WOA	Mean	1136730	5406.56	3.915471	30.77151	1.276499
	Std	922087.2	2361.012	2.443677	12.68874	0.091078
OWOA	Mean	779364.9	4653.333	2.499844	37.25132	1.300599
	Std	1106081	1458.837	1.142788	12.24921	0.177698
IWOA	Mean	1	4.972495	5.984107	78.88697	69.49849
	Std	0	0.070917	0.321113	5.712161	5.985289
LWOA	Mean	1	4.707167	3.505091	41.47247	4.265642
	Std	0	0.359144	1.267259	12.16756	1.157581
RDWOA	Mean	316.0575	225.3075	2.81854	34.64596	1.603115
	Std	608.372	116.3398	2.469398	12.81126	0.278692
EWOA	Mean	1	4.629993	1.327308	31.25582	1.421748
	Std	0	0.37009	0.163654	11.38734	0.20662
Rank		1	1	1	2	2
		F6	F7	F8	F9	F10
WOA	Mean	5.228556	1027.869	3.866849	1.21714	17.5457
	Std	1.287408	330.2903	0.460375	0.083124	6.460649
OWOA	Mean	6.103254	761.4645	4.110753	1.227723	16.04797
	Std	1.522155	267.7764	0.276818	0.077846	7.565816
IWOA	Mean	8.119862	1453.994	4.696449	1.731149	21.26931
	Std	0.477117	127.1673	0.156455	0.279334	0.087608
LWOA	Mean	7.439611	1262.555	4.18032	1.351483	21.17994
	Std	0.954562	303.978	0.361467	0.13281	0.117611
RDWOA	Mean	5.413942	1101.973	4.437798	1.292702	21.00488
	Std	1.160805	257.5754	0.396312	0.127134	0.008393
EWOA	Mean	4.428849	732.6278	3.586337	1.193317	12.31261
	Std	0.891604	218.4377	0.255233	0.063455	8.67736
Rank		1	1	1	1	1

Table S6: The results of wilcoxon's rank sum test

Function	EWOA Vs.					
		WOA	OWOA	IWOA	LWOA	RDWOA
F1	<i>p</i>	6.39E-05	6.39E-05	NaN	NaN	7.79E-02
	<i>h</i>	1	1	0	0	0
F2	<i>p</i>	1.63E-04	1.63E-04	3.32E-01	4.82E-01	1.63E-04
	<i>h</i>	1	1	0	0	1
F3	<i>p</i>	1.83E-04	1.83E-04	1.83E-04	1.83E-04	7.28E-03
	<i>h</i>	1	1	1	1	1
F4	<i>p</i>	9.70E-01	5.21E-01	1.83E-04	1.62E-01	4.73E-01
	<i>h</i>	0	0	1	0	0
F5	<i>p</i>	8.90E-02	8.90E-02	1.83E-04	1.83E-04	1.86E-01
	<i>h</i>	0	0	1	1	0
F6	<i>p</i>	1.62E-01	1.13E-02	1.83E-04	1.83E-04	8.90E-02
	<i>h</i>	0	1	1	1	0
F7	<i>p</i>	2.11E-02	5.21E-01	1.83E-04	2.20E-03	1.73E-02
	<i>h</i>	1	0	1	1	1
F8	<i>p</i>	2.73E-01	1.01E-03	1.83E-04	3.61E-03	1.71E-03
	<i>h</i>	0	1	1	1	1
F9	<i>p</i>	3.85E-01	3.45E-01	1.83E-04	5.80E-03	1.04E-01
	<i>h</i>	0	0	1	1	0
F10	<i>p</i>	1.40E-01	1.62E-01	1.83E-04	1.83E-04	1.83E-04
	<i>h</i>	0	0	1	1	1

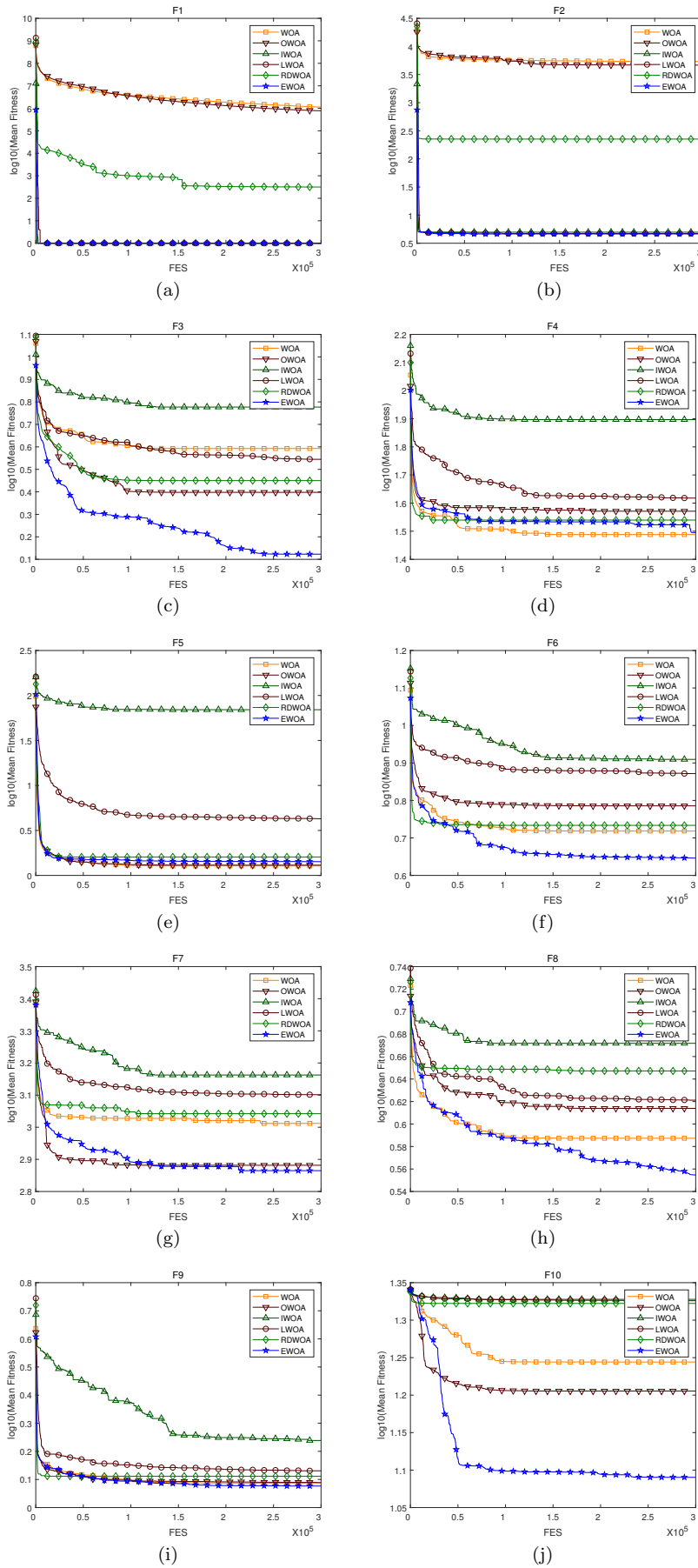


Fig. S1: Convergence trends of EWOA and compared algorithms on CEC 2019 functions.

Table S7: Friedman tests on CEC 2019.

i	Algorithms	Average ranking	$z = (R_0 - R_i) / SE$	unadjusted p	p_{Holm}
6	IWOA	5.3	4.661392	0.000003	0.000016
5	LWOA	4.2	3.34664	0.000818	0.003272
4	RDWOA	3.8	2.868549	0.004124	0.012371
3	OWOA	3.2	2.151411	0.031444	0.062887
2	WOA	3.1	2.031889	0.042165	0.062887
1	EWOA	1.4			