Predicting System Workload through Global Optimization for Neural Network Modeling

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ARTICLE HISTORY
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1. Full Experiment with Benchmark Functions Tests

In this test, we used 30 benchmark functions which are mathematical functions that need to find the global optima. These functions can be divided into four types, including unimodal, multi-modal, hybrid, and composition. The unimodal function is the function that contains only one optimum.

Meanwhile, multi-modal contains more than one optimum. A hybrid function is a combination of different basic functions (i.e., unimodal and multi-modal). In this way, the optima number of a hybrid function depends on its basic functions. Composition function is a combination of different hybrid functions. We briefly list them by name and optimal global aspect by Table 1.

1.0.1. Unimodal Functions

The gained results with unimodal functions F1, F2, and F3 are shown in Table 2. An observation can be made from this test. According to the achieved mean values, IQSO proves its excellence as compared with the other meta-heuristic algorithms in searching global optima. This mean value represents the average difference between the global optima and the best solution of each run. Thus, the smaller mean value is equivalent to the better searchability. Besides, the gained mean values of IQSO for F1 and F3 are nearly 0, and they are smaller remarkably than the rest. Although for F2, the mean value of IQSO is approximately equal to 2. This value is still smaller than the others. Based on these analyses, it can be concluded that IQSO outperforms other algorithms in terms of the global search capability for unimodal functions.

Meantime, the obtained mean and *std* values presented in Table 2 also shows that IQSO runs stably in ten runs as compared with others. With the best and worst values, the differences between each run of IQSO vary in a minuscule range. Figure 1 describes the convergence rate of all algorithms with unimodal functions. A remark can be made from the experiment as follows. IQSO (enhanced by opposition-based learning) converges quickly after the first few dozen loops, even though the gained

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Type	Code	Function	Global optimal
Unimodal	F1	Rotated High Conditioned Elliptic Function	100
	F2	Rotated Bent Cigar Function	200
	F3	Rotated Discus Function	300
Multimodal	F4	Shifted and Rotated Rosenbrock's Function	400
	F5	Shifted and Rotated Ackley's Function	500
	F6	Shifted and Rotated Weierstrass Function	600
	F7	Shifted and Rotated Griewank's Function	700
	F8	Shifted Rastrigin's Function	800
	F9	Shifted and Rotated Rastrigin's Function	900
	F10	Shifted Schwefel's Function	1000
	F11	Shifted and Rotated Schwefel's Function	1100
	F12	Shifted and Rotated Katsuura Function	1200
	F13	Shifted and Rotated HappyCat Function	1300
	F14	Shifted and Rotated HGBat Function	1400
	F15	Shifted and Rotated Expanded Griewank's plus Rosenbrock's Function	1500
	F16	Shifted and Rotated Expanded Scaffer's F6 Function	1600
Hybrid	F17	Hybrid Function 1 (N=3)	1700
	F18	Hybrid Function 2 (N=3)	1800
	F18	Hybrid Function 3 (N=4)	1900
	F20	Hybrid Function 4 (N=4)	2000
	F21	Hybrid Function 5 (N=5)	2100
	F22	Hybrid Function 6 (N=5)	2200
Composition	F23	Composition Function 1 (N=5)	2300
	F24	Composition Function 2 (N=3)	2400
	F25	Composition Function 3 (N=3)	2500
	F26	Composition Function 4 (N=5)	2600
	F27	Composition Function 5 (N=5)	2700
	F28	Composition Function 6 (N=5)	2800
	F29	Composition Function 7 (N=3)	2900
	F30	Composition Function 8 (N=3)	3000

Table 1. CEC 2014 benchmark functions

Function	Criteria	GA	PSO	ABC	CRO	WOA	QSO	IQSO
F1	std	5.01E+05	9.91E+05	1.38E+08	1.67E+05	1.08E+03	3.09E+00	**1.69E-02**
	mean	4.59E+05	8.69E+05	1.26E+08	1.48E+05	8.64E+02	2.48E+00	**1.36E-02**
	worst	1.04E+06	2.05E+06	2.26E+08	2.88E+05	2.63E+03	1.06E+02	**1.00E+02**
	best	2.30E+05	2.20E+05	6.20E+07	2.30E+04	1.87E+02	1.00E+02	**1.00E+02**
	rank	5	6	7	4	3	2	**1**
F2	std	1.33E+07	5.54E+07	2.38E+10	1.00E+06	4.29E+03	9.09E+02	**2.02E+00**
	mean	1.27E+07	4.43E+07	2.34E+10	1.00E+06	3.05E+03	7.82E+02	**1.72E+00**
	worst	2.22E+07	1.04E+08	2.94E+10	1.00E+06	1.20E+04	2.01E+03	**2.04E+02**
	best	8.19E+06	7.69E+06	1.31E+10	1.00E+06	4.79E+02	4.31E+02	**2.00E+02**
	rank	5	6	8	4	3	2	**1**
F3	std	2.75E+03	8.96E+03	5.04E+04	1.33E+03	1.27E+02	3.10E-03	**1.70E-03**
	mean	1.41E+03	8.62E+03	4.94E+04	4.96E+02	1.00E+02	2.70E-03	**9.00E-04**
	worst	1.00E+04	1.43E+04	6.05E+04	5.34E+03	6.34E+02	3.00E+02	**3.00E+02**
	best	3.22E+02	4.79E+03	2.18E+04	3.03E+02	3.11E+02	3.00E+02	**3.00E+02**
	rank	5	6	7	4	3	2	**1**

Table 2. Algorithm performance with unimodal functions

convergence results of other algorithms are fast, they are still worse than IQSO.

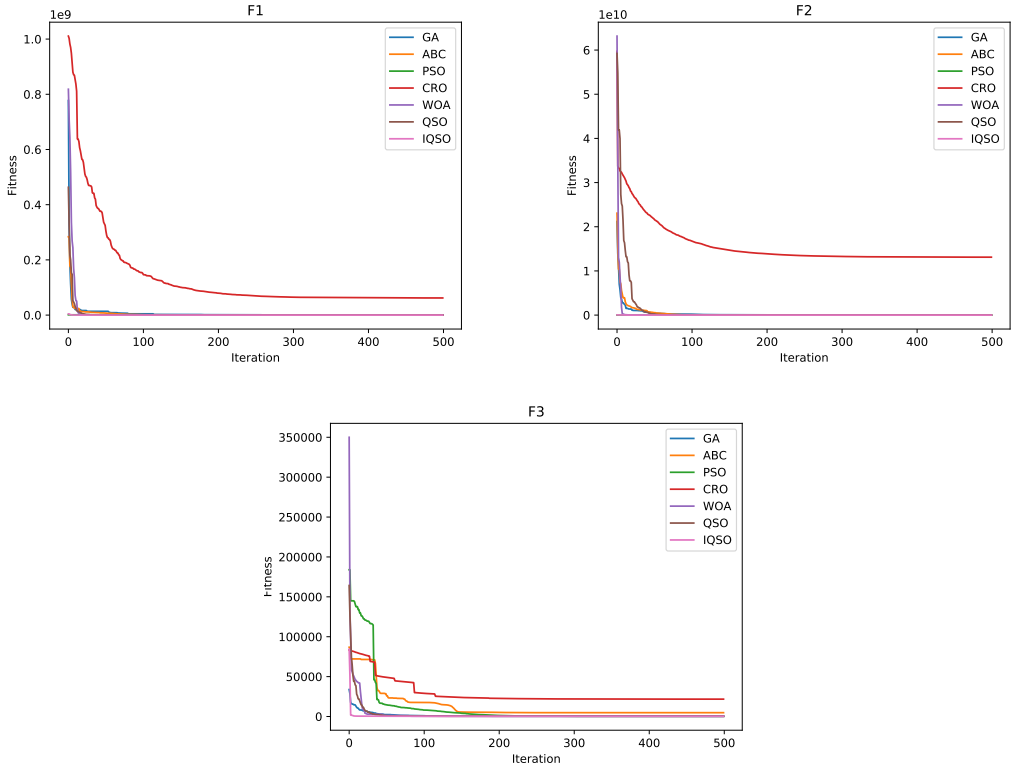

Figure 1. Convergence capability of tested algorithms with unimodal functions

1.0.2. Multi-modal Functions

Obtained experimental results with multi-modal functions are presented in Table 3. Here, IQSO has the best results with 6 of 13 functions (i.e., F6, F7, F8, F9, F10, and F11). For the rest, IQSO stands at the second place, except for the third place with F14. It also can be observed that the IQSO is better than WOA in all test cases. Also, the original QSO has worse performance than IQSO except for the tests with F14. In short, there are no algorithms, which yield as good results as IQSO in our experiments with multi-modal functions.

To evaluate the algorithm stability, we rely on the gained *std* values. The test outcomes are shown in Table 3, where IQSO and WOA achieved *std* values of approximately zero in all cases. This phenomenon showed that IQSO and WOA have stability in the optimization process. For QSO, its *std* values are higher than in 1000 in F10 and F11 functions. The results prove that except for IQSO and WOA, other algorithms are not stable in these experiments.

1.0.3. Hybrid functions

For the hybrid benchmark functions, IQSO yielded the most effective performance as compared with other algorithms in 5 out of 6 cases (F17, F18, F20, F21, and F22). The outcomes are shown in Table 4, in which WOA and QSO hold the second place in these cases. Meanwhile, also in those 5 cases, the difference between IQSO's mean values and the second-best algorithm's mean values (QSO or WOA) is significant. For the F19 function (in this case, IQSO did not gain the first rank), the difference between

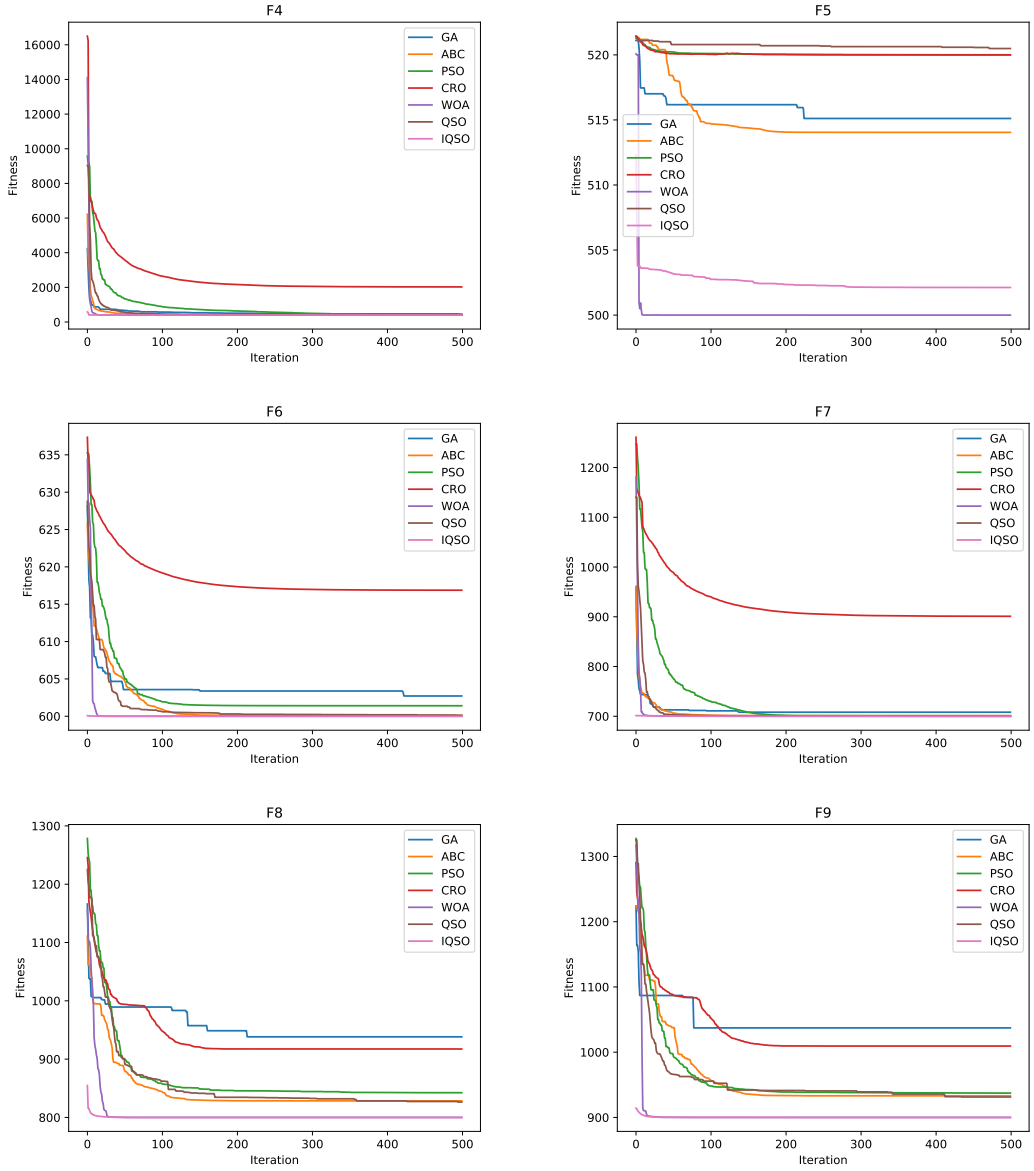

Figure 2. Convergence capability of tested algorithms with multi-modal functions(F4-F9)

the mean value of IQSO and mean value of WOA (the first rank) is minimal. In this experiment, the original QSO is usually ranked in the third place after WOA and IQSO. These results showed that with the proposed improvements, IQSO enhances the performance significantly as compared with the original QSO.

Table 4 also presents the operation stability of test algorithms with hybrid functions. Like the mean metric, *std* values of IQSO are the smallest in 5 out of 6 test functions. This outcome is convincing proof to show that IQSO has better stability than other algorithms. Here, only CRO (red line) has worse performance for F17, F18, and F19 functions, while the others achieved good fitness outcomes.

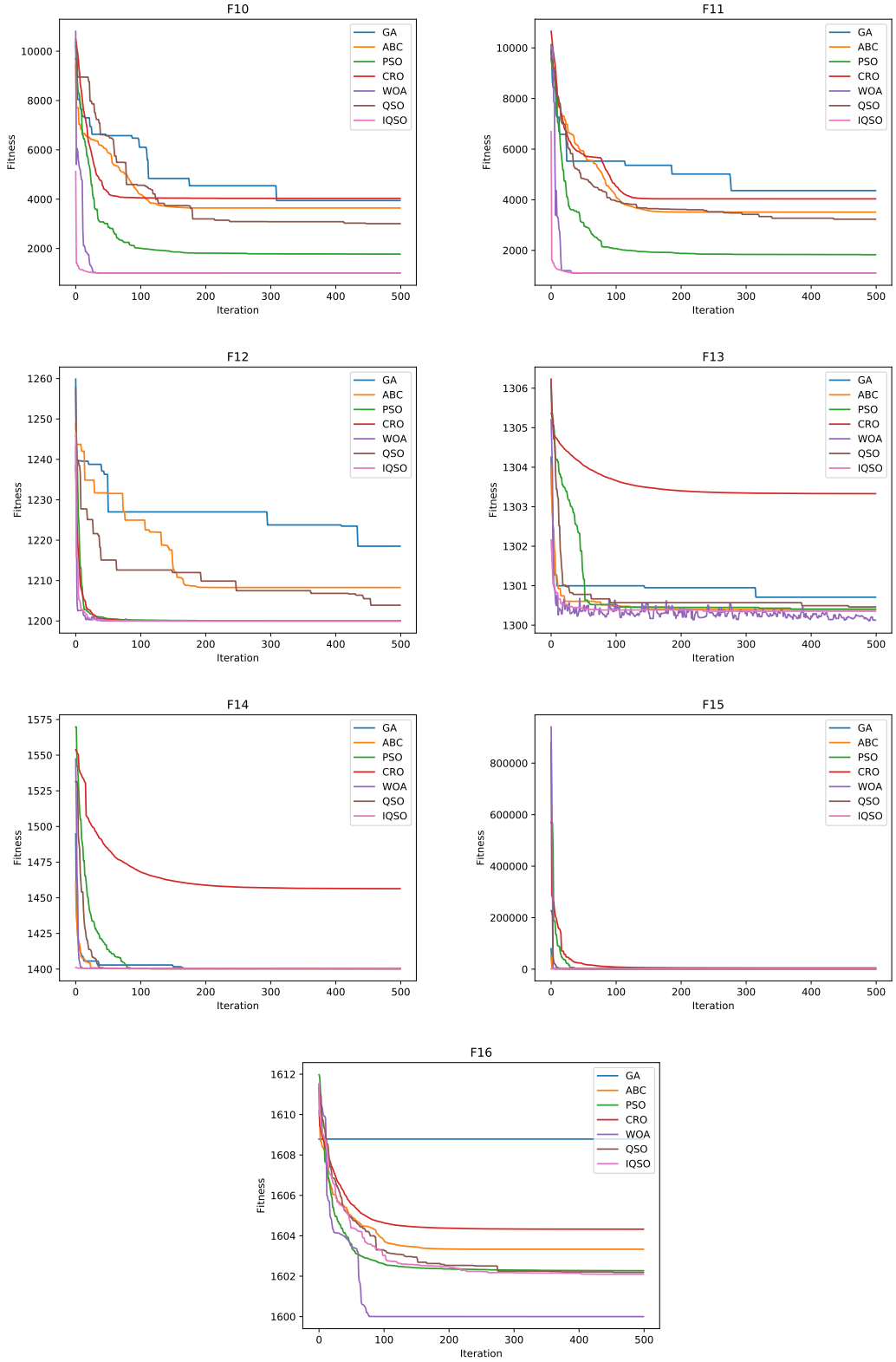

Figure 3. Convergence capability of tested algorithms with multi-modal functions(F10-F16)

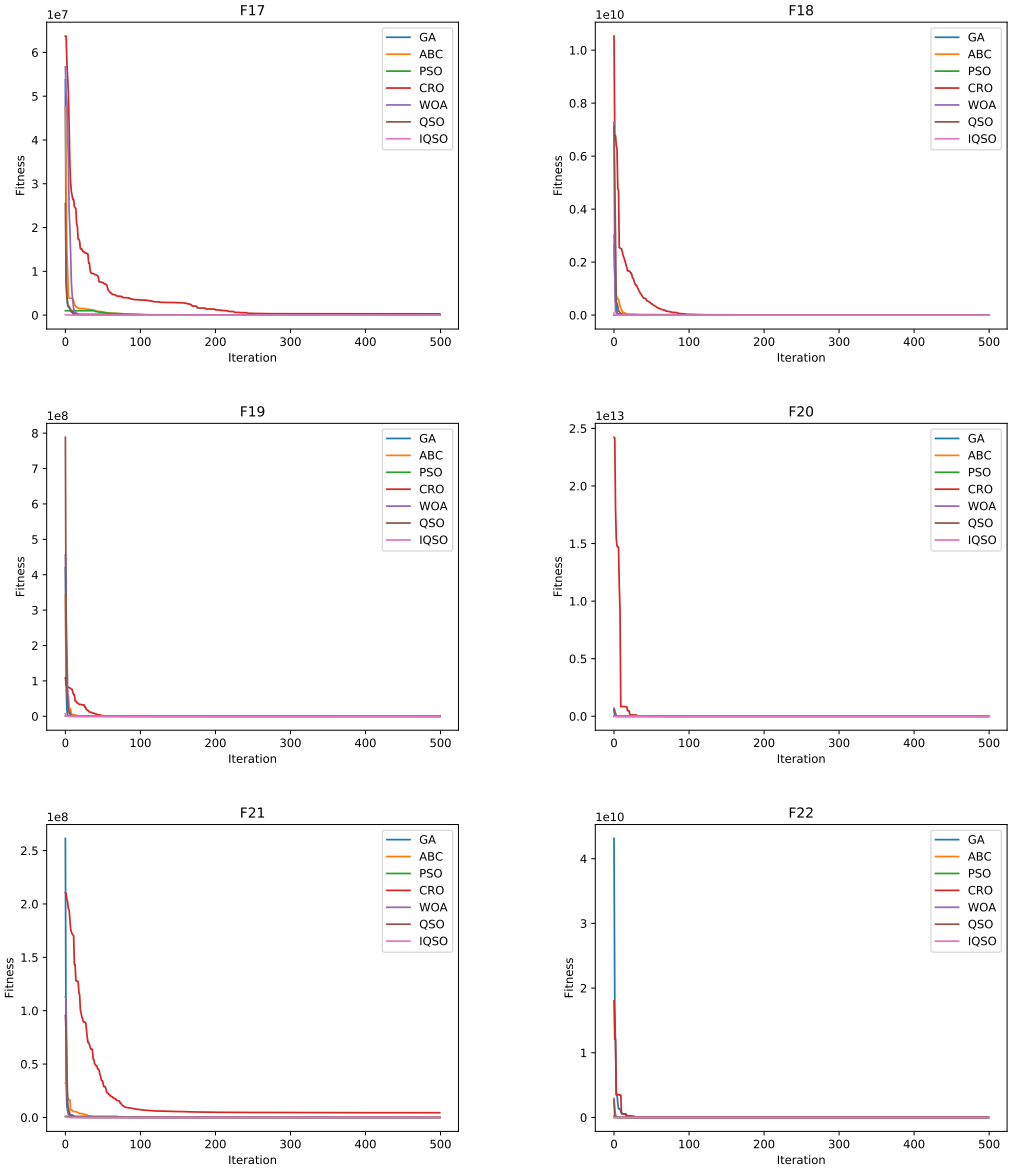

Figure 4. Convergence capability of tested algorithms hybrid functions

1.0.4. Composition functions

The test results with the composition functions for the experimented algorithms are presented in Table 5. IQSO also outperforms as compared with the rest. Explicitly, IQSO holds the first rank in all experiments. Except for F30, the difference between mean values of IQSO and the second-best mean values is quite significant. In terms of the stability, according to *std* values, IQSO also places at the first rank for all functions. The results prove that IQSO has the best stable characteristics for the composition functions. The convergence speed is illustrated by Figure 5. From F23 to F28 functions, IQSO (purple line) has breakneck convergence speed after around 50 to 100 iterations. WOA is very competitive as it converges as fast as IQSO. Meanwhile, for F23, F26, and F25 functions, the original QSO (brown line) needs more than 300

iterations to converge to global optima.

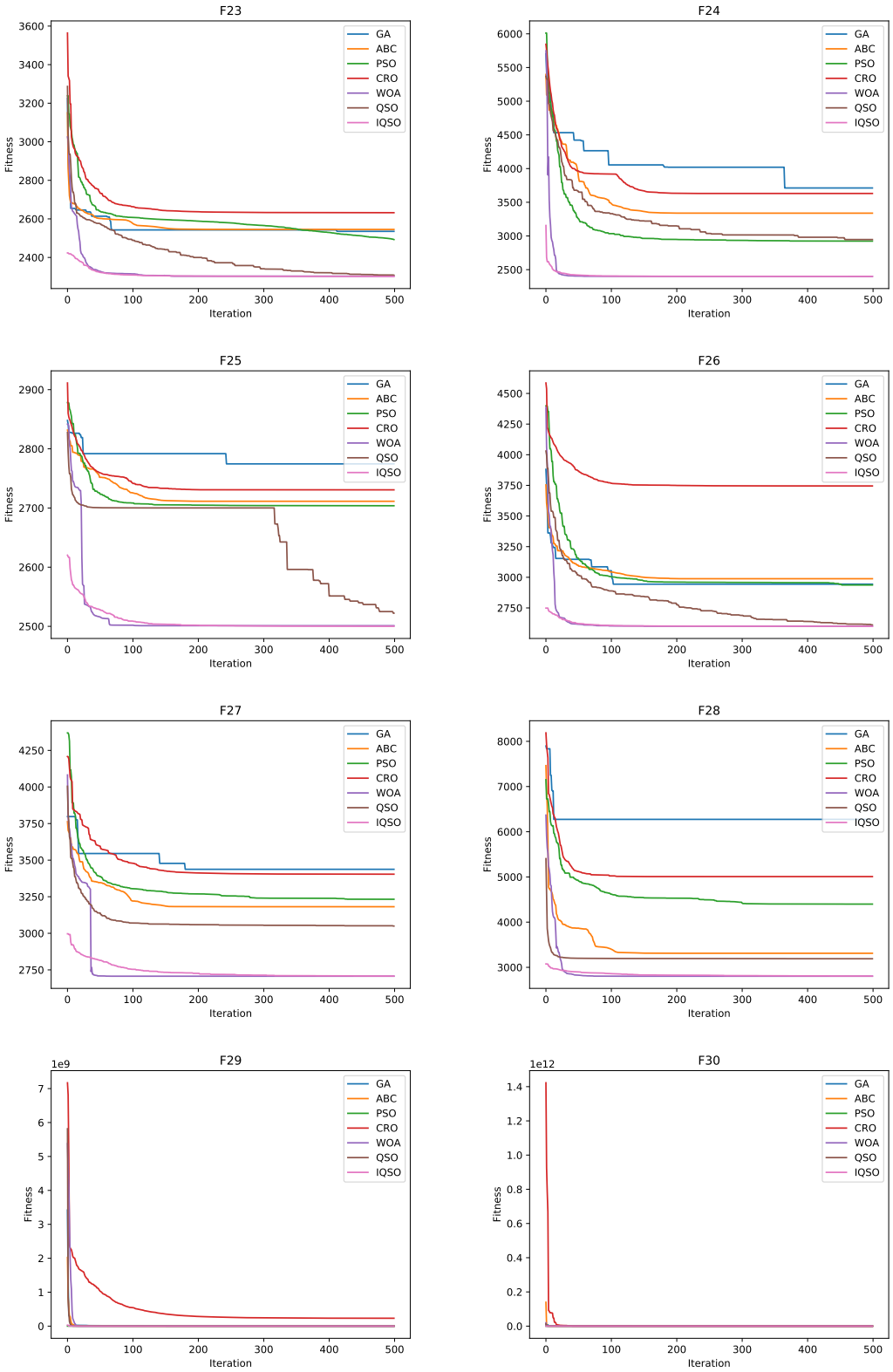

Figure 5. Algorithm performance with composition functions

Function	Criteria	GA	PSO	ABC	CRO	WOA	QSO	IQSO
	std	6.16E+01	8.26E+01	3.02E+03	7.40E+01	**5.00E-04**	3.30E+01	2.00E-03
	mean	6.13E+01	6.87E+01	2.96E+03	6.56E+01	**4.00E-04**	2.94E+01	1.00E-03
F4	worst	4.71E+02	5.63E+02	4.31E+03	5.46E+02	**4.00E+02**	4.85E+02	4.00E+02
	best	4.53E+02	4.09E+02	2.03E+03	4.19E+02	**4.00E+02**	4.20E+02	4.00E+02
	rank	4	6	8	5	**1**	3	2
	std	1.59E+01	1.96E+01	2.00E+01	2.00E+01	**4.55E-02**	2.05E+01	2.63E+00
	mean	1.59E+01	1.95E+01	2.00E+01	2.00E+01	**3.61E-02**	2.05E+01	2.62E+00
F5	worst	5.17E+02	5.21E+02	5.20E+02	5.20E+02	**5.00E+02**	5.21E+02	5.03E+02
	best	5.15E+02	5.14E+02	5.20E+02	5.20E+02	**5.00E+02**	5.20E+02	5.02E+02
	rank	3	5	6	7	**1**	8	2
	std	3.02E+00	1.18E+00	1.97E+01	5.29E+00	0.00E+00	2.78E+00	**0.00E+00**
	mean	3.01E+00	7.89E-01	1.97E+01	4.96E+00	0.00E+00	1.74E+00	**0.00E+00**
F6	worst	6.03E+02	6.03E+02	6.22E+02	6.08E+02	6.00E+02	6.08E+02	**6.00E+02**
	best	6.03E+02	6.00E+02	6.17E+02	6.01E+02	6.00E+02	6.00E+02	**6.00E+02**
	rank	5	3	8	6	2	4	**1**
	std	9.67E+00	1.70E+00	2.47E+02	9.82E-01	1.24E-01	7.27E-02	**7.90E-03**
	mean	9.63E+00	1.67E+00	2.46E+02	9.82E-01	7.26E-02	6.13E-02	**4.40E-03**
F7	worst	7.11E+02	7.02E+02	9.75E+02	7.01E+02	7.00E+02	7.00E+02	**7.00E+02**
	best	7.08E+02	7.01E+02	9.01E+02	7.01E+02	7.00E+02	7.00E+02	**7.00E+02**
	rank	6	5	8	4	3	2	**1**
	std	1.58E+02	7.10E+01	1.60E+02	8.33E+01	2.90E-01	5.61E+01	**0.00E+00**
	mean	1.57E+02	6.75E+01	1.59E+02	8.06E+01	7.68E-02	5.08E+01	**0.00E+00**
F8	worst	9.78E+02	9.21E+02	9.92E+02	9.12E+02	8.01E+02	9.10E+02	**8.00E+02**
	best	9.38E+02	8.28E+02	9.17E+02	8.42E+02	8.00E+02	8.26E+02	**8.00E+02**
	rank	7	5	8	6	2	3	**1**
	std	1.56E+02	8.20E+01	1.56E+02	7.50E+01	2.84E-01	6.49E+01	**0.00E+00**
	mean	1.55E+02	7.88E+01	1.54E+02	7.28E+01	7.73E-02	6.21E+01	**0.00E+00**
F9	worst	1.08E+03	1.02E+03	1.11E+03	9.93E+02	9.01E+02	1.00E+03	**9.00E+02**
	best	1.04E+03	9.33E+02	1.01E+03	9.37E+02	9.00E+02	9.31E+02	**9.00E+02**
	rank	8	6	7	5	2	4	**1**
	std	3.84E+03	4.26E+03	3.74E+03	1.90E+03	3.82E+00	4.04E+03	**8.00E-04**
	mean	3.83E+03	4.20E+03	3.71E+03	1.84E+03	1.37E+00	3.97E+03	**7.00E-04**
F10	worst	5.18E+03	6.12E+03	5.64E+03	3.67E+03	1.01E+03	5.85E+03	**1.00E+03**
	best	3.95E+03	3.64E+03	4.03E+03	1.77E+03	1.00E+03	3.01E+03	**1.00E+03**
	rank	6	8	5	3	2	7	**1**
	std	3.78E+03	4.32E+03	4.04E+03	1.67E+03	6.47E-01	3.87E+03	**9.00E-04**
	mean	3.76E+03	4.23E+03	4.01E+03	1.58E+03	2.42E-01	3.76E+03	**8.00E-04**
F11	worst	5.68E+03	7.57E+03	5.93E+03	3.70E+03	1.10E+03	6.01E+03	**1.10E+03**
	best	4.36E+03	3.51E+03	4.04E+03	1.83E+03	1.10E+03	3.23E+03	**1.10E+03**
	rank	6	8	7	3	2	5	**1**
	std	2.41E+01	1.36E+01	**5.50E-03**	1.08E-01	1.97E-01	5.10E+00	8.13E-02
	mean	2.39E+01	1.31E+01	**3.70E-03**	1.03E-01	1.05E-01	5.07E+00	3.64E-02
F12	worst	1.23E+03	1.22E+03	**1.20E+03**	1.20E+03	1.20E+03	1.21E+03	1.20E+03
	best	1.22E+03	1.21E+03	**1.20E+03**	1.20E+03	1.20E+03	1.20E+03	1.20E+03
	rank	8	7	**1**	3	4	5	2
	std	8.48E-01	6.86E-01	3.81E+00	6.18E-01	**3.05E-01**	5.51E-01	5.02E-01
	mean	8.43E-01	6.63E-01	3.80E+00	6.13E-01	**2.89E-01**	5.48E-01	4.95E-01
F13	worst	1.30E+03	1.30E+03	1.30E+03	1.30E+03	**1.30E+03**	1.30E+03	1.30E+03
	best	1.30E+03	1.30E+03	1.30E+03	1.30E+03	**1.30E+03**	1.30E+03	1.30E+03
	rank	6	5	8	4	**1**	3	2
	std	6.18E-01	**4.30E-01**	6.82E+01	7.65E-01	4.63E-01	4.90E-01	4.39E-01
	mean	6.07E-01	**4.15E-01**	6.80E+01	7.03E-01	4.60E-01	4.25E-01	4.38E-01
F14	worst	1.40E+03	1.40E+03	1.48E+03	1.40E+03	1.40E+03	1.40E+03	**1.40E+03**
	best	1.40E+03	1.40E+03	1.46E+03	1.40E+03	1.40E+03	**1.40E+03**	1.40E+03
	rank	5	**1**	8	6	4	2	3
	std	1.69E+01	2.22E+01	2.08E+04	1.14E+01	**5.52E-02**	1.28E+01	5.55E-02
	mean	1.69E+01	2.09E+01	1.78E+04	1.05E+01	**1.43E-02**	1.27E+01	2.08E-02
F15	worst	1.52E+03	1.54E+03	4.88E+04	1.52E+03	1.50E+03	1.52E+03	**1.50E+03**
	best	1.52E+03	1.51E+03	4.65E+03	1.51E+03	**1.50E+03**	1.51E+03	1.50E+03
	rank	5	6	8	3	**1**	4	2
	std	1.04E+01	4.81E+00	5.77E+00	2.94E+00	**4.10E-03**	2.85E+00	2.80E+00
	mean	1.04E+01	4.70E+00	5.72E+00	2.92E+00	**1.50E-03**	2.79E+00	2.76E+00
F16	worst	1.61E+03	1.61E+03	1.61E+03	1.60E+03	**1.60E+03**	1.60E+03	1.60E+03
	best	1.61E+03	1.60E+03	1.60E+03	1.60E+03	**1.60E+03**	1.60E+03	1.60E+03
	rank	8	5	7	4	**1**	3	2

Table 3. Algorithm performance with multi-modal function

Function	Criteria	GA	PSO	ABC	CRO	WOA	QSO	IQSO
	std	3.84E+04	2.92E+04	4.12E+06	2.91E+03	2.99E+02	6.38E+02	**1.68E+01**
	mean	3.19E+04	2.28E+04	2.98E+06	2.55E+03	2.43E+02	5.79E+02	**1.20E+01**
F17	worst	8.22E+04	7.24E+04	1.05E+07	7.84E+03	2.43E+03	2.75E+03	**1.75E+03**
	best	1.01E+04	7.00E+03	2.88E+05	2.55E+03	1.75E+03	1.84E+03	**1.70E+03**
	rank	6	5	7	4	2	3	**1**
	std	3.54E+06	3.25E+04	2.32E+08	1.92E+04	1.21E+03	4.80E+01	**2.43E+01**
	mean	3.11E+06	2.81E+04	1.30E+08	1.17E+04	1.06E+03	4.71E+01	**2.40E+01**
F18	worst	6.59E+06	7.96E+04	7.70E+08	6.87E+04	3.85E+03	1.87E+03	**1.83E+03**
	best	1.13E+06	1.07E+04	7.15E+04	3.20E+03	2.12E+03	1.84E+03	**1.82E+03**
	rank	6	5	7	4	3	2	**1**
	std	3.89E+03	1.85E+02	1.73E+06	2.71E+03	**1.09E+01**	4.15E+01	1.20E+01
	mean	3.02E+03	6.55E+01	1.02E+06	1.41E+03	**1.02E+01**	2.52E+01	1.19E+01
F19	worst	1.23E+04	2.61E+03	4.01E+06	9.42E+03	1.92E+03	2.05E+03	**1.91E+03**
	best	3.09E+03	1.92E+03	1.91E+03	1.91E+03	**1.91E+03**	1.91E+03	1.91E+03
	rank	6	4	7	5	**1**	3	2
	std	3.77E+04	2.31E+04	2.85E+09	6.03E+03	3.11E+02	1.30E+02	**1.26E+01**
	mean	2.25E+04	1.98E+04	1.98E+09	4.19E+03	2.16E+02	8.00E+01	**1.22E+01**
F20	worst	1.32E+05	5.31E+04	6.93E+09	1.46E+04	2.98E+03	2.45E+03	**2.02E+03**
	best	4.48E+03	8.00E+03	7.46E+04	2.30E+03	2.04E+03	2.02E+03	**2.01E+03**
	rank	6	5	7	4	3	2	**1**
	std	2.83E+04	2.53E+04	1.79E+07	5.40E+03	2.30E+02	5.86E+02	**5.54E+00**
	mean	2.64E+04	2.22E+04	1.49E+07	4.61E+03	1.80E+02	4.82E+02	**5.41E+00**
F21	worst	4.34E+04	4.76E+04	4.32E+07	1.29E+04	2.73E+03	3.47E+03	**2.11E+03**
	best	1.13E+04	7.81E+03	4.44E+06	3.20E+03	2.13E+03	2.21E+03	**2.10E+03**
	rank	6	5	7	4	2	3	**1**
	std	3.72E+03	4.38E+02	5.10E+05	4.84E+03	1.12E+01	5.18E+01	**4.30E+00**
	mean	1.36E+03	3.91E+02	1.34E+05	1.45E+03	1.06E+01	4.53E+01	**4.06E+00**
F22	worst	1.63E+04	3.04E+03	1.98E+06	2.09E+04	2.22E+03	2.30E+03	**2.21E+03**
	best	2.27E+03	2.34E+03	3.48E+03	2.22E+03	2.20E+03	2.22E+03	**2.20E+03**
	rank	5	4	7	6	2	3	**1**

Table 4. Algorithm performance with hybrid functions

Function	Criteria	GA	PSO	ABC	CRO	WOA	QSO	IQSO
	std	2.59E+02	2.88E+02	3.76E+02	2.56E+02	8.05E+00	1.80E+01	**1.82E+00**
	mean	2.59E+02	2.88E+02	3.75E+02	2.54E+02	7.11E+00	1.71E+01	**1.82E+00**
F23	worst	2.57E+03	2.61E+03	2.74E+03	2.60E+03	2.31E+03	2.33E+03	**2.30E+03**
	best	2.54E+03	2.55E+03	2.63E+03	2.49E+03	2.30E+03	2.31E+03	**2.30E+03**
	rank	5	6	7	4	2	3	**1**
	std	1.51E+03	1.49E+03	1.54E+03	8.55E+02	3.58E+01	1.09E+03	**7.86E-02**
	mean	1.51E+03	1.45E+03	1.53E+03	8.38E+02	1.20E+01	1.04E+03	**7.58E-02**
F24	worst	4.05E+03	4.38E+03	4.17E+03	3.62E+03	2.54E+03	3.98E+03	**2.40E+03**
	best	3.71E+03	3.34E+03	3.63E+03	2.92E+03	2.40E+03	2.95E+03	**2.40E+03**
	rank	7	6	8	3	2	4	**1**
	std	2.88E+02	2.24E+02	2.58E+02	2.20E+02	3.94E+00	1.39E+02	**5.31E-01**
	mean	2.88E+02	2.24E+02	2.58E+02	2.20E+02	3.50E+00	1.18E+02	**4.61E-01**
F25	worst	2.80E+03	2.77E+03	2.77E+03	2.75E+03	2.51E+03	2.70E+03	**2.50E+03**
	best	2.77E+03	2.71E+03	2.73E+03	2.70E+03	2.50E+03	2.52E+03	**2.50E+03**
	rank	8	5	7	4	2	3	**1**
	std	4.69E+02	4.49E+02	1.20E+03	4.40E+02	5.49E+00	5.25E+01	**1.24E-01**
	mean	4.67E+02	4.47E+02	1.20E+03	4.36E+02	5.06E+00	3.31E+01	**1.21E-01**
F26	worst	3.10E+03	3.17E+03	3.95E+03	3.13E+03	2.61E+03	2.78E+03	**2.60E+03**
	best	2.94E+03	2.99E+03	3.75E+03	2.94E+03	2.60E+03	2.61E+03	**2.60E+03**
	rank	6	5	8	4	2	3	**1**
	std	7.94E+02	5.90E+02	7.90E+02	5.57E+02	1.65E+01	3.59E+02	**1.20E+01**
	mean	7.93E+02	5.87E+02	7.88E+02	5.57E+02	1.50E+01	3.59E+02	**1.15E+01**
F27	worst	3.54E+03	3.36E+03	3.54E+03	3.29E+03	2.73E+03	3.09E+03	**2.72E+03**
	best	3.44E+03	3.18E+03	3.40E+03	3.23E+03	**2.71E+03**	3.05E+03	2.71E+03
	rank	7	5	6	4	2	3	**1**
	std	4.07E+03	1.02E+03	2.61E+03	1.86E+03	3.68E+02	3.93E+02	**1.90E+01**
	mean	4.05E+03	9.55E+02	2.60E+03	1.85E+03	1.10E+02	3.93E+02	**1.64E+01**
F28	worst	7.63E+03	4.49E+03	5.74E+03	4.87E+03	4.22E+03	3.19E+03	**2.84E+03**
	best	6.27E+03	3.31E+03	5.01E+03	4.40E+03	**2.80E+03**	3.19E+03	2.81E+03
	rank	8	4	6	5	2	3	**1**
	std	1.28E+06	1.47E+06	8.41E+08	2.92E+04	1.60E+03	2.48E+02	**1.99E+02**
	mean	1.20E+06	1.31E+06	7.70E+08	2.90E+04	1.17E+03	2.44E+02	**1.95E+02**
F29	worst	1.97E+06	2.40E+06	1.64E+09	3.55E+04	6.78E+03	3.26E+03	**3.11E+03**
	best	1.90E+05	3.24E+03	2.32E+08	2.83E+04	3.12E+03	3.11E+03	**2.99E+03**
	rank	5	6	8	4	3	2	**1**
	std	8.33E+04	2.10E+04	3.40E+08	2.89E+05	1.25E+03	2.33E+02	**2.23E+02**
	mean	7.59E+04	1.83E+04	2.59E+08	2.24E+05	6.23E+02	2.33E+02	**2.23E+02**
F30	worst	1.30E+05	4.15E+04	9.56E+08	6.44E+05	7.57E+03	3.26E+03	**3.23E+03**
	best	1.77E+04	9.49E+03	4.78E+06	2.76E+04	**3.04E+03**	3.23E+03	3.21E+03
	rank	5	4	7	6	3	2	**1**

Table 5. Algorithm performance with composition functions