Table 2. Settings for comparative algorithms

|  |  |
| --- | --- |
| Method | Settings |
| WOA |  |
| FA |  |
| SCA |  |
| GWO |  |
| HHO |  |
| PSO |  |
| MFO |  |

Table 3. Comparison of the numerical results obtained by SSMA and other well-established methods

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Function | Metric | SSMA | WOA | FA | SCA | GWO | HHO | PSO | MFO |
| F1 | mean | **4.9411E+06** | 3.9049E+07 | 7.9447E+08 | 6.0784E+08 | 9.0836E+07 | 2.4426E+07 | 2.1159E+07 | 3.3376E+08 |
|  | std | **1.6883E+06** | 1.4785E+07 | 1.0561E+08 | 1.2413E+08 | 4.9052E+07 | 7.9233E+06 | 4.9799E+06 | 2.4914E+08 |
| F2 | mean | **9.5498E+03** | 5.2033E+07 | 4.4187E+10 | 5.1371E+10 | 8.8507E+09 | 5.6820E+07 | 4.2560E+08 | 4.8870E+10 |
|  | std | **9.9842E+03** | 4.2456E+07 | 3.5378E+09 | 5.3433E+09 | 4.4384E+09 | 1.1288E+07 | 3.2933E+07 | 2.0508E+10 |
| F3 | mean | **5.6959E+02** | 5.0916E+04 | 1.4331E+05 | 8.2307E+04 | 6.3654E+04 | 1.1144E+04 | 1.6602E+03 | 1.7360E+05 |
|  | std | **1.6840E+02** | 1.0706E+04 | 1.3512E+04 | 1.2051E+04 | 1.5118E+04 | 3.5430E+03 | 1.9970E+02 | 8.2733E+04 |
| F4 | mean | **5.0621E+02** | 6.7950E+02 | 5.4296E+03 | 7.4426E+03 | 1.4119E+03 | 5.9921E+02 | 5.3737E+02 | 6.1343E+03 |
|  | std | **2.9189E+01** | 7.2028E+01 | 6.2665E+02 | 1.1297E+03 | 6.0283E+02 | 5.9079E+01 | 5.0226E+01 | 3.9436E+03 |
| F5 | mean | **5.2002E+02** | 5.2053E+02 | 5.2113E+02 | 5.2114E+02 | 5.2113E+02 | 5.2047E+02 | 5.2113E+02 | 5.2033E+02 |
|  | std | **3.9095E-02** | 1.9550E-01 | 4.9547E-02 | 3.7045E-02 | 4.0343E-02 | 1.4743E-01 | 3.1065E-02 | 1.3438E-01 |
| F6 | mean | 6.3076E+02 | 6.6561E+02 | 6.6475E+02 | 6.6606E+02 | **6.3067E+02** | 6.5696E+02 | 6.4209E+02 | 6.4551E+02 |
|  | std | 6.0563E+00 | 4.3023E+00 | 1.2281E+00 | 3.4148E+00 | **4.0952E+00** | 5.4010E+00 | 5.0091E+00 | 5.5795E+00 |
| F7 | mean | **7.0001E+02** | 7.0137E+02 | 1.1419E+03 | 1.1983E+03 | 7.8220E+02 | 7.0152E+02 | 7.0513E+02 | 1.1462E+03 |
|  | std | **6.9270E-03** | 2.3632E-01 | 3.7939E+01 | 5.8613E+01 | 3.8344E+01 | 8.5779E-02 | 4.1560E-01 | 1.7605E+02 |
| F8 | mean | **9.1473E+02** | 1.1519E+03 | 1.2607E+03 | 1.3117E+03 | 1.0007E+03 | 1.0405E+03 | 1.1763E+03 | 1.0913E+03 |
|  | std | **2.0046E+01** | 6.0347E+01 | 2.3186E+01 | 2.0785E+01 | 3.1026E+01 | 2.1411E+01 | 3.4531E+01 | 6.7251E+01 |
| F9 | mean | 1.1126E+03 | 1.3302E+03 | 1.4450E+03 | 1.4642E+03 | **1.1029E+03** | 1.2624E+03 | 1.3552E+03 | 1.3802E+03 |
|  | std | 4.7745E+01 | 6.0901E+01 | 2.0135E+01 | 3.1394E+01 | **3.7400E+01** | 4.1376E+01 | 3.9017E+01 | 1.0123E+02 |
| F10 | mean | **2.8597E+03** | 8.5003E+03 | 1.3891E+04 | 1.3286E+04 | 6.6067E+03 | 5.3106E+03 | 9.8238E+03 | 7.5530E+03 |
|  | std | **3.8497E+02** | 1.3725E+03 | 3.1209E+02 | 6.0685E+02 | 8.0466E+02 | 1.1256E+03 | 7.2667E+02 | 1.7353E+03 |
| F11 | mean | 7.0928E+03 | 1.0175E+04 | 1.4278E+04 | 1.4583E+04 | **6.7422E+03** | 9.1199E+03 | 1.0962E+04 | 8.6780E+03 |
|  | std | 1.0736E+03 | 1.3912E+03 | 3.7395E+02 | 3.9862E+02 | **1.3008E+03** | 8.1901E+02 | 7.0924E+02 | 1.1327E+03 |
| F12 | mean | **1.2003E+03** | 1.2022E+03 | 1.2034E+03 | 1.2034E+03 | 1.2024E+03 | 1.2022E+03 | 1.2033E+03 | 1.2005E+03 |
|  | std | **1.6586E-01** | 5.2442E-01 | 3.1580E-01 | 2.8988E-01 | 1.5550E+00 | 5.5894E-01 | 3.2719E-01 | 2.0773E-01 |
| F13 | mean | 1.3007E+03 | 1.3005E+03 | 1.3043E+03 | 1.3045E+03 | 1.3008E+03 | 1.3006E+03 | **1.3005E+03** | 1.3037E+03 |
|  | std | 9.2001E-02 | 9.8135E-02 | 1.6230E-01 | 3.0018E-01 | 5.1356E-01 | 1.1043E-01 | **7.6497E-02** | 1.0930E+00 |
| F14 | mean | 1.4006E+03 | 1.4004E+03 | 1.5226E+03 | 1.5215E+03 | 1.4217E+03 | 1.4004E+03 | **1.4003E+03** | 1.5019E+03 |
|  | std | 3.4496E-01 | 1.3792E-01 | 1.0484E+01 | 1.8587E+01 | 1.4294E+01 | 1.2614E-01 | **1.5756E-01** | 4.6993E+01 |
| F15 | mean | **1.5162E+03** | 1.7883E+03 | 2.4594E+05 | 1.1656E+05 | 3.3348E+03 | 1.5837E+03 | 1.5362E+03 | 1.1043E+06 |
|  | std | **3.8627E+00** | 8.9424E+01 | 7.7657E+04 | 5.5122E+04 | 2.5185E+03 | 1.6443E+01 | 1.9095E+00 | 1.8230E+06 |
| F16 | mean | 1.6206E+03 | 1.6220E+03 | 1.6226E+03 | 1.6224E+03 | **1.6202E+03** | 1.6218E+03 | 1.6216E+03 | 1.6221E+03 |
|  | std | 8.0006E-01 | 6.7656E-01 | 2.0784E-01 | 2.8337E-01 | **9.3389E-01** | 5.3861E-01 | 5.0997E-01 | 5.5938E-01 |
| F17 | mean | **7.7645E+05** | 2.0782E+07 | 4.2340E+07 | 4.1866E+07 | 4.6390E+06 | 3.4590E+06 | 1.3835E+06 | 1.0300E+07 |
|  | std | **4.5161E+05** | 1.1380E+07 | 9.1906E+06 | 1.5444E+07 | 3.4191E+06 | 1.9942E+06 | 5.1351E+05 | 1.2013E+07 |
| F18 | mean | **6.0377E+03** | 1.4848E+04 | 1.8939E+09 | 1.3111E+09 | 1.3298E+08 | 9.3481E+05 | 1.3521E+07 | 5.0799E+08 |
|  | std | **2.1612E+03** | 1.9352E+04 | 3.2168E+08 | 3.1157E+08 | 2.0125E+08 | 6.0194E+05 | 2.8943E+06 | 8.2326E+08 |
| F19 | mean | 1.9479E+03 | 1.9790E+03 | 2.1925E+03 | 2.1813E+03 | 1.9949E+03 | 1.9609E+03 | **1.9352E+03** | 2.1159E+03 |
|  | std | 2.7214E+01 | 3.1952E+01 | 2.9809E+01 | 5.4052E+01 | 3.6310E+01 | 2.9902E+01 | **1.1537E+01** | 1.2541E+02 |
| F20 | mean | **2.4554E+03** | 9.5353E+04 | 6.8705E+04 | 3.0145E+04 | 1.7587E+04 | 1.3242E+04 | 2.6549E+03 | 1.2888E+05 |
|  | std | **1.0637E+02** | 8.3475E+04 | 1.9794E+04 | 1.2718E+04 | 5.9960E+03 | 3.8163E+03 | 7.7731E+01 | 9.0207E+04 |
| F21 | mean | **5.0362E+05** | 6.5002E+06 | 1.6572E+07 | 1.0273E+07 | 2.3796E+06 | 1.7110E+06 | 6.6048E+05 | 6.3396E+06 |
|  | std | **2.5585E+05** | 3.8769E+06 | 3.9831E+06 | 5.0019E+06 | 2.4152E+06 | 8.7092E+05 | 2.1746E+05 | 7.8192E+06 |
| F22 | mean | 3.2526E+03 | 4.1966E+03 | 4.4965E+03 | 4.5462E+03 | **3.0238E+03** | 3.9914E+03 | 3.5236E+03 | 4.0310E+03 |
|  | std | 3.2229E+02 | 4.1718E+02 | 1.8367E+02 | 2.0375E+02 | **2.7011E+02** | 3.9930E+02 | 2.6900E+02 | 3.2794E+02 |
| F23 | mean | **2.5000E+03** | 2.6553E+03 | 3.0995E+03 | 3.0020E+03 | 2.7407E+03 | **2.5000E+03** | 2.6505E+03 | 2.8301E+03 |
|  | std | **0.0000E+00** | 8.4514E+01 | 5.4830E+01 | 6.1801E+01 | 4.1427E+01 | **0.0000E+00** | 3.1799E+00 | 9.8234E+01 |
| F24 | mean | **2.6000E+03** | 2.6005E+03 | 2.8497E+03 | 2.6555E+03 | 2.6000E+03 | 2.6000E+03 | 2.6841E+03 | 2.7938E+03 |
|  | std | **0.0000E+00** | 7.5194E-01 | 9.9184E+00 | 6.4045E+01 | 6.8918E-04 | 9.7613E-06 | 7.2303E+00 | 6.1240E+01 |
| F25 | mean | **2.7000E+03** | 2.7082E+03 | 2.8201E+03 | 2.7613E+03 | 2.7231E+03 | **2.7000E+03** | 2.7236E+03 | 2.7347E+03 |
|  | std | **0.0000E+00** | 2.2819E+01 | 1.1967E+01 | 2.9788E+01 | 1.1640E+01 | **0.0000E+00** | 1.0586E+01 | 1.5938E+01 |
| F26 | mean | **2.7007E+03** | 2.7044E+03 | 2.7215E+03 | 2.7049E+03 | 2.7861E+03 | 2.7881E+03 | 2.8018E+03 | 2.7485E+03 |
|  | std | **1.1760E-01** | 1.9705E+01 | 5.9847E+01 | 4.5637E-01 | 3.4852E+01 | 3.2683E+01 | 5.1903E-01 | 9.9656E+01 |
| F27 | mean | **2.9000E+03** | 4.8085E+03 | 4.6189E+03 | 4.7868E+03 | 3.7960E+03 | **2.9000E+03** | 4.1783E+03 | 4.2671E+03 |
|  | std | **0.0000E+00** | 1.1493E+02 | 2.9515E+01 | 7.0598E+01 | 1.1103E+02 | **0.0000E+00** | 2.0089E+02 | 1.1181E+02 |
| F28 | mean | **3.0000E+03** | 7.9063E+03 | 6.0144E+03 | 8.3927E+03 | 5.2662E+03 | **3.0000E+03** | 1.1457E+04 | 4.8237E+03 |
|  | std | **4.5936E-13** | 1.4051E+03 | 4.9457E+02 | 8.1794E+02 | 5.6716E+02 | **4.5936E-13** | 1.9595E+03 | 5.5016E+02 |
| F29 | mean | 3.1000E+03 | 3.1736E+07 | 6.1888E+07 | 2.0717E+08 | 6.1580E+06 | **3.1000E+03** | 2.2125E+05 | 3.1818E+07 |
|  | std | 2.6954E-07 | 2.0546E+07 | 1.4098E+07 | 3.3630E+07 | 8.1642E+06 | **0.0000E+00** | 5.3098E+05 | 1.2829E+07 |
| F30 | mean | 1.1522E+04 | 1.3547E+05 | 9.2341E+05 | 1.7561E+06 | 1.6467E+05 | **5.1325E+03** | 2.6521E+04 | 1.4968E+05 |
|  | std | 6.7506E+03 | 1.2146E+05 | 2.3587E+05 | 5.0644E+05 | 9.7160E+04 | **1.3665E+04** | 2.4863E+04 | 1.4962E+05 |

Table 4. Wilcoxon signed-rank test results between SSMA and other well-established competitors

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Function | WOA | FA | SCA | GWO | HHO | PSO | MFO |
| F1 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 |
| F2 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 |
| F3 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 |
| F4 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 1.6552E-09 | 1.1609E-03 | 7.5569E-10 |
| F5 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 |
| F6 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.4640E-01 | 7.5569E-10 | 4.7783E-09 | 1.6552E-09 |
| F7 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 |
| F8 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 |
| F9 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 4.0917E-01 | 8.0311E-10 | 7.5569E-10 | 7.5569E-10 |
| F10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 8.0311E-10 | 7.5569E-10 | 7.5569E-10 |
| F11 | 1.1548E-09 | 7.5569E-10 | 7.5569E-10 | 6.5923E-02 | 1.0089E-08 | 7.5569E-10 | 4.7902E-08 |
| F12 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 2.4738E-07 | 7.5569E-10 | 7.5569E-10 | 8.0203E-06 |
| F13 | 2.6045E-07 | 7.5569E-10 | 7.5569E-10 | 8.5069E-01 | 2.7769E-06 | 3.1750E-09 | 8.0311E-10 |
| F14 | 2.8083E-02 | 7.5569E-10 | 7.5569E-10 | 8.0311E-10 | 5.4126E-02 | 1.9817E-04 | 7.5569E-10 |
| F15 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 |
| F16 | 8.2125E-08 | 7.5569E-10 | 8.0311E-10 | 1.1277E-02 | 1.7742E-08 | 2.6045E-07 | 1.9791E-09 |
| F17 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 1.3831E-09 | 8.5342E-10 | 5.0466E-07 | 5.9494E-08 |
| F18 | 1.8745E-02 | 7.5569E-10 | 7.5569E-10 | 7.3784E-08 | 7.5569E-10 | 7.5569E-10 | 1.3953E-07 |
| F19 | 1.7796E-05 | 7.5569E-10 | 7.5569E-10 | 4.5365E-08 | 1.8264E-02 | 3.5765E-02 | 1.0235E-09 |
| F20 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 1.6552E-09 | 7.5569E-10 |
| F21 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 4.2535E-09 | 4.2535E-09 | 8.0533E-03 | 1.5860E-08 |
| F22 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 9.0628E-05 | 1.8648E-09 | 3.1082E-05 | 1.9791E-09 |
| F23 | 5.2553E-08 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 1.0000E+00 | 7.5569E-10 | 7.5569E-10 |
| F24 | 1.1101E-09 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 1.2207E-04 | 7.5569E-10 | 7.5569E-10 |
| F25 | 3.1250E-02 | 7.5569E-10 | 7.5569E-10 | 1.6087E-09 | 1.0000E+00 | 7.5569E-10 | 7.5569E-10 |
| F26 | 3.0382E-07 | 7.5569E-10 | 7.5569E-10 | 2.2286E-09 | 2.6611E-09 | 7.5569E-10 | 7.5569E-10 |
| F27 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 1.0000E+00 | 7.5569E-10 | 7.5569E-10 |
| F28 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 1.0000E+00 | 7.5569E-10 | 7.5569E-10 |
| F29 | 7.5552E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 5.0000E-01 | 7.5569E-10 | 7.5535E-10 |
| F30 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 7.5569E-10 | 1.4368E-05 | 1.0214E-04 | 7.5569E-10 |
| +/=/- | 28/0/2 | 30/0/0 | 30/0/0 | 24/4/2 | 22/6/2 | 27/0/3 | 30/0/0 |

Table 5. Average ranking values using the Friedman test

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Algorithm | SSMA | WOA | FA | SCA | GWO | HHO | PSO | MFO |
| AVR | **1.6213** | 4.3323 | 6.9573 | 6.9120 | 3.9700 | 3.0090 | 3.9227 | 5.2753 |
| rank | **1** | 5 | 8 | 7 | 4 | 2 | 3 | 6 |



Fig. 5. Convergence curves of SSMA and other well-established methods on twelve functions

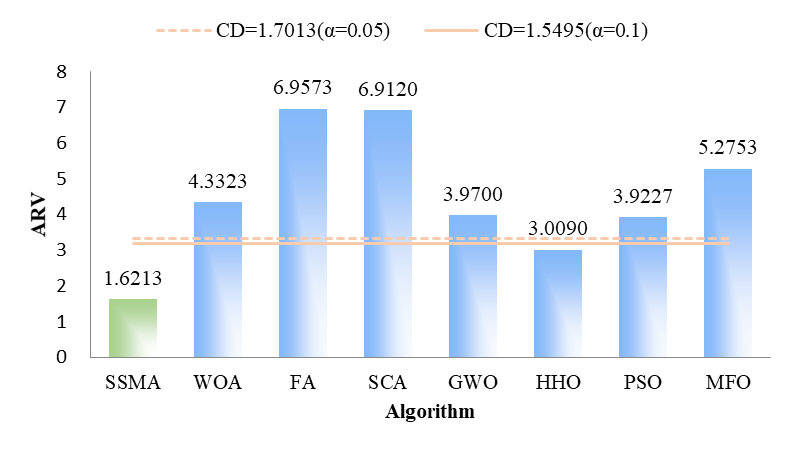


Fig. 7 Bonferroni-Dunn test for comparing SSMA with other well-established methods