

Performance Analysis of Tree Seed Algorithm for Small Dimension Optimization Functions

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Abstract—Tree-Seed Algorithm (TSA) simulates the growth of trees and seeds on a land. TSA is a method proposed to solve continuous optimization problems. Trees and seeds indicate possible solutions in the search space for optimization problems. Trees are planted in the ground at the beginning of the search and each tree produces several seeds during iterations. While the trees were selected randomly during seed formation, the tournament selection method was used and also hybridized by adding the C parameter, which is the acceleration coefficient calculated according to the size of the problem. In this study, continuous optimization problem has been solved by the hybrid method. First, the performance analyses of the five best known numerical benchmark functions have been done, in both TSA and hybrid method TSA with 2, 3, 4 and 5 dimensions, and 10-50 population numbers. After that, well-known algorithms in the literature like Particle Swarm Optimization (PSO), TSA, Artificial Bee Colony (ABC), Harmony Search (HS), as well as hybrid method TSA (HTSA) have been applied to twenty-four numerical benchmark functions and the performance analyses of algorithms have been done. Hopeful and comparable conclusions based on solution quality and robustness can be obtained with the hybrid method.

Index Terms—benchmark testing, algorithms, optimization, heuristic algorithms, optimization methods.

I. INTRODUCTION

Considering the literature, many optimization algorithms have been recommended to resolve continuous and binary problems in recent years [1]. Particle Swarm Optimization (PSO) is an optimization method proposed by inspiring birds and fish [2]. Ant Colony Optimization (ACO) algorithm is based on the movements of ants between the colony and food by imitating their real behaviors [3]. Artificial Bee Colony (ABC) is an optimization method that considers some behaviors of bees like food search, nectar resources and dance movement [4]. Harmony Search (HS) is an intuitive algorithm that simulates the notes played by musicians [5]. Gravitational Search Algorithm (GSA) is an optimization method developed by inspiring Newton's law of gravity [6]. Tree-Seed Algorithm (TSA) is based on the relation between trees and seeds [7]. The performance of TSA about optimizing numerical comparison problems and a multi-level thresholding problem was investigated by Kiran [8]. At the beginning, trees are planted on a land, which indicates the search space of the optimization problem. The position of each tree represents a possible solution of the problem. This method produces a specified number of seeds for each tree in each iteration. If the objective value of the best seed is better than the current tree

value, new seed is updated as a new tree. This method based on tree and seed relation continues during stopping criteria in the iteration operation.

In many studies in literature, improvements were made to the algorithm and benchmark test functions were performed and performance analyzes were performed [9-13]. In this study, TSA was added hybrid method and applied to solve constrained optimization problem and then the results obtained were compared with those of algorithms in the literature.

In the second section of this study, the hybrid method made to the algorithm is discussed. Third section of the study includes the implementation of the TSA and HTSA on the problem. Test results are given in Section 4 while the results achieved are provided in the last section.

II. TREE SEED ALGORITHM

The population was obtained by using for TSA proposed by Kiran in 2015 [14].

$$i = 1, 2, \dots, N \text{ and } j = 1, 2, \dots, D \quad (1)$$

The number of trees in the population is N and D is the problem size [15]. After producing trees in the population, objective values of trees are calculated by using the fitness function. One seed is produced for each tree by using Equations 2 and 3 until satisfying the stopping criteria [16].

$$S_{k,j} = T_{i,j} + (B_j - T_{r,j}) \times (\text{rand} - 0.5) \quad (2)$$

$$S_{k,j} = T_{i,j} + (T_{i,j} - T_{r,j}) \times (\text{rand} - 0.5) \quad (3)$$

where $S_{k,j}$ is the j^{th} size of the k^{th} seed production for $T_{i,j}$. $T_{r,j}$ is the j^{th} size of randomly selected r^{th} tree. Moreover, Equations 2 and 3 are oriented by search tendency (ST) control parameter and take a value in [0, 1] interval [17]. If randomly production worth is less than ST parameter, Equation 2 is used; otherwise, Equation 3 is used. ST parameter is an important parameter for the selection of seed production [18]. In TSA, minimum number of seeds is calculated as 10% of number of trees while maximum number of seeds is 25% of number of trees [12]. Therefore, the number of seeds is found depending on the population. TSA, at the beginning, the positions of the first trees of possible solutions of optimization problems are calculated according to Equation 4 [19].

$$T_{i,j} = L_{j,\min} + r_{i,j} (H_{j,\max} - L_{j,\min}) \quad (4)$$

The lower and upper limits of the search space are $L_{j,\min}$ and $H_{j,\max}$, respectively. $r_{i,j}$ is a random number generated in [0,1] interval for position and each dimension.

Equation 5 is used to select the best solution from the population [20].

$$B = \min \{ f \overline{T}_i \} \quad i = 1, 2, \dots, N \quad (5)$$

The number of trees in the population is expressed as N and the positions of new seeds are produced for each tree. The number of seeds produced depending on the population size must be higher than one.

Step 1. The Initialization of the Algorithm.

Set the number of population size (N).

Set the ST parameter for the method.

Set the dimensionality of the problem (D).

Decide the termination condition

Generate N random tree location on the D -dimensional search space using Eq. 4 (T).

Evaluate the tree location using objective function specified for the problem.

Select the best solution (B) using Eq. 5.

Step 2. Searching with Seeds.

FOR all trees

Decide the number of seeds produced for his tree.

FOR all seeds

FOR all dimensions

IF ($\text{rand} < \text{ST}$)

Update this dimension using Eq. 6 (*With Hybrid Method*) (S)

ELSE

Update this dimension using Eq. 7 (*With Hybrid Method*) (S)

END IF

END FOR

END FOR

Select the best seed and compare it with the tree.

If the seed location is better than tree location, the seed substitutes for his tree.

END FOR

Step 3. Selection of Best Solution

Select the best solution of population using Eq. 9.

If new best solution is better than the previous best solution, new best solution substitutes for the previous best solution.

Step 4. Testing Termination Condition

If termination condition is not met, go to Step 2.

Step 5. Reporting

Report the best solution.

Figure 1. HTSA flow diagram

A. Hybrid Method Made to the TSA

Hybrid method was made in the production of seeds produced based on ST parameter. In the equation, in the study carried out by Beşkirli et al. [21], the proposed tournament selection method instead of randomly selected trees, and the acceleration coefficient calculated according to the magnitude of the problem in the study conducted by Arslan et al. [17] were hybridized in this study.

In the Equation, tournament selection method was used rather than randomly selected trees ($T_{t,j}$). Tournament selection method is a very effective method [21, 22]. Therefore, trees selected by using random selection mechanism were selected by tournament selection method after this step. Tournament selection method organizes a tournament among randomly selected trees from the population and the best tree wins the tournament. Tournament size takes values between 2 and the population size [23].

The formula obtained by using hybrid method was revised as in the case of Equations 6 and 7.

$$S_{k,j} = T_{i,j} + (B_j - T_{t,j}) \times (\text{rand} - 0.5) \times C \quad (6)$$

$$S_{k,j} = T_{i,j} + (T_{i,j} - T_{t,j}) \times (\text{rand} - 0.5) \times C \quad (7)$$

where $S_{k,j}$ is the j th dimension of the k th seed produced

for $T_{i,j}$. $T_{t,j}$ is the j th dimension of t th tree selected by tournament selection method. C parameter used for Equation 6 and Equation 7 is calculated by Equation 8. parameter D indicates the size of the problem. The maximum value of the C factor is 2 and the minimum value is 1.

$$C = 2 - (D^2 \times 0.0001) \quad (8)$$

Hybrid method was used to eliminate handicaps caused by randomness in TSA, this algorithm was called hybrid method tree-seed algorithm (HTSA). The flow chart of HTSA obtained by hybrid method is shown in Figure 1.

III. EXPERIMENTAL STUDIES

A. Comparisons and Performance Analyses on Benchmark Functions

Benchmark functions are often used by researchers in the global optimization domain to test and evaluate the effectiveness and efficiency of most global optimization algorithms. Table I shows twenty four benchmark functions used in this study, as well as their formulas. The analysis of the effect of ST control parameter on HTSA and TSA methods was performed on 5 basic functions (F1, F10, F11, F13 and F15) given in Table I. Moreover, these methods were compared with HS, ABC, PSO and TSA methods by using twenty four 2, 3, 4, and 5 dimensional numerical

functions given in Table I. Maximum number of function evaluations (MaxFes) of TSA method is shown in Equation 9 [24].

$$\text{MaxFes} = D \times 10,000 \quad (9)$$

B. Analyses of the Control Parameter of HTSA

In the original TSA, analysis was done on population

number and control parameter. Thus, another analysis was performed in HTSA with the same parameters. Population number was 10, 20, 30, 40 and 50 while ST parameter value was used as 0.1. HTSA was run for thirty times by using these values for 2, 3, 4 and 5 dimensions. The best value and standard deviation (Std. dev.) results of functions are shown in Table I-X.

TABLE I. BENCHMARK FUNCTIONS USED IN EXPERIMENTS

No	Name	Function
F1	Sphere	$f_1(\bar{X}) = \sum_{i=1}^n x_i^2$
F2	Elliptic	$f_2(\bar{X}) = \sum_{i=1}^n (10^6)^{(i-1)/(n-1)} x_i^2$
F3	SumSquares	$f_3(\bar{X}) = \sum_{i=1}^n i x_i^2$
F4	SumPower	$f_4(\bar{X}) = \sum_{i=1}^n x_i ^{(i+1)}$
F5	Schwefel2.22	$f_5(\bar{X}) = \sum_{i=1}^n x_i + \prod_{i=1}^n x_i $
F6	Schwefel2.21	$f_6(\bar{X}) = \max_i \{ x_i , 1 \leq i \leq n\}$
F7	Step	$f_7(\bar{X}) = \sum_{i=1}^n \left(\left[x_i + 0.5 \right] \right)^2$
F8	Quartic	$f_8(\bar{X}) = \sum_{i=1}^n i x_i^4$
F9	QuarticWN	$f_9(\bar{X}) = \sum_{i=1}^n i x_i^4 + \text{random}[0,1)$
F10	Rosenbrock	$f_{10}(\bar{X}) = \sum_{i=1}^{n-1} \left[100(x_{i+1} - x_i^2)^2 + (x_i - 1)^2 \right]$
F11	Rastrigin	$f_{11}(\bar{X}) = \sum_{i=1}^n \left[x_i^2 - 10 \cos(2\pi x_i) + 10 \right]$
F12	Non-Continuous Rastrigin	$f_{12}(\bar{X}) = \sum_{i=1}^n \left[y_i^2 - 10 \cos(2\pi y_i) + 10 \right]$ $y_i = \begin{cases} x_i & x_i < \frac{1}{2} \\ \text{round}(2x_i) & x_i \geq \frac{1}{2} \end{cases}$
F13	Griewank	$f_{13}(\bar{X}) = \frac{1}{4000} \sum_{i=1}^n x_i^2 - \prod_{i=1}^n \cos\left(\frac{x_i}{\sqrt{i}}\right) + 1$
F14	Schwefel2.26	$f_{14}(\bar{X}) = 418.98 * n - \sum_{i=1}^n \sin(\sqrt{ x_i })$
F15	Ackley	$f_{15}(\bar{X}) = -20 \exp\left\{ -0.2 \sqrt{\frac{1}{n} \sum_{i=1}^n x_i^2} \right\} - \exp\left\{ \frac{1}{n} \sum_{i=1}^n 2\pi x_i \right\} + 20 + e$
F16	Penalized1	$f_{16}(\bar{X}) = \frac{\pi}{n} \left\{ 10 \sin^2(\pi y_1) \sum_{i=1}^{n-1} (y_i - 1)^2 \left[1 + 10 \sin^2(\pi y_{i+1}) \right] + (y_n - 1)^2 \right\} + \sum_{i=1}^n u(x_i, 10, 100, 4)$

F17	Penalized2	$f_{17}(\bar{X}) = \frac{1}{10} \left\{ \sin^2(\pi x_1) + \sum_{i=1}^{n-1} (x_i - 1)^2 [1 + \sin^2(3\pi x_{i+1})] + (x_n - 1)^2 [1 + \sin^2(2\pi x_{i+1})] \right\} + \sum_{i=1}^n u(x_i, 5, 100, 4)$
F18	Alpine	$f_{18}(\bar{X}) = \sum_{i=1}^n x_i \cdot \sin(x_i) + 0.1 \cdot x_i $
F19	Levy	$f_{19}(\bar{X}) = \sum_{i=1}^{n-1} (x_i - 1)^2 [1 + \sin^2(3\pi x_{i+1})] + \sin^2(3\pi x_1) + x_n - 1 [1 + \sin^2(3\pi x_n)]$
F20	Weierstrass	$f_{20}(\bar{X}) = \sum_{i=1}^D \left(\sum_{k=0}^{k_{\max}} [a^k \cos(2\pi b^k (x_i + 0.5))] \right) - D \sum_{k=0}^{k_{\max}} [a^k \cos(2\pi b^k 0.5)] \quad a = 0.5, b = 3, k_{\max} = 20$
F21	Schaffer	$f_{21}(\bar{X}) = 0.5 + \frac{\sin^2 \left(\sqrt{\sum_{i=1}^n x_i^2} \right) - 0.5}{\left(1 + 0.001 * \left[\sum_{i=1}^n x_i^2 \right] \right)^2}$
F22	Himmelblau	$f_{22}(\bar{X}) = \frac{1}{n} \sum_{i=1}^n (x_i^4 - 16x_i^2 + 5x_i)$
F23	Michalewicz	$f_{23}(\bar{X}) = -\sum_{i=1}^n \sin(x_i) \sin^{20} \left(\frac{i * x_i^2}{\pi} \right)$
F24	Dixon&Price	$f_{24}(\bar{X}) = (x_1 - 1)^2 + \sum_{i=2}^n i(2x_i^2 - x_{i-1})^2$

TABLE II. THE ANALYSIS RESULTS OF 2-DIMENSIONAL FUNCTIONS FOR HTSA

	Pop=10		Pop=20		Pop=30		Pop=40		Pop=50	
	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.
F1	7,18E-295	8,56E-19	3,14E-147	6,51E-60	1,17E-86	1,54E-80	1,47E-60	3,32E-56	3,74E-44	2,44E-40
F10	3,99E-28	3,10E-19	1,38E-19	1,14E-11	1,47E-15	3,41E-10	1,37E-13	2,56E-10	4,46E-13	1,81E-08
F11	0,00E+00	1,79E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
F13	0,00E+00	6,87E-03	0,00E+00	1,32E-03	0,00E+00	1,36E-03	0,00E+00	1,84E-03	0,00E+00	1,33E-03
F15	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00

TABLE III. THE ANALYSIS RESULTS OF 2-DIMENSIONAL FUNCTIONS FOR TSA

	Pop=10		Pop=20		Pop=30		Pop=40		Pop=50	
	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.
F1	9,15E-237	0,00E+00	1,19E-114	1,57E-101	3,80E-67	4,19E-65	2,83E-46	4,50E-43	1,47E-34	4,14E-32
F10	1,41E-23	1,42E-15	6,63E-13	5,36E-09	9,57E-11	9,37E-06	8,42E-09	1,84E-05	1,07E-08	4,61E-04
F11	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
F13	0,00E+00	2,80E-03	0,00E+00	1,39E-03	0,00E+00	7,51E-04	0,00E+00	1,08E-03	1,89E-15	1,61E-04
F15	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00

TABLE IV. THE ANALYSIS RESULTS OF 3-DIMENSIONAL FUNCTIONS FOR HTSA

	Pop=10		Pop=20		Pop=30		Pop=40		Pop=50	
	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.
F1	2,95E-292	3,36E-13	5,49E-151	5,27E-35	3,35E-90	5,64E-47	5,76E-62	7,47E-16	1,02E-44	2,38E-28
F10	2,44E-07	1,41E-01	9,40E-08	1,33E-01	5,69E-06	1,35E-01	6,91E-06	2,63E-02	1,03E-06	3,37E-02
F11	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
F13	0,00E+00	1,46E-02	0,00E+00	3,93E-03	0,00E+00	4,13E-03	0,00E+00	3,41E-03	0,00E+00	3,69E-03
F15	0,00E+00	3,38E-04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00

TABLE V. THE ANALYSIS RESULTS OF 3-DIMENSIONAL FUNCTIONS FOR TSA

	Pop=10		Pop=20		Pop=30		Pop=40		Pop=50	
	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.
F1	4,18E-258	0,00E+00	8,41E-119	3,62E-109	1,95E-69	5,11E-66	6,13E-47	2,72E-44	3,58E-34	1,34E-32
F10	1,05E-07	1,05E-02	3,81E-05	1,37E-02	1,66E-04	4,92E-02	1,61E-04	3,58E-02	5,44E-06	2,62E-02
F11	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,95E-15
F13	0,00E+00	3,88E-03	0,00E+00	3,99E-03	1,58E-12	4,07E-03	2,73E-07	4,32E-03	1,31E-03	4,54E-03
F15	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00

TABLE VI. THE ANALYSIS RESULTS OF 4-DIMENSIONAL FUNCTIONS FOR HTSA

	Pop=10		Pop=20		Pop=30		Pop=40		Pop=50	
	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.
F1	9,51E-294	6,22E-12	1,24E-150	9,24E-13	1,39E-93	5,49E-13	1,18E-64	1,71E-57	3,13E-46	1,09E-30
F10	5,80E-05	1,24E+00	6,27E-09	5,73E-01	1,71E-03	7,66E-01	4,92E-03	4,49E-01	1,61E-05	3,33E-01
F11	0,00E+00	4,40E-01	0,00E+00	2,48E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
F13	0,00E+00	7,21E-02	0,00E+00	6,37E-03	0,00E+00	8,62E-03	0,00E+00	5,55E-03	0,00E+00	5,56E-03
F15	0,00E+00	4,59E-01	0,00E+00	5,07E-05	0,00E+00	1,15E-08	0,00E+00	7,78E-05	0,00E+00	2,14E-14

TABLE VII. THE ANALYSIS RESULTS OF 4-DIMENSIONAL FUNCTIONS FOR TSA

	Pop=10		Pop=20		Pop=30		Pop=40		Pop=50	
	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.
F1	3,53E-258	0,00E+00	3,32E-122	9,27E-111	2,75E-70	5,78E-68	4,85E-48	7,62E-44	1,89E-34	2,68E-33
F10	3,57E-05	3,67E-01	3,79E-04	4,14E-01	9,99E-04	2,07E-01	1,26E-04	1,30E-01	1,70E-03	1,13E-01
F11	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	4,41E-14	0,00E+00	1,05E-08
F13	0,00E+00	6,69E-03	1,44E-07	8,15E-03	8,69E-06	1,15E-02	2,83E-03	1,06E-02	1,64E-03	1,29E-02
F15	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	6,49E-16

TABLE VIII. THE ANALYSIS RESULTS OF 5-DIMENSIONAL FUNCTIONS FOR HTSA

	Pop=10		Pop=20		Pop=30		Pop=40		Pop=50	
	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.
F1	6,93E-285	1,81E+00	6,18E-152	9,70E-23	3,88E-93	2,46E-12	7,83E-66	9,80E-17	7,02E-47	6,10E-39
F10	1,47E-03	1,43E+00	1,95E-03	1,05E+00	2,52E-03	8,39E-01	2,92E-05	7,26E-01	1,80E-02	7,21E-01
F11	0,00E+00	8,42E-01	0,00E+00	2,48E-01	0,00E+00	9,94E-10	0,00E+00	0,00E+00	0,00E+00	0,00E+00
F13	0,00E+00	1,20E-02	0,00E+00	8,38E-03	0,00E+00	7,94E-03	0,00E+00	6,99E-03	7,61E-11	7,55E-03
F15	0,00E+00	6,40E-01	0,00E+00	5,75E-09	0,00E+00	1,17E-11	0,00E+00	0,00E+00	0,00E+00	2,35E-08

TABLE IX. THE ANALYSIS RESULTS OF 5-DIMENSIONAL FUNCTIONS FOR TSA

	Pop=10		Pop=20		Pop=30		Pop=40		Pop=50	
	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.
F1	8,90E-261	0,00E+00	1,72E-120	4,16E-113	1,40E-70	5,94E-69	5,13E-48	1,35E-45	1,23E-34	7,79E-34
F10	4,92E-03	1,05E+00	3,47E-03	6,62E-01	1,60E-03	2,99E-01	1,51E-02	3,00E-01	8,40E-03	3,09E-01
F11	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	4,41E-14	0,00E+00	1,52E-06	1,03E-13	4,81E-03
F13	0,00E+00	1,57E-02	7,42E-03	1,53E-02	1,55E-02	2,23E-02	2,19E-02	1,74E-02	1,71E-02	2,20E-02
F15	0,00E+00	1,45E-15	0,00E+00	6,49E-16	0,00E+00	0,00E+00	0,00E+00	6,49E-16	0,00E+00	1,08E-15

In the section including from Table II to Table IX, the best values obtained by TSA and HTSA in 2, 3, 4, and 5 dimensions and 10, 20, 30, 40 and 50 populations were compared with each other. The best value was indicated in bold. Those with the same value were not marked. Examining Tables II and III, the problem dimension was considered as 2. HTSA had the best degree for F1 and F10 functions while both algorithms had optimum result in other functions. In Tables IV and V, the problem dimension was 3 and HTSA was successful in F1 and F10 functions, as well as in F13 function. Tables VI and VII include 4 dimensional functions. HTSA had a better result than TSA in F1 and F10 functions and HTSA method presented a more successful solution in F3 function. In Tables VIII and IX, the problem was solved by considering the function dimension as 5. HTSA was successful in F1, F10 and F13 functions while

HTSA and TSA obtained the same values in other functions.

Table X-XIII shows the comparison of HTSA with other algorithms in the literature. Parameter values of algorithms were adjusted according to the study of [8, 21]. In this comparative study, ST parameter value and population number of TSA and HTSA was used to be 0.1 and 10, respectively. HS algorithm [25] has four parameters: harmony memory parameter dimension was 5, harmony memory consideration ratio parameter was 0.9, pitch adjusting ratio was 0.3 and arbitrary distance bandwidth parameter was 0.01. The number of bees in the hive of ABC, which consists of two control parameters, is set as 40 limit and 100 according to the operation of Karaboga [4]. Parameter value of PSO was designed according to the study of Hu [26]. In PSO, the number of particles was 30, c1 and c2 parameter was set to 2.

TABLE X. THE COMPARISON RESULTS OF HS, ABC, PSO, TSA AND HTSA ON THE 2-DIMENSIONAL BENCHMARK FUNCTIONS

	HS		ABC		PSO		TSA		HTSA	
	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.
F1	1,20E-05	1,13E-02	1,06E-22	1,64E-18	5,66E-09	6,86E-05	3,75E-240	0,00E+00	4,67E-290	4,26E-73
F2	4,62E-05	1,99E+04	1,27E-19	2,03E-18	4,40E-07	4,12E+03	7,12E-237	0,00E+00	7,42E-293	2,97E-95
F3	4,59E-10	1,87E-09	5,56E-24	1,23E-18	7,50E-11	1,50E-06	4,12E-241	0,00E+00	4,65E-293	4,43E-90
F4	1,08E-11	1,26E-09	2,49E-27	6,53E-19	2,32E-14	7,72E-07	2,06E-280	0,00E+00	0,00E+00	6,05E-17
F5	5,54E-06	2,68E-05	1,43E-19	8,74E-18	1,55E-06	1,85E-02	2,23E-126	2,35E-124	1,00E-157	8,56E-146
F6	8,36E-03	2,73E-01	1,08E-18	2,04E-17	4,52E-05	6,88E-02	1,11E-101	1,47E-98	7,85E-125	7,61E-09
F7	5,89E-05	6,26E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
F8	2,56E-19	1,41E-17	2,94E-44	7,32E-20	9,45E-21	7,66E-17	0,00E+00	0,00E+00	0,00E+00	3,64E-83
F9	2,61E-05	5,35E-03	2,09E-04	2,95E-04	6,06E-04	3,45E-03	1,40E-04	2,14E-04	2,80E-05	1,96E-04
F10	9,19E-02	2,89E+00	3,94E-03	1,19E-02	4,48E-03	2,26E+00	1,75E-16	1,42E-15	4,93E-32	5,70E-19
F11	1,35E-04	1,82E-01	0,00E+00	0,00E+00	2,17E-06	2,12E-01	0,00E+00	0,00E+00	0,00E+00	2,98E-01
F12	9,56E-08	1,44E-06	0,00E+00	0,00E+00	3,13E-04	2,09E-01	0,00E+00	0,00E+00	0,00E+00	1,80E-01
F13	9,89E-03	3,23E-02	0,00E+00	0,00E+00	9,87E-03	8,50E-03	0,00E+00	2,80E-03	0,00E+00	3,82E-02
F14	2,91E-05	1,49E+00	0,00E+00	0,00E+00	2,55E-05	1,10E+02	2,55E-01	2,16E+01	2,55E-05	2,13E+01
F15	8,32E-05	9,29E-05	0,00E+00	0,00E+00	1,47E-04	1,59E-01	0,00E+00	0,00E+00	0,00E+00	1,65E-11
F16	1,94E-06	2,84E-01	3,00E-22	9,84E-19	1,68E-09	6,61E-03	2,36E-31	4,45E-47	2,36E-31	9,94E-14

F17	1,89E-05	1,79E-02	2,08E-21	1,73E-18	2,64E-09	2,71E-05	1,35E-32	5,57E-48	1,35E-32	3,40E-03
F18	8,13E-06	1,23E-04	5,70E-19	9,57E-18	2,50E-07	1,90E-02	0,00E+00	1,11E-16	0,00E+00	1,18E-15
F19	1,43E-04	4,47E-02	1,51E-20	1,48E-19	1,27E-05	1,75E-03	1,35E-31	6,68E-47	1,35E-31	1,99E-17
F20	7,40E-03	4,14E-03	0,00E+00	0,00E+00	8,66E-04	1,03E-02	0,00E+00	0,00E+00	0,00E+00	0,00E+00
F21	9,72E-03	2,09E-02	4,08E-06	4,34E-05	9,72E-04	3,81E-03	0,00E+00	2,93E-03	0,00E+00	0,00E+00
F22	-7,83E+01	2,34E-08	-7,83E+01	1,45E-14	-7,83E+01	2,33E-01	-7,83E+01	1,45E-14	-7,83E+01	1,42E-14
F23	-5,94E-01	2,29E-08	-5,94E-01	9,03E-16	-5,94E-01	2,64E-01	-5,94E-01	9,03E-16	-5,94E-01	1,16E-16
F24	3,15E-08	6,61E-07	1,46E-17	1,83E-15	9,77E-09	3,06E-02	3,70E-32	2,25E-33	3,70E-32	1,42E-09

TABLE XI. THE COMPARISON RESULTS OF HS, ABC, PSO, TSA AND HTSA ON THE 3-DIMENSIONAL BENCHMARK FUNCTIONS

	HS		ABC		PSO		TSA		HTSA	
	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.
F1	7,89E-05	5,73E-03	1,23E-21	4,59E-18	4,41E-07	1,69E-03	8,71E-247	0,00E+00	1,04E-291	1,27E-27
F2	1,70E-03	3,07E+00	4,57E-22	3,37E-18	2,20E-05	3,56E+06	1,95E-240	0,00E+00	6,00E-290	7,80E-19
F3	2,42E-09	3,58E-09	1,68E-24	3,09E-18	3,42E-10	2,12E-01	1,54E-244	0,00E+00	3,52E-295	6,80E-19
F4	7,07E-11	1,97E-10	1,07E-31	1,23E-18	6,79E-11	2,67E-01	0,00E+00	0,00E+00	0,00E+00	2,06E-18
F5	2,54E-06	3,41E-05	4,93E-18	1,22E-17	1,17E-04	1,91E-01	1,62E-143	1,90E-134	9,61E-171	5,72E-19
F6	2,54E-03	2,30E-01	2,74E-17	1,02E-16	8,54E-04	6,64E-02	2,23E-88	7,96E-86	8,18E-103	1,09E-03
F7	4,56E-05	4,61E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
F8	1,32E-18	1,13E-16	1,85E-42	1,84E-19	2,63E-11	2,80E-04	0,00E+00	0,00E+00	0,00E+00	6,25E-19
F9	1,05E-04	3,49E-03	6,27E-04	6,49E-04	7,85E-04	5,04E-03	1,01E-04	1,81E-04	7,03E-05	2,07E-04
F10	2,17E-02	1,73E+00	2,19E-02	2,57E-02	2,75E-04	4,65E+00	2,49E-03	1,05E-02	5,93E-08	2,43E-01
F11	2,15E-07	7,40E-07	0,00E+00	0,00E+00	7,44E-03	1,31E+00	0,00E+00	0,00E+00	0,00E+00	2,98E-01
F12	1,07E-06	6,26E-06	0,00E+00	0,00E+00	1,13E-01	4,32E+00	0,00E+00	2,54E-01	0,00E+00	7,89E-01
F13	3,83E-03	6,09E-02	9,72E-14	6,49E-12	2,66E-02	5,32E-02	0,00E+00	3,88E-03	0,00E+00	5,52E-03
F14	2,07E-04	6,49E-01	3,82E-17	4,15E-14	2,77E-04	1,16E+02	3,82E+00	2,16E+01	3,82E-05	4,74E+01
F15	4,50E-05	6,60E-05	4,55E-17	1,08E-15	1,82E-04	2,59E+00	0,00E+00	0,00E+00	0,00E+00	3,81E-01
F16	1,74E-05	1,89E-01	1,01E-21	3,64E-18	2,47E-07	1,10E-01	1,57E-31	6,68E-47	1,57E-31	1,13E-12
F17	2,97E-05	9,76E-03	2,65E-21	3,84E-18	8,40E-07	4,77E-02	1,35E-32	5,57E-48	1,35E-32	4,95E-24
F18	3,00E-05	6,56E-05	5,47E-18	1,79E-17	3,21E-05	4,65E-01	0,00E+00	3,69E-11	0,00E+00	7,97E-17
F19	1,67E-04	3,35E-02	2,95E-19	1,73E-18	6,33E-05	1,64E+00	1,35E-31	6,68E-47	1,35E-31	1,78E-01
F20	2,31E-03	6,33E-03	0,00E+00	0,00E+00	1,03E-02	1,08E-01	0,00E+00	0,00E+00	0,00E+00	8,29E-15
F21	9,72E-03	2,32E-02	4,18E-03	4,63E-03	9,72E-03	1,33E-02	2,45E-03	5,79E-03	6,22E-04	2,02E-03
F22	-7,83E+01	1,91E-08	-7,83E+01	1,45E-14	-7,83E+01	3,42E+00	-7,83E+01	1,45E-14	-7,83E+01	1,69E+00
F23	-2,76E+00	8,74E-08	-2,76E+00	6,85E-16	-2,76E+00	3,23E-01	-2,76E+00	5,09E-16	-2,76E+00	6,66E-16
F24	1,79E-04	6,33E-06	1,67E-15	5,69E-14	8,09E-07	1,44E+02	8,75E-31	1,76E-25	8,75E-31	2,04E-02

TABLE XII. THE COMPARISON RESULTS OF HS, ABC, PSO, TSA AND HTSA ON THE 4-DIMENSIONAL BENCHMARK FUNCTIONS

	HS		ABC		PSO		TSA		HTSA	
	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.
F1	1,05E-08	2,03E-08	1,38E-20	7,80E-18	5,42E-03	5,94E+00	6,02E-245	0,00E+00	1,18E-258	0,00E+00
F2	3,46E-07	2,07E-01	2,17E-19	8,12E-18	2,75E+00	1,68E+07	6,91E-246	0,00E+00	1,54E-255	0,00E+00
F3	4,05E-10	1,15E-08	4,89E-22	8,04E-18	3,94E-04	2,24E+00	7,39E-251	0,00E+00	1,48E-261	0,00E+00
F4	4,71E-14	8,17E-10	1,68E-28	1,81E-18	1,59E-06	2,69E+01	0,00E+00	0,00E+00	0,00E+00	0,00E+00
F5	2,42E-05	3,85E-05	4,92E-17	1,85E-17	1,76E-02	3,29E+00	8,92E-143	1,02E-141	2,34E-150	1,03E-144
F6	1,58E-04	2,70E-01	2,63E-16	3,44E-16	2,57E-01	6,69E+00	1,30E-77	3,09E-74	5,70E-85	1,50E-77
F7	1,08E-08	5,96E-01	0,00E+00	0,00E+00	1,14E-02	2,35E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
F8	1,01E-16	3,01E-16	4,39E-39	8,21E-19	6,64E-04	1,53E-02	0,00E+00	0,00E+00	0,00E+00	0,00E+00
F9	1,90E-05	4,27E-03	1,14E-03	1,04E-03	1,89E-03	3,25E-02	2,65E-04	2,25E-04	5,22E-05	2,18E-04
F10	3,87E-02	1,48E+00	2,28E-01	2,81E-02	1,38E+00	2,53E+03	1,17E-02	3,67E-01	3,63E-03	2,14E-01
F11	1,03E-08	6,98E-07	0,00E+00	0,00E+00	1,42E+00	6,78E+00	0,00E+00	0,00E+00	0,00E+00	3,71E-01
F12	8,60E-09	5,83E-07	0,00E+00	0,00E+00	2,00E+00	9,03E+00	0,00E+00	4,90E-01	0,00E+00	4,58E-01
F13	2,35E-07	5,07E-02	1,26E-12	1,39E-09	9,18E-02	2,24E-01	0,00E+00	6,79E-03	0,00E+00	6,68E-03
F14	5,10E-05	6,88E-01	5,09E-15	4,15E-14	2,06E+01	1,79E+02	1,09E+01	4,82E+01	5,09E-05	4,41E+01
F15	1,51E-04	2,06E-04	1,84E-15	1,77E-15	1,14E-01	5,40E+00	0,00E+00	0,00E+00	0,00E+00	3,30E-01
F16	5,53E-10	1,13E-08	4,78E-21	6,52E-18	8,22E-03	1,67E+00	1,18E-31	2,23E-47	1,18E-31	2,19E-47
F17	2,07E-09	1,04E-02	5,87E-21	6,79E-18	5,88E-03	2,28E+01	1,35E-17	5,57E-48	1,35E-32	5,47E-48
F18	1,01E-06	1,22E-04	4,36E-19	4,32E-17	4,99E-03	7,95E-01	0,00E+00	1,55E-16	0,00E+00	5,27E-97
F19	2,87E-07	3,80E-02	5,69E-18	4,94E-18	4,37E-03	4,90E+00	1,35E-31	6,68E-47	1,35E-31	6,57E-47
F20	1,50E-03	7,33E-03	0,00E+00	0,00E+00	1,32E-01	7,14E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00
F21	9,72E-03	2,85E-02	9,09E-03	2,38E-03	3,73E-02	1,35E-01	4,72E-03	5,65E-10	7,29E-03	4,36E-04
F22	-7,83E+01	2,37E-08	-7,83E+01	1,71E-14	-7,83E+01	6,78E+00	-7,83E+01	2,19E-14	-7,83E+01	2,12E+00
F23	-2,42E+00	1,93E-06	-2,42E+00	1,49E-15	-2,42E+00	3,36E-01	-2,42E+00	1,70E-02	-2,42E+00	4,29E-16
F24	4,13E-08	2,85E-01	1,92E-13	5,86E-13	2,98E-02	1,07E+02	3,70E-32	8,70E-26	3,70E-32	3,50E-28

TABLE XIII. THE COMPARISON RESULTS OF HS, ABC, PSO, TSA AND HTSA ON THE 5-DIMENSIONAL BENCHMARK FUNCTIONS

	HS		ABC		PSO		TSA		HTSA	
	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.	Best	Std. dev.
F1	5,45E-08	2,81E-08	7,60E-20	8,00E-18	5,55E-01	5,14E+01	2,67E-245	0,00E+00	1,99E-260	0,00E+00
F2	1,02E-06	8,02E-01	1,61E-18	9,31E-18	2,72E+01	1,92E+07	3,85E-242	0,00E+00	5,88E-256	0,00E+00
F3	1,25E-09	5,12E-08	1,78E-21	8,59E-18	5,19E-03	3,94E+01	5,44E-245	0,00E+00	1,84E-261	0,00E+00
F4	4,03E-14	3,23E-10	1,55E-28	2,15E-18	3,41E-04	2,35E+02	0,00E+00	0,00E+00	0,00E+00	0,00E+00
F5	3,88E-05	8,49E-05	4,66E-21	2,06E-17	1,23E-01	6,67E+00	1,03E-148	1,75E-146	3,74E-154	1,27E-148
F6	5,14E-04	3,35E-01	8,35E-16	4,56E-14	1,19E+00	1,37E+01	1,50E-64	5,15E-62	6,81E-74	5,65E-67
F7	5,56E-08	4,84E-01	0,00E+00	0,00E+00	1,54E-01	1,07E+03	0,00E+00	1,83E-01	0,00E+00	0,00E+00

F8	4,24E-19	9,64E-17	1,50E-37	1,90E-18	1,57E-03	1,91E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00
F9	6,08E-05	5,29E-03	6,93E-04	1,22E-03	8,16E-03	2,64E-01	1,04E-04	3,05E-04	7,73E-05	2,58E-04
F10	6,80E-03	1,68E+00	8,81E-02	3,57E-02	2,33E+00	3,81E+03	9,34E-02	1,05E+00	1,55E-02	1,22E+00
F11	1,70E-08	1,36E-06	0,00E+00	0,00E+00	4,82E+00	9,34E+00	0,00E+00	0,00E+00	0,00E+00	4,93E-01
F12	3,79E-08	1,83E-01	0,00E+00	0,00E+00	3,48E+00	1,09E+01	0,00E+00	5,71E-01	0,00E+00	4,42E-01
F13	7,55E-07	4,84E-02	4,38E-05	2,80E-03	3,19E-01	1,06E+01	1,36E-03	1,57E-02	0,00E+00	1,34E-02
F14	6,39E-05	3,62E-01	0,00E+00	0,00E+00	1,14E+01	1,96E+02	6,36E+01	3,61E+01	6,36E-05	5,01E+01
F15	1,23E-04	4,72E-02	3,51E-15	1,08E-15	5,48E-01	3,30E+00	0,00E+00	1,45E-15	0,00E+00	3,99E-16
F16	1,44E-09	2,25E-08	4,20E-20	8,82E-18	5,90E-03	7,90E+03	9,42E-32	3,34E-47	9,42E-32	4,38E-47
F17	1,14E-08	1,04E-02	2,82E-20	7,85E-18	3,28E-02	5,83E+05	1,35E-17	2,01E-03	1,35E-32	3,40E-03
F18	1,40E-06	1,20E-04	2,34E-18	7,56E-17	2,25E-02	1,52E+00	0,00E+00	7,14E-09	0,00E+00	1,58E-07
F19	9,32E-07	3,80E-02	1,95E-19	4,66E-18	2,81E-02	4,57E+00	1,35E-16	2,79E-02	1,35E-31	1,97E-02
F20	3,70E-03	8,45E-03	0,00E+00	0,00E+00	2,72E-01	1,38E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
F21	9,72E-03	3,63E-02	9,72E-03	1,07E-03	5,75E-02	1,57E-01	7,16E-03	9,38E-10	9,72E-03	2,24E-09
F22	-7,83E+01	4,71E-08	-7,83E+01	1,58E-14	-7,83E+01	7,77E+00	-7,83E+01	1,77E-14	-7,83E+01	1,70E+00
F23	-2,78E+00	1,11E-06	-2,78E+00	1,54E-15	-2,78E+00	2,71E-01	-2,78E+00	6,70E-02	-2,78E+00	2,81E-16
F24	4,94E-07	2,87E-01	3,24E-14	6,46E-13	7,79E-03	1,57E+03	9,86E-32	8,99E-26	9,86E-32	4,63E-26

In this section, HS, ABC, PSO, TSA and HTSA were run for thirty times for 2, 3, 4 and 5 dimensions and the best values obtained were compared for each dimension in Tables X–XIII, respectively. When examining Table X, although ABC and TSA methods achieved a better solution than HS and PSO methods, HTSA achieved a better result than any value obtained by all methods in 2 dimensional numerical functions. In Table XI, HS, ABC and PSO methods could not obtain a very good result while TSA was more successful than these methods. On the other hand, HTSA achieved a better result than all other methods, revealing its success on 3 dimensional numerical benchmark functions. It was seen in 4 dimensional benchmark functions shown in Table XII that HS, ABC and PSO methods could not achieve a very good success, HTSA method was the most successful one, followed by TSA method. In Table XIII, HTSA reached the best solution, TSA, ABC, PSO and HS methods were ranked in terms of success rate, respectively. When the results in Tables X, XI, XII and XIII are analyzed, HTSA has been successful in a majority of the 24 benchmark functions according to other algorithms.

Considering all tables in general, the hybrid method made to TSA method increased the effectiveness of the algorithm and thus its robustness; accordingly, it positively affected the success based on its result obtained from the solutions of numerical benchmark functions.

In Table X-XIII, the solution results of the benchmark function of HS, ABC, PSO, TSA, and HTSA algorithms are given. The best results are a summary of the best results in terms of number ranking as pie charts in Figure 2-5.

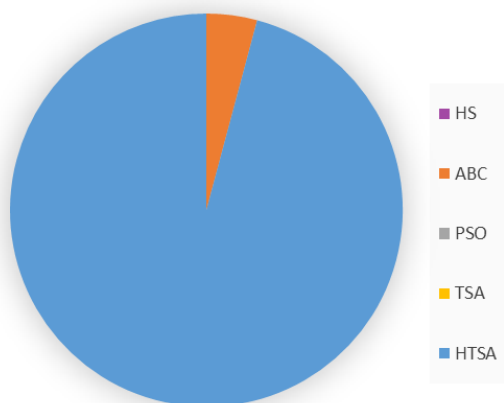


Figure 2. The comparison result of 2-dimensional functions

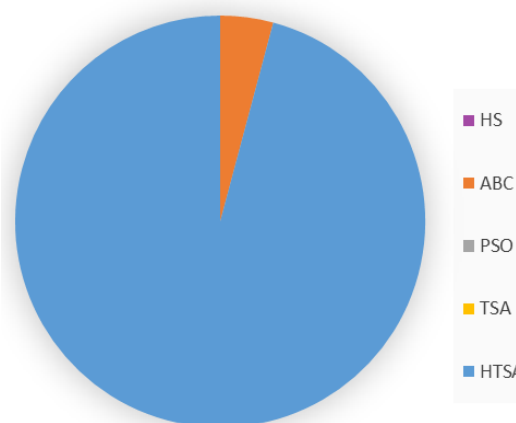


Figure 3. The comparison result of 3-dimensional functions

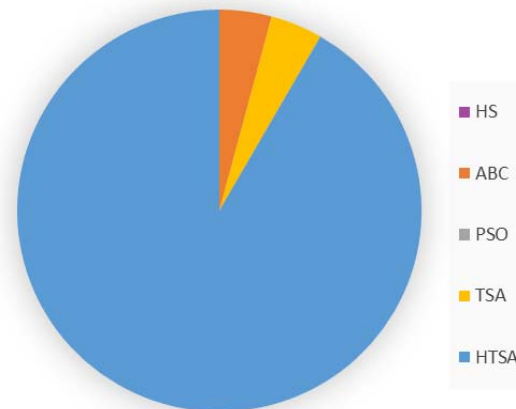


Figure 4. The comparison result of 4-dimensional functions

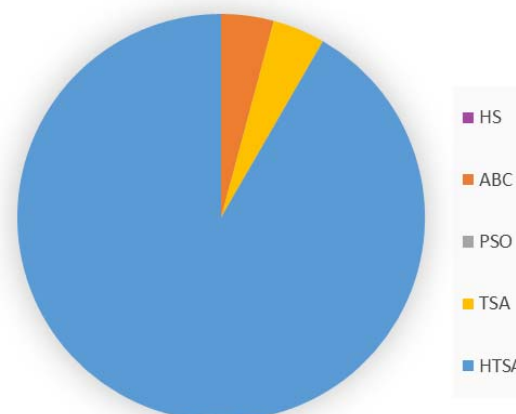


Figure 5. The comparison result of 5-dimensional functions

IV. CONCLUSION

In this study, the acceleration coefficient method and the tournament selection method were hybridized in the seed formation formula. The hybrid method obtained was called HTSA and applied to numerical benchmark functions. The best known five benchmark functions were considered as 2, 3, 4, and 5 dimensional while 10, 20, 30, 40 and 50 values were used as population number of the algorithm. The solution results obtained according to these values indicate that HTSA was successful. In addition, twenty four numerical benchmark functions were solved by using 2, 3, 4 and 5 dimension values with HS, ABC, PSO and TSA methods and the results obtained were compared with those of HTSA. Evaluating these results, it was observed that HTSA has been successful in a majority of the 24 benchmark functions according to other algorithms. With the hybrid method made, improvements were seen in the performance and solution quality of HTSA method. Moreover, the fitness of HTSA method to extremely high-dimensional benchmark problems can be tested. Various improvements can be done to TSA method or results can be compared by using different selection methods through numerical benchmark functions used in this study.

ACKNOWLEDGMENT

The author also would like to thank “The Scientific Projects Coordinatorship of Şırnak University” for their institutional supports. (Project number: 2019.FNAP.06.01.01).

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